Portrait painted from a photograph which hangs in the Yale University Graduate Club

Yale University News Bureau

JOSIAH WILLARD GIBBS

by Muriel Rukeyser

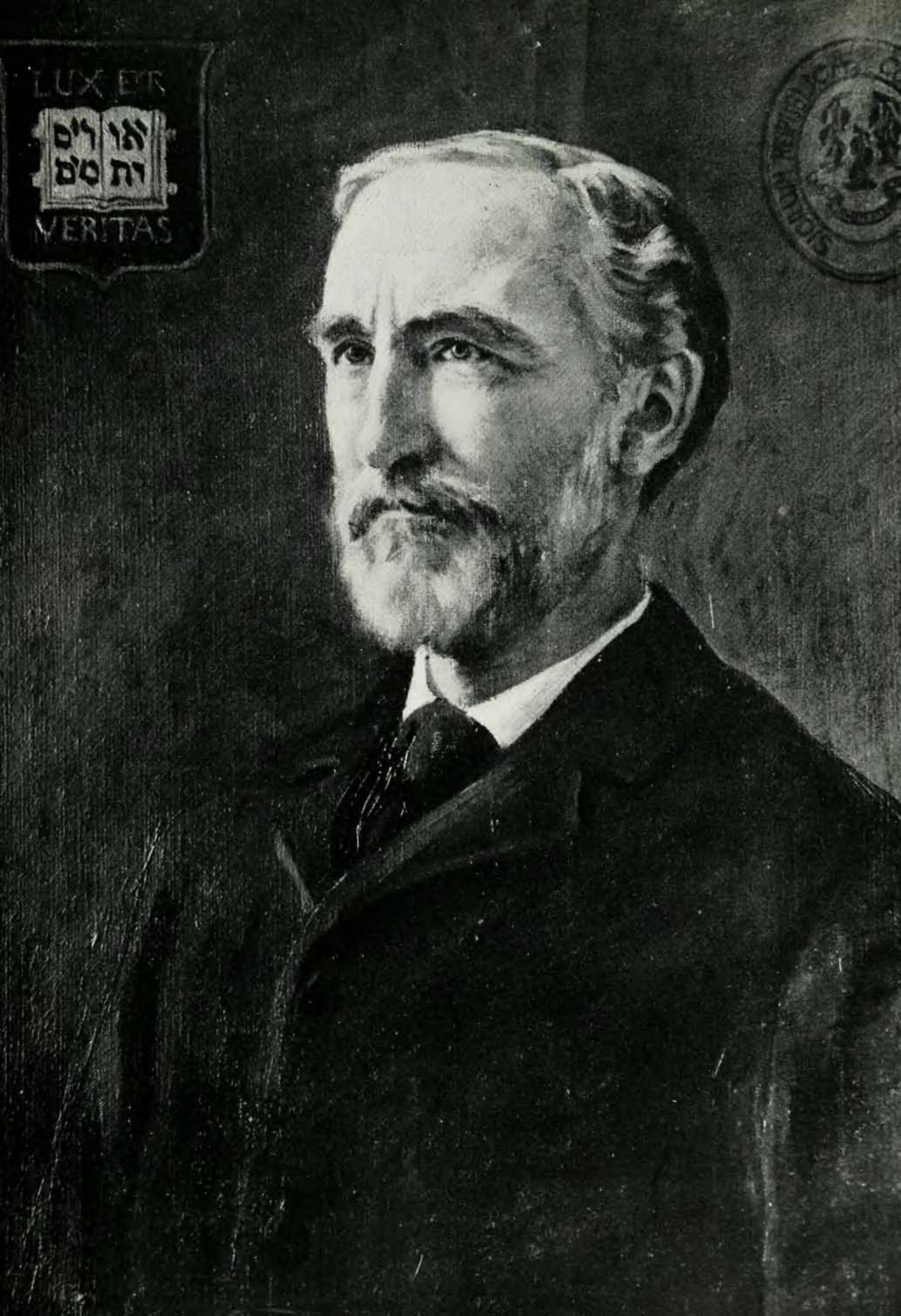
First coming upon Gibbs through the writing of a poem, Muriel Rukeyser was drawn into a study of his work and later wrote his biography. In this article on the founder of statistical mechanics, and on imagination, she writes of the man who said, "The whole is simpler than the sum of its parts." The material from which this was taken was presented as a lecture under the auspices of the University of Chicago and the Institute for Religious and Social Studies.

Willard Gibbs is the type of the imagination at work in the world. His story is that of an opening-up which has had its effect on our lives and our thinking; and, it seems to me, it is the emblem of the naked imagination—which is called abstract and impractical, but whose discoveries can be used by anyone who is interested, in whatever "field"—an imagination which for me, more than that of any other figure in American thought, any poet, or political, or religious figure, stands for imagination at its essential points.

It is because he dealt in law and in relationships that one may come to him from any point of interest, however inadequate one's background be. I came to him through poetry, without any of the proper training, feeling that in this time, full of its silence in spite of the weight of paper and the weight of words poured on us every day, full of its barriers set up between the peoples of the world and any two people—in this time, our sources are to be reached. It seems to me that if we are in any way free, we are also free in relation to the past, and that we may to some extent choose our tradition.

Gibbs' work has been approached through need by workers in many kinds of science. He has had deep effect on those who work in the chemical industry and in nuclear energy, in colloids and crystal habit, in medicine, fuel changes, the design of aircraft engines, those biologists who work with cell equilibrium and blood, in permeable membranes; and, further, with historians who deal with social equilibrium, with those who work to further the industries of war, with those whose concern is a theory of history. As the imagination finds its ways, as a cloud, say, over Hiroshima acts out for us principles and threats and the great tragic hopes, we see the relationship past barriers. We see that the barriers which have been erected between "field" and "field," between people and people, are artificial. If we believe in the unity of man, if we believe in the unity of nature, if we believe in the unity of

Muriel Rukeyser wrote her biography of Willard Gibbs as a "footnote" to her poem "Gibbs," published in "A Turning Wind" (Viking). Her most recent book of poems is "The Green Wave" (Doubleday, 1948). In San Francisco, where she is living with her small son, she is writing poems and a book on poetry, producing an FM series of broadcasts of poetry and music, and reading toward a biography of the anthropologist Franz Boas. Her other books include "Theory of Flight," "U.S.1," "Beast in View," and the forthcoming "Elegies."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knowledge, then we believe also in the unity of imagination.

The method of science approaches the method of poetry. As Epicurus and Lucretius, scientist and poet of the sum of things, match each other, the workers in systems—in poetry and in science—approach and touch. Poets and scientists give themselves closely to the creation and description of systems. To the poet, his own nature is his chief instrument; the nature of the physical scientist is apart, he deals with a world of law in which there is no understanding. The world of the poet, however, is the scientist's world. Their claim on systems is the same claim. And as the Englishman, looking for explosives, came to Gibbs; as the American, looking for democracy, came to Gibbs; as many, looking for the nature of relationship came, I came; first through a poem, and later to an inquiry into the life of this quiet man, living without spectacle and without experiment, making discoveries. Who was he? What is his impact and his gift?

Giving Shape to Research

Willard Gibbs was born in New Haven, where he lived and worked and died. He and the men in his family were identified with Yale. His father was a philologist at Yale, and he spoke about language in terms of "the deep things of the human spirit . . . the sacred symbols of human thought." Working on his grammars, his lexicons and vocabularies, he said, and kept continually before himself the saying: *Language is a cast of the human mind.* In the year that his son, Willard Gibbs, was born, the father began the one political work in which he was ever engaged: his work for the prisoners of the slave ship *Amistad.*

These Africans had been brought to the New Haven jail, and were being held there. There could not even be a trial, for no one understood their dialect. Gibbs' father went to see them in jail, learned to count ten in Mendi dialect, and searched from boat to boat in New York Harbor until he found an interpreter. He supplied the link of communication; and then the trials began, going from court to court in the most celebrated case of the period—a set of trials and an issue comparable to the Sacco-Vanzetti case in our century. Finally, the Supreme Court was reached, and the defense looked for a man to make the last plea. Not a lawyer, but an idealist philosopher, was needed. And the man they went to was John Quincy Adams—the ex-President, old, ill, tired, and defeated in a great and personal defeat. In a speech cutting deep to the core of human rights, laying open what he called "the death-struggle now in continual operation between the spirit of liberty and the spirit of bondage on this continent of North America," John Quincy Adams won freedom for the *Amistad* captives. And made the other link, of system and law.

Willard Gibbs grew up as the struggle advanced. He was a graduate student as civil war broke out. He needed to do his work, and he was needed at home, for his father had died. He went ahead, into the new science of mathematical physics, as America was valuing most highly its generation of inventors, the practical men who followed the Civil War with one patentable item after another.

It was not until 1873 that Gibbs presented his first two papers, on representations in his science, thermodynamics. The steam engine itself draws a graph of its own changes, if you attach a pencil to the gauge. Gibbs was outlining ways of diagraming these forces, including energy—the main concern, the theme of the nineteenth century—and entropy, the running downhill of energy, the other term of energy. Now he worked, not in graphs which would run across a sheet of paper according to two terms. Gibbs was working with a cluster of terms, and paper would no longer do. He worked out a set of equations which could be represented only by a solid, whose curves and hollows, reaches and valleys, would be like a mountain which one could *read*—a solid which would explain ice, water, and steam—a statue of water. You may have seen a picture of this solid, one of the most beautiful of abstract sculptures it would be if it were not for the fact that it is *not* abstract, that it is to be read.

Gibbs was one of those rare intellects which tower over art, over many kinds of conquest, as over science, from whom the human race receives its pictures of the world. One such picture is contained in his third paper, read when he was thirty-seven. This study in relationship has been called "the finest cultural expression of the age of steam." It is this great paper which devotes itself to relationships at a time when only concrete factors could seize the public mind; that sums up in itself not only the work that Gibbs had already done, that lays down not only the complete basis for a new science and a dynasty of applications, but that also foreshadows—*that releases*—an age. In this paper he created the science of chemical thermodynamics; in a quickset of equations, he brought this knowledge "to such a degree of perfection that in fifty years almost nothing has been added." Condensed, rigorous, full of terrifying difficulties, even for the specialist, the paper opens up a world of process.

The paper opens with a statement of Clausius, used as a statement of theme and indication of method: "The energy of the world is constant. The entropy of the world tends toward a maximum." Gibbs begins by defining his own terms. He is absorbed in the problem of equilibrium between two or many components. He is dealing with the behavior of components, whatever they may be, and the system, whatever it become. He is searching our relationships, and deriving the facts from them. He is concerned with internal relations, "the private lives of systems." He goes on to set forth the terms —the criteria of equilibrium and stability. The groundwork for his most famous discovery, the Phase Rule, here is laid. He discusses the effect of solidity on the parts of a mass, and studies the equilibrium of osmotic forces. By differentiating the energy with respect to the mass of any one of the component substances, he obtains—and discovers—the chemical potential.

This was the link between the classical science and modern physical chemistry and electrochemistry. In Gibbs' work, as this is, everything is deduced; there is no willingness, and at the same time, there is no condescension. He does not do what scientists are implored, and writers are commanded to do, write down for an imaginary audience with imaginary demands. The people who ask this are idealistic cynics, for these standards *are* imaginary. Discovery lives otherwise.

The Phase Rule occurs incidentally. It is a law for determining the degree of freedom of a system. You will understand that I am speaking of Gibbs in a highly improper manner. His terms are equations, delicate and complete. I am simply chalking in the broad lines of his attitude. But the Phase Rule has become a guide by which innumerable experimental details can be classified, by which facts can be explained and gathered in from their scattered outlying districts. Not only the Rule, but the developing work of this great paper, was capable—in Gibbs' own words—of "giving shape to research." It goes on to the geometrical illustrations, diagrams to represent three-phase equilibria by sheets of lines, heavy-walled expressive triangles. It speaks of critical phases, and strikes suddenly at the universal in a famous sentence, which in its own terms deals with infinity, eternity, and the infinite chance. We have heard a great deal about entropy, the heat-death, the sliding downhill of all things; Gibbs throws out a challenge to the demons, to the degradation of energy, in one characteristic, many-modified statement of the chance of reorganization and survival: "In other words, the impossibility of an uncompensated decrease of entropy seems to be reduced to improbability."

"I Wish to Know Systems"

What was his life during this time? What was the life of the work he was doing? Of his own life, we do not know. Locked in the family and the college, we know only about his closeness to his sister Julia, and his position in the house, which was dominated by his other sister and her husband, the librarian of Yale, and a solid, "practical" and successful man. Of his work, we know that it hardly reached out from the journal in which it was printed; except as the finest abstract work reaches out, to those who are ready for it. Scientists, poets, workers in form, have taken this attitude toward the world; the completeness and form of their work *is* its simplicity. This is an attitude that has its costs, in personality as well as in the effect of the work; and Gibbs faced penalties. But the responsibility is shared; it is a meeting place that is needed, and the fault is neither on the side of the public, nor on the side of the person who makes an original statement. That is not to say that there is no fault. The fault is in the ignoring of possible meeting places, between people and what the academic and business worlds call "fields,"—between the kinds of imagination. It seems to me that a function of poetry is to make such a meeting place. But I would not even seem to put poetry on a pedestal; this is also a function of science, or of the best of any creative work. And the fine work does reach through. The fine poems filter through to an audience, through prose writers, say, and through the young; abstract science reaches applied science.

It is fifty years now since Gibbs' death. That is not very long; and he stands evaluated. But where

Benjamin Franklin's name is known widely, as it was known in his own time to the citizens of three countries, Gibbs' name is just beginning to penetrate the histories. In a list of the great, however, we see time catching up with them; we see them as they are diluted by their admirers, or as half-knowledge misinterprets and misuses their gifts. We feel them best in their impact on other minds. And here we see Gibbs' ramifying thought, which struck deep to the other sciences, until biologists knew that their future was Gibbsian, until laws were seen to be of his discovery, although sometimes he did not name them; until metallurgists, for instance, knew that he had the key, until it was clear that the combining science in which he worked was to be the clue to many contemporary mysteries. For our time depends, not on single points of knowledge, but on clusters and combinations. This is true of the arts—of poetry—in its dealing with clusters of emotion, clusters of fact; it is true in the most aware treatments of psychic disturbance, in which the disturbance is acknowledged to be in the *relationship* between people, rather than simply in the individual; and it is true of Willard Gibbs.

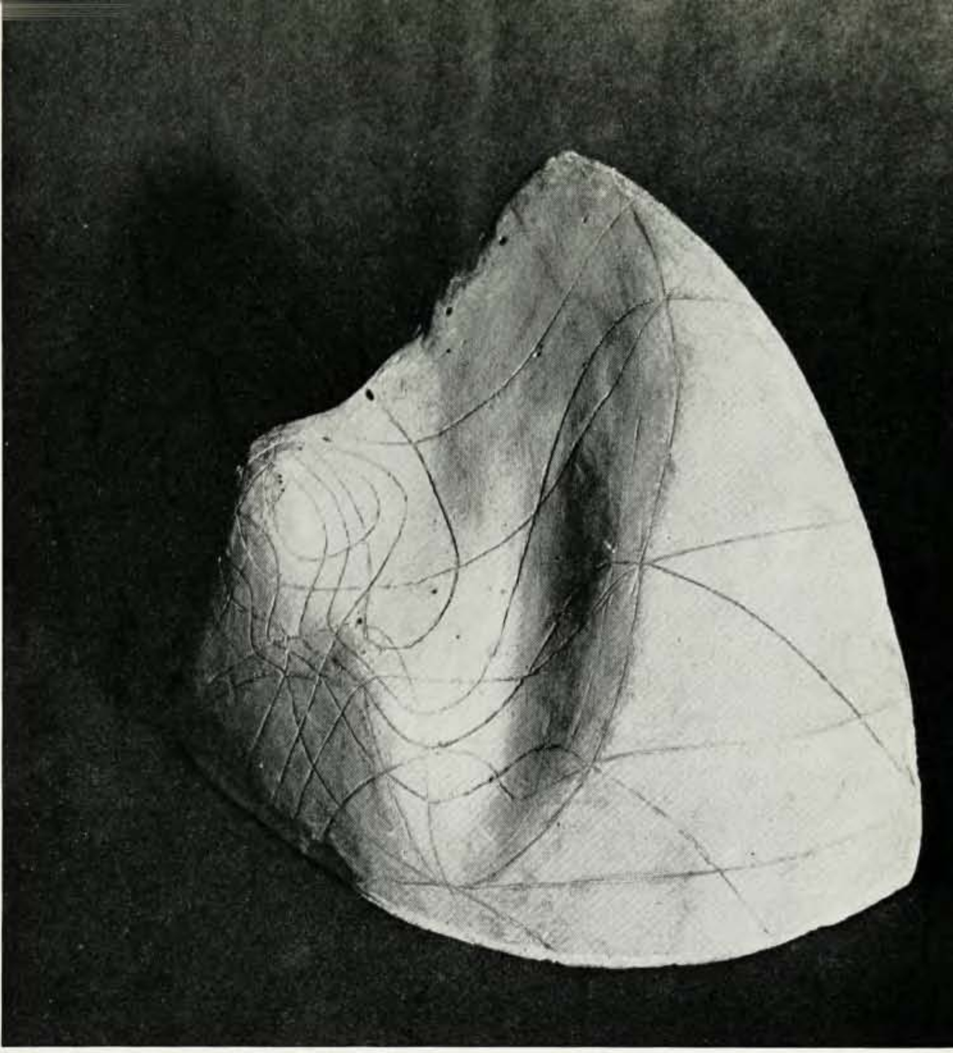
The gifts of Gibbs to the world have barely been opened. He made no experiments. He pursued law; he said, "I wish to know systems." His greatness is the greatness of the worker in pure imagination, working close to the spirit—whoever he is, in whatever "field" he finds his sources. To think of Gibbs is to think of all such human beings, and their wish: to discover, to make known, to find a language for discovery.

"The Whole is Simpler than the Sum of all its Parts"

At the time of his paper "The Equilibrium of Heterogeneous Substances" to which I have scarcely referred, Gibbs was a professor serving at Yale without salary. This state of affairs lasted for ten years, in spite of an invitation of Johns Hopkins which might have changed the whole story of his reputation. They were years in which the intense split in our democracy can be seen clearly, as clearly as it was visible between John Quincy Adams and Andrew Jackson, or in these our own years: they were the years of crashing expansion after the Civil War. But Gibbs, isolated at Yale, was beginning to be recognized by the scientists whose opinion might have mattered to him: Hubert Newton, at Yale; Clerk Maxwell, who sent him from England a plaster model of the "statue of water" which Gibbs had described; Gibbs received the Rumford Medal. At home, a joke grew up; at dinner, there was a debate about who would mix the salad dressing—until Willard said, smiling, "I am the authority in this household on the equilibrium of heterogeneous substances."

He was working out his vector analysis, which was circulated in a condensed version, and later became the basis for a series of lectures. Vector analysis provided an expression for space relations, using an arrow for a quantity having both magnitude and direction—the wind, for example, or any force—and he was printing the abstract of his vastly important work on statistical mechanics. He served outwardly; at the National Conference of Electricians, and speaking as vice president of one section of the American Association for the Advancement of Science. At the moment at which his work was in process of translation in Germany, where it had more immediate impact than at home, Gibbs was speaking on multiple algebra, quoting from the Nation a remark saying that "the human mind has never invented a labor-saving machine equal to algebra," and going on to declare that this machine, too, has been developed—"this most refined and most beautiful of machines," he says. "I do not know that anything useful or interesting, which relates to multiple quality, and can be symbolically expressed, falls outside of the domain of multiple algebra," he says, after suggesting its history. "But if it is asked what notions are to be regarded as fundamental, we must answer, here as elsewhere, those which are most simple and fruitful."

In closing, he speaks of the many applications of this science, and of our spatial intuitions, which lead us to these methods. "Here, Nature herself takes us by the hand and leads us along by easy steps, as a mother teaches her child to walk." The concepts with which he is concerned are space concepts as distinguished from point concepts. We need to think in terms of space; and we need to understand one of Gibbs' most effective phrases: "In mathematics, a part often contains the whole." He concludes by calling our attention, not to diversity, but to the simplicity and unity of the few central principles to which are attached "all that is most useful and beautiful." He is concerned with law.



The plaster model of Gibbs' "Statue of Water" made by Clerk Maxwell and sent to Gibbs shortly before Maxwell died in 1879.
Yale University News Bureau

And with communication. In the meeting, he said, and it was remembered always—in the midst of a discussion about classics and mathematics—he said with emphasis, this man who seldom spoke, and cut through the knot of their discussion: "Mathematics *is* a language."

Now, in Holland, and Germany, and England, his work was beginning to find its audience of workers who would go on, detail by detail, with what he had opened; and the battles about his principles began. The battles themselves reveal him well; when he was asked what the first duty of the vector analyst was, he answered: "It is to present the subject in such a form as to be most easily acquired, and most useful when acquired."

Usefulness, to him, was completeness. When one of his students suggested that Gibbs' system could be restated in a form more widely useful, Gibbs replied: "What is the good of that? It is complete as it is." It is that point of view, I think, that often is part of the imaginative genius, as against the person who oversimplifies continually, with the excuse that he does it for the sake of use. The most useful *idea* is very likely to be the most complete idea; the compactness, as of poetry, in Gibbs' work has made him extremely difficult even for the specialist; but this compactness is for the sake of completeness, and to Gibbs, completeness and simplicity are the same thing. It is only a man like that who can say, "The whole is simpler than the sum of its parts."

When he defended his vector system, his defense was a fight for the essential, a strong stand for the organic in thought. He asks: "Can we wonder that [many] feel some doubt as to the value or necessity of something so separate from all other branches of learning? Can that be a natural treatment of the subject which has no relations to any other method, and . . . has only occurred to a single man? . . .

". . . Whatever is special, accidental, and individual, will die, as it should, but that which is universal and essential should remain as an organic part of the whole intellectual acquisition. If that which is essential dies with the accidental, it must be because the accidental has been given the prominence which belongs to the essential. For myself, I should preach no such doctrine to those whom I wish to convert to the true faith. . . .

"There are two ways in which we may measure the progress of any reform. The one consists in counting those who have adopted the *shibboleth* of the reformers; the other measure is the degree in which the community is imbued with the essential principles of the reform. . . ."

Exactness for the Average

Many of our leaders entered the twentieth century consciously, aware of changes of form and freaks of force, and prefiguring change to come with them. Henry Adams, the grandson of John Quincy Adams, who had supplied Gibbs' father with the link of communication he needed for the *Amistad* captives, was preparing himself for the enormous pressures he saw ahead. Henry Adams was trying to make his answers to life, as life asked its questions, and he was saying that the question itself was "only another form of the kinetic theory of gases, of which your German problem is an illustration. . . . Anyway, Germany is and always has been a remarkably apt illustration of Maxwell's concept of 'sorting demons.' By bumping against all its neighbors, and being bumped in turn, it gets and gives at last a common motion, which is, and of necessity must be, a vortex or cycle. . . . We can pretty well measure the possible *x* which is the ultimate quantity we want to eliminate. Another generation will have the figures, and the limit of ultimate concentration will then be calculable—barring war, which may of course delay, or wholly defeat, further vortical movement. . . ."

In that year of 1900, Gibbs was beginning the work that has summed much of his life's concern. Out of the results of fourteen years of preparation and teaching, he was writing the book of a new science. Maxwell, Clausius, and Boltzmann had worked here before him, but it was Gibbs who was bringing this work to a form that could be reconciled with the new physics, reconciled with the twentieth century. It was Gibbs, too, who would give the science its name: Statistical Mechanics. The book is about possibility and blending, about the tendency of the universe. The uniformity presented here is not the final sameness we contemplate with dread, the likeness of every particle with every other—that heat-death which is the end of horror—but it is a blending which is out of range of our senses.

If we were not gross and limited, our infinite eyes could see the distinctions among grains, could see each grain and single and original; variety is there; it remains; and as the random mixing of the world goes on, it is the limitlessly perceptive sense we long for, the keen eye which will not be fooled by any trick of the dimensions. Mathematics throws us a formal world in which all is beginning to be visible—this is a sop to our weak perception. There is the drop of wine in water, the grain of brown rice in a heap of white; to put them in is easy, but this is the type of the irreversible phenomenon: the laws then involved are best described by Gibbs. As in all of his work, there were hardly any assumptions. There were the laws of probability, the universal shuffling, applied to the flowing of matter through time.

People had dealt with the particles, Gibbs would again deal with the whole. He invents a vast system, he applied all the ideas which have been his near concern—ideas of phase and space and chance, the vectors moving in a new kind of space, a phase-space whose balance he will describe, whose models he will make. He launches these models into space. He is not stopped by the weakness inherent in analogy, he can use analogy's strength and then throw away his model. He adds dimensions. These are no longer the statues, solid as mountains, whose contours may be understood—like our mountains if their timberlines and shadows could be read. These are even subtler maps, of many dimensions. The charts and diagrams of conservation have become even more fictional; ghostly and more real at the same time. This is an ideal world that does not reckon with atoms and molecules, or even with gases and liquids; it reckons with creations invented only *because* they can be applied. The most sensitive analogies are here, and they lead on. From this book of 200 pages, says Langer, "emerged in fine succession all the basic laws of heat as they are embodied in the science of thermodynamics."

Gibbs sums up the work in his own preface. He opens by speaking of contemporary mechanics, which set as its problem the finding of the condition of a system at a given time. Gibbs says, "For some purposes, however, it is desirable to take a broader view. We may imagine a great number of systems of the same nature, but differing in the configurations and velocities which they have at a given instant, and differing not merely infinitesimally, but it may be so as to embrace every conceivable combination of configuration and velocities."

This great number of systems is called an *ensemble;* it is dealt with collectively. The problem is now set; not to follow a particular system through its voyage, but to determine how the whole number of systems will be distributed at any time, if we know the distribution for some one time. It is a picture of the massing of systems along a curve of probability—the gathering of atoms, of constellations.

These inquiries are statistical. The laws here determined empirically express the behavior of systems—their *probable* and *approximate* behavior "as they appear to beings who have not the fineness of perception" to enable them to appreciate these small quantities, and who cannot repeat their experiments often enough for exactness. The exactness we deal with here does not apply to the individual case—this is exactness for the average.

Gibbs believed that "nothing will more conduce to" the clear understanding of relations between several branches of science than this study.

"Moreover, we avoid the gravest difficulties," he writes, when we make these inquiries without talking about the constitution of matter. "In the present state of science, it seems hardly possible to form a dynamic theory of molecular action which shall embrace the phenomena of thermodynamics, of

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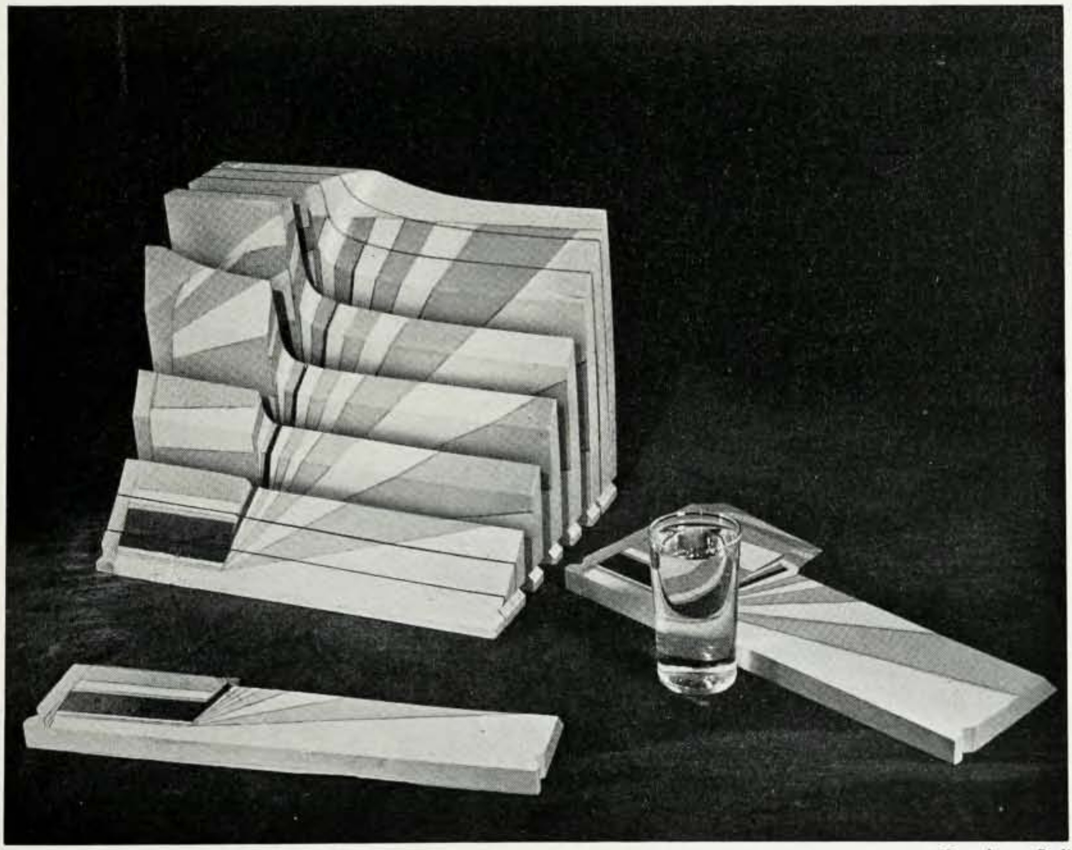

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This model of a Gibbs surface was made by Robert Ledley when an undergraduate at Columbia. It represents the relation of internal energy (height), entropy (depth), and volume (width) for pure water. (Courtesy Columbia University Physics Department.)

GIBBS *Continued from page 13*

radiation, and of the electrical manifestations which accompany the union of atoms. Yet any theory is obviously inadequate which does not take account of all these phenomena. . . . Certainly, one is building on an insecure foundation, who rests his work on hypotheses concerning the constitution of matter."

Truth is, according to Gibbs, not a stream that flows from a source, but an agreement of components. Truth is an accord that actually makes the whole "simpler than its parts," as he is fond of saying. Not originality, but order, becomes the important factor; the point of view and the arrangements may be different. "These results, given to the public one by one in the order of their discovery," were not arranged before he seized them and discovered their pattern. This arrangement turns them into a tool, a new science. Here, as everywhere, the arrangement is the life.

Phase space, phase fluid, and various ensembles are used; this is a way of dealing with many kinds of things in changing arrangements on their flow toward statistical equilibrium. And at this last level the blending is complete; the glacier of motion has slipped down the slope of time. There is permanent distribution.

Dr. Harold Urey, worker in many kinds of energy, Nobel Prize chemist and Gibbs medallist, writes in a letter:

"I believe that the debt of modern physics and physical chemistry to the work of Willard Gibbs is greater than to any other American scientist of the nineteenth century or earlier. It is probably true that very few scientists of the world have ever contributed as much to physics of physical chemistry as Gibbs. . . .

"In the past decade physical chemistry has used to an increasing extent the methods of statistical mechanics. It appears to be probable that this use will increase in the near future. Our fundamental notion of statistical mechanics is based almost entirely on the work of Gibbs.

"The extraordinary usefulness of Gibbs' method . . . is the more uncanny because of his necessary ignorance at that time of the fundamental nature of atoms and molecules. . . . It is a tribute to his unusual foresight that the Gibbs statistics required practically no modification with the introduction of the quantum theory."

Dr. Urey points out that the development of quantum mechanics was necessitated by the breakdown of the predictions of classical mechanics. "It was only due to the rigor with which the theory of statistical mechanics had been developed by Gibbs that it became necessary to alter the assumptions of the laws of classical mechanics. Thus Gibbs unwittingly played a role in one of the two great developments of the twentieth century, that of the quantum mechanics."

This book was Gibbs' last. "He was a worn-out man," according to a close friend. Less than two years later, on April 28, 1903, he died of an intestinal obstruction. All of his life had been centered on one street, High Street in New Haven—school, college, all his days—and he is buried at the end of that street, under a stone that carries his name, his dates, and the words:

PROFESSOR OF MATHEMATICAL
PHYSICS, IN YALE UNIVERSITY,
1871–1903

Gibbs said, and the remark has been taken as modesty: "Anyone with the same desires could have made the same researches." But this is a statement about desire itself, clearly pointing out the criterion for many kinds of effort. It *is* the desire. This clue for the understanding of your own desires so that you may know how best to feed them and let them gain their fertility, is only one of the clues we find in Gibbs' work and the connections of his life. Its signs are in the concentrated applicability of his work, and in his prophetic images, so close to the wish of his age that many of them were found afterward, and rapidly, by scientists working independently of him and of one another.

Gibbs' attitude provides a clue for us, in beauty and rigor reaching past barriers. He reached past order while the barriers faded; as he became more real, they could be clearly seen as phantom and untrue.

He creates what the great make. For it is not simply enough to create a thing, an object, an end. There is no goal in such work, there is not static goal in such culture. There is a moving goal—another principle, in the dynamic of which Gibbs is a part, and toward which at our best we tend: to create the creative.