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J. N. BRØNSTED MEMORIAL ISSUE

J. N. Brønsted *

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Johannes Nicolaus Brønsted was born on the 22nd February, 1879, at Varde. His father was an engineer of note in 'The Society for Cultivation of Heaths' whose memory lived for a long time in the places where he had worked, and on visiting those parts in later life Brønsted received much evidence of the high esteem in which his father was still held there. Brønsted's mother died shortly after his birth, and his father married again a few years later. His stepmother, who became a widow when the boy was only 14, understood how richly talented he was, and in spite of her modest income saw to it that he received the best possible education.

Until the boy was 12 years old the family lived at one of the farms of the Society for Cultivation of Heaths: Hesselvig Enggaard at the river Skern, where his sense of the beauty of unspoilt nature and his natural faculty of observation were developed. To his death Brønsted knew and loved the few unspoilt and lonely parts which still exist in our populous country, and by letters to the newspapers and correspondence with persons of influence in that matter he fought to protect them from encroachments. This often brought him in opposition even to the Society for Cultivation of Heaths. He was also a keen opponent of the kind of preservation of wild nature which aims at attracting visitors to a place thereby spoiling its very charm.

His well known interest in birds and bird-life no doubt also goes back to those years. Later on it was developed by his artistic bent which was encouraged by his connection with Johannes Larsen, the painter.

12 years old the boy moved with his parents to Aarhus and was sent to school there.

I am told that he felt at home in and loved the countryside around Aarhus, which was also in harmony with his natural bent, and that he distinguished himself at school, especially at mathematics. However, his life at Aar-

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hus came to an end when his father died, only two years after their move to that town. The family, the mother and the two children, Johannes and his sister, moved to Copenhagen. Johannes entered the Metropolitan School and came into the form from which so strikingly many men of great merit were to issue. Among his school-fellows was Niels Bjerrum, one of the sons of Professor J. Bjerrum, the well known oculist. In 1897 he passed his 'Studentereksamen' (corresponds to the School Certificate Examination), commenced his studies on chemical engineering at the Polytechnic Institute of Copenhagen and passed the 1st part of the examination in this subject two years later. Then he passed on to studying at the University and took his 'Magister scientiarum' (m. sc.) degree of Chemistry in 1902, three weeks after Niels Bjerrum. A 'Magister', especially of chemistry, was at the time a rare bird, so rare indeed that Brønsted for many years afterwards was still called the 'Magister' among his friends. While he studied for his degree he had many other interests besides chemistry, and all through his life he continued to cultivate them. Thus he was very fond of song and music and was a performer in the circle of his family and friends. After his graduation he was among other things for a time Valdemar Poulsen's collaborator on the 'telegraphone', and not until 1905 he became assistant at the Chemical Laboratory of the University. But his first experimental works are from 1903. So although he himself said that he was lazy, he evidently was not, probably because scientific work came so easy to him that he had leisure for other interests. At that time he married Louise Brønsted, nee Warberg, chemical engineer. The family settled down a little north of the small town of Birkerød in a little house on a very large site which was for the greater part left in its natural state, sheltered as it were by 'Nordbanen' (the Northern Railway) which is still to-day protecting the lovely unspoilt place from being built in. Mrs. Brønsted's sister was married to Johannes Larsen, the painter, and through him Brønsted came into touch with artists like the Funen painters. Being of an artistic bent, he derived much pleasure from his connection with these circles, and perhaps it was their influence which made him take to painting in the years around the war of 1914—18. For some time during that war the house was lighted by electricity produced by galvanic batteries designed by the master of the house himself. A patent was, by the way, taken out for these batteries. Later on when the family increased to six members, and as communications to Copenhagen were bad, the home was moved in 1923 to Willemoesgade in Town, and from there in 1930 to the house for the head of the new Institute of Physical Chemistry at Blegdamsvej.

In May, 1908, Brønsted defended his thesis: *Affinitetsstudier III* (Studies on Affinity III), six months before Niels Bjerrum's defence of his thesis.

Opponents *ex officio* were Dr. E. Biilmann, recently appointed Professor of Chemistry, and K. Prytz, Professor of Physics at the Polytechnic Institute. Opponent *ex auditorio* was G. A. Hagemann, head of the Polytechnic Institute, who always followed Brønsted's work with great interest. Hagemann was a chemical engineer and a large-scale industrialist. He was well acquainted with Julius Thomsen, the renowned thermo-chemist. The latter was still alive at the time (he died in 1909), and Hagemann's enthusiasm for physical chemistry certainly had its offspring from his interest in Julius Thomsen's work.

On the 17th December of the same year Brønsted was appointed to the new third chair of chemistry at the University of Copenhagen after a competition with Niels Bjerrum before a committee set up by the University. Also to-day we understand that it must have been a difficult choice to make, and actually the report of the committee of the 7th December gives the most laudatory opinions on both applicants. As a matter of curiosity it may be mentioned that the costs of the competition amounted to 71 Kr. 40 Øre (abt. £ 3/10/—).

The Brønsted family had the news of the result in a most dramatic manner when a passing goods-train suddenly stopped at the house at Birkerød, and a uniformed official from the station got off to deliver a telegram from Niels Bjerrum congratulating them on the decision of the committee. This episode probably took place on the 17th December, exactly 39 years before Brønsted's death.

The actual establishment of the new chair had not passed off without friction. It was agreed that the chair was needed, but there was some disagreement as to whether it was to be placed under the University or under the Polytechnic Institute. In the Faculty of the University there was a majority, but not unanimous agreement that it should come within the University. The Polytechnic Institute seems to have wavered in taking its stand. No doubt there has been a general wish to get the chair for that Institute, but G. A. Hagemann, Director of the Institute, strongly advocated in a letter that the new professorship of chemistry should be placed on an equal footing with the existing two, so that it should come under the University but with obligation for the professor to teach the students of the Polytechnic Institute as well. The following quotation, which might serve as motto to his whole letter, testifies to G. A. Hagemann's farsightedness: 'Chemistry and Physics, I was almost going to say Mathematics, know no border line between Science and its Applications, and there is no reason whatever to believe that the future will change this fact.'

The outcome was that Brønsted was appointed Professor of Chemistry in the University with obligation 1) to teach elementary inorganic chemistry to

the students of the Polytechnic Institute, excepting the chemical engineers, and 2) to teach the latter and the students of the University physical chemistry. Not until 1919 was he exempted from the teaching of inorganic chemistry which took much of his time. The premises in the chemical wing of the Polytechnic Institute where he now got his working place were very modest, not to say insufficient, but nevertheless it was here that his scientific work came into full bloom. His own work and his many collaborators, particularly from England and U. S. A., brought his fame far abroad. A visible result of this was that the International Education Board built for the University of Copenhagen an institute of Physical Chemistry, where Brønsted also got his residence. Here in this hospitable home he could unfold his quiet charm in all its aspects. At the same time, of course, he continued his scientific work, which from the middle of the Thirties was concentrated on the exposition of thermodynamics. This work, which for periods absorbed him completely and no doubt wore upon his health, occupied him to his death, but concurrently he worked on other more tangible problems. Only part of the last results obtained did he get time to publish.

Those who in the course of time got to know him closely were much taken with Brønsted's whole personality and the charm he would display in his many-sided interests. To the students and his younger colleagues, who had difficulty in overcoming the feeling of awe he involuntarily inspired, he was more distant. Perhaps it was owing to the stringent logic which he employed in expressing his thoughts and opinions, and his firm belief in the convincing power of logical arguments, also outside scientific circles. The same stringency in logic he would inexorably demand from his collaborators and his opponents in discussions. Occasionally these qualities of his would cause him personal trouble, and possibly they did not always benefit the causes he advocated. Perhaps he liked polemical discussions, but one thing is certain that the causes he stood up for, among other places in the daily press, he had deeply and seriously at heart. In his early years it was especially questions of preservation of the countryside he wrote about, but during and after World War II his interest centred on political questions and particularly the South Slesvig problem. It is well known that he was a violent opponent of the policy that the border of 1920 should be final, and his letters to the newspapers about this problem were no doubt conducive to his election in 1947 to the Lower House of the Danish Parliament by a great number of personal votes. His election was completely unexpected to him and his family. At first they took it as a fine joke but then, true to his scientific habits, he immediately set to work to study Parliamentary Procedure and the matters in which he took a special interest. To his friends it was a grief that he never occupied his seat

in Parliament to which his power of oratory and his competence would alike have been an adornment and a benefit.

Brønsted travelled widely. In his youth he mainly went southwards. But in 1912 he also participated in the International Chemical Congress in New York where he met for the second time Th. W. Richards. Their first meeting had taken place some years before at Hamburg. Brønsted admired Richards both as a man and as a scientist, and the admiration was mutual, which was not without importance for the honourable American grant for the new Institute.

Already during the first World War Brønsted took a certain dislike to our southern neighbours, and as moreover van't Hoff, the colleague from those parts whom he most estimated, had died already in 1911, he especially attached himself to English and American colleagues after the War. He loved England and often went there, particularly for meetings of the Faraday Society. In 1926—1927 he was visiting professor at Yale University in U. S. A. From one of the meetings of the Faraday Society Mrs. Brønsted relates the following: Brønsted was giving an address, and one of his friends was among the audience. There he heard one of the audience say to his neighbour, 'He has read Brønsted', to which the other replied, 'Yes, but he hasn't quite understood him'.

His sympathy for England was easily understandable, for himself he had some of the very qualities which we usually consider the best and most characteristic English qualities, a quiet humour and a deep interest in human affairs. By look he might to a Dane pass for a typical Englishman, and he wrote and spoke English easily and fluently.

During the last World War he never doubted its final issue, even when matters were at their worst, and from the summer of 1945 I remember the heartfelt sincerity with which he welcomed the first English colleague after the many years of isolation.

The number of scientific honours he was awarded in the course of time are legion, the last was the Degree of Doctor of Science, honoris causa, of the University of London, the conferment of which took place during the XIth International Congress of Pure and Applied Chemistry in London in the summer of 1947. He was a member of the Royal Danish Academy of Sciences and Letters from 1914 and of the Danish Academy of Technical Sciences from its establishment in 1937. Finally it should be mentioned that in 1928 he was awarded the Ørsted-Medal at the same time as Niels Bjerrum. But the greatest memorial to his honour was set by himself by his publications which number about 130, including two well known papers issued in the publications of the University of Copenhagen.

We are still in a position to picture fairly well the scientific environment in which Brønsted grew up. In 1901 Julius Thomsen had been succeeded by Emil Petersen as head of the Chemical Laboratory of the University of Copenhagen while S. M. Jørgensen was still head of the Chemical Laboratory of the Polytechnic Institute. Assistants at this Laboratory were: S. P. L. Sørensen (1892—1901), E. Biilmann (1898—1907), and Julius Petersen (1892—1908). Among Brønsted's fellow-students of his own age Niels Bjerrum and Charlotte Louise Warberg, student of chemical engineering, should be mentioned again.

The works on the chemistry of inorganic complex compounds published by S. M. Jørgensen himself and his group have no doubt impressed the young chemist. This appears among other things from the preference he had later on for using such compounds as the object of physico-chemical works. But in accordance with his natural disposition he went his own ways right from the beginning, his very first works being physico-chemical. Physical Chemistry practically was not cultivated in this country for a number of years after J. Thomsen had concluded his thermo-chemical works. It is well known that it was a subject in great progress after the basic works by van't Hoff, W. Ostwald, Arrhenius, and W. Nernst in the Eighties and Nineties, but as far as I know Emil Petersen was the only one in this country to take an active part in the development of the Nineties. The subject: Physical Chemistry constitutes a domain which it is in principle hard to define. But at the time it was rather well defined. Notably it included the application of thermodynamics and electricity to chemical problems, and reaction-kinetics. But these fields were teeming with problems which would obviously have a great attraction to the rising generation of chemists. According to the statements of contemporaries, Arrhenius' dissociation theory from the Eighties came like a revelation. At one blow they got quite new and much simpler possibilities of describing well known phenomena, *e. g.* the analytical precipitation reactions. Add to this that the law of mass action and thermodynamics afforded the possibility of expressing in figures what formerly had to be described in more or less vague terms such as the strengths of acids and the tendency in general of substances to react with each other, the affinity.

Julius Thomsen originally thought that the amount of heat evolved in chemical processes afforded a measure of their affinity, but already about 1900 it had been widely known for a long time that this did not hold true. The true measure of affinity had been found to be the maximum work which a given process will produce, and it was Brønsted's endeavour to develop methods for such determinations to provide means for reaching the end Julius Thomsen had aimed at by his investigations.

In accordance with this programme the object of his first works was to measure the electromotive force of certain galvanic cells, and later on to measure vapour pressures and solubilities. His experiments were always distinguished by precision and the elegance with which by simple and inexpensive means he would overcome the frequent experimental difficulties. But we, who were then young, were perhaps even more impressed by the imagination with which he knew how to construct the objects of his measurements, particularly galvanic cells. I still retain the memory of his description in 1911 of a reversibly working ammonium electrode, probably one of the first lectures I heard in the Danish Chemical Society.

It was characteristic of him that for a number of years he avoided as far as possible to work with cells with diffusion potential. In this way his results had the advantage of considerable precision, but on the other hand he debarred himself from taking part in the particularly fertile development in those years of the application of concentration cells especially to measurements of hydrogen ion concentrations. This development was initiated in this country by Niels Bjerrum and dealt with in detail by S. P. L. Sørensen.

Brønsted was also deeply interested in the theoretical treatment of the problem of affinity. This appears among other things from papers published in 1904 and 1906 in the publications of the Royal Danish Academy of Sciences and Letters. The theoretical problems which occupied not only him but a number of chemists of the time like F. Haber and W. Nernst, was the question of the relation between affinity and heat of reaction, especially the problem (which Brønsted, however, does not state expressly) whether it would be possible to calculate the affinity from purely thermal data. The question is of exceedingly great practical importance. For while the methods for determination of specific heat and evolution of heat are fairly simple, the determination of affinity often requires a refined experimental technique, and moreover it must be varied so to speak from system to system. Add to this that it is only possible to measure affinity if the reaction in question can actually be effected, while a calculation from thermal data may be carried out also for reactions not yet realized. The problem was solved in its broad lines by W. Nernst in 1906 when he put forward his famous theorem. Brønsted was only 27 then. As, however, the number of reliable affinity measurements was still very limited, and further experimental confirmation of the theorem was consequently needed, Brønsted continued his studies on affinity for many years. The last paper in this series (no. 13) appeared in 1921.

It was, by the way, through Nernst that Brønsted's name early became known internationally. In 1904 Brønsted published a work in the publications of the Royal Danish Academy of Sciences and Letters in which

there is among other things a determination of the differences in energy and free energy between rhombic and monoclinic sulphur. In 1906 the work was published in *Zeitschrift für physikalische Chemie,* and in the 5th edition of his famous *Theoretische Chemie* (1907) W. Nernst quoted it as an example of experimental corroboration of his theorem. Unfortunately the friendly connection between Nernst and Brønsted established by this event did not last long. A violent controversy in 1914 bears sufficient testimony to this. The immediate cause was probably that in his thesis: *Affinitetsstudier III* (1908) Brønsted categorically declared in a so-called 'thesis' at the end of his book that the conception set up by Nernst: ideal concentrated solutions had no justification, and in another place in the same book he deals with this conception in similar terms, although less outspokenly. This provoked Nernst to some sharp remarks in the 7th edition (1913) of his above-mentioned book, and Brønsted paid him back in his own coin. The vehemence with which the controversy was carried on by both parties gives a good impression of the two men's passionate desire to find the best possible expressions for experimental facts. The subject of discord is of historical interest, because according to Nernst's own statements it was the special thermodynamic properties of these solutions which led him to the proposition of the above-mentioned theorem. But his definition of 'ideal concentrated solutions' has not prevailed, and it is now, and was already then as mentioned by Brønsted, preferred to define ideal solutions (mixtures) in a different way.

In connection with his studies on affinity, for which purpose he mainly used measurements of electromotive forces and vapour pressures, Brønsted also undertook determinations of the specific heats of certain substances. These measurements required a special technique, and here as always when it was a question of devising, realizing and applying apparatus which could work with the required precision in the simplest possible way, Brønsted to a very great extent took part in the work together with his trusted collaborators, and so avoided the risk of error involved by the employment of less skilled workers. In these years the interest of physicists and chemists was focussed on the determination of specific heats, P. Debye, A. Einstein and W. Nernst having contrived by means of the quantum theory to interpret the course of specific heats as a function of temperature, which course was completely unintelligible to classical statistical mechanics. Brønsted was hampered in his investigations because he had no liquid hydrogen at his disposal, but by means of liquid air he succeeded in continuing his measurements down to temperatures where it was just possible for him to apply the expression deduced by Debye for very low temperatures.

However, his attention was turning towards other problems. As pointed out by Dr. E. Güntelberg, his collaborator since 1913, Brønsted's production holds indications at an early stage that he has noticed the increase of the solubility of certain electrolytes which occurs on addition of salts without a common ion.

During these years it was being realized, especially through Niels Bjerrum's works from 1909 and 1916, that many salts and some other electrolytes must be practically completely dissociated in ions. But it was well known that thermodynamically such solutions deviated considerably from solutions of uncharged molecules. According to proposals from various quarters, and particularly under the influence of previous works by G. N. Lewis, so-called activity coefficients were now introduced. They are concentration functions which multiplied by the known concentrations give the activities defined by Lewis so as to follow the simple laws which hold for uncharged particles in dilute solution. These activity coefficients may be determined empirically, but it was also an attractive task for the theorists to derive their values theoretically for certain simple systems, particularly very dilute electrolytic solutions. Such attempts at theoretical derivations were made by S. R. Milner, N. Bjerrum and O. Klein. Brønsted, ever first and foremost attaching weight to experiments, concentrated his work on the possibilities of the experimental determination of activity coefficients on the very systems which also theoretically were easiest to handle, viz. dilute solutions of electrolytes. His introductory works perhaps did not attract the attention they deserved, in spite of the clarity with which they deal with the problems and discuss the views of previous authors. But the coping-stone on this work was his purely empirical determination together with V. K. La Mer of activity coefficients as functions of charge and ionic strength. Brønsted and La Mer hereby found the very law which shortly before the publication of their work had been found theoretically by P. Debye and E. Hückel. Brønsted was unusually well equipped through his previous work for this achievement, which raised much well deserved admiration in all those interested. In his preliminary works he had shown that the determination of the solubilities of slightly soluble substances in dilute salt solutions was the most suitable way to determine activity coefficients. Further the slightly soluble substances had to be of such a nature that their concentrations could be determined easily and exactly. For this purpose he could draw on his knowledge, inherited from S. M. Jørgensen, of inorganic complex compounds of cobalt, as many of them are only slightly soluble and contain ammonia, which makes the quantitative determination easy. And finally, to establish equilibrium between solution and crystals he could use the same simple method: percolation of the solvent through a

suitable high layer of crystals, as he had used in the work quoted by Nernst, where he determined the solubility of rhombic and monoclinic sulphur.

While those works were in hand Brønsted together with G. Hevesy took up a work from quite a different field, *viz.* an attempt at separating the isotopes of mercury. By means of the molecular distillation, now used so frequently in other fields of chemistry, it was contrived for the first time to attain a separation which could be proved by analysis, when they succeeded in producing mercury the specific gravity of which deviated perceptibly from normal. The results were mentioned in public for the first time by E. Rutherford in his lecture given in the Commemoration Hall of the University of Copenhagen in 1920. By distillation of concentrated hydrochloric acid according to the same principle, a partial separation was also obtained for chlorine.

Probably the task was set by G. Hevesy, but in the report it is easy to discern Brønsted's knack of accomplishing by very simple methods the precision necessary to prove with certainty the extremely small differences in specific gravity and atomic weight to be determined here.

Also the theory of the separation was dealt with in detail on the lines which have nowadays become so important in the production of pure isotopes by distillation and related methods.

In spite of the sensation created by these works they were not to play such a great role to Chemistry in a more restricted sense, as the works on problems from the sphere of reaction-kinetics which Brønsted published in the same fertile years. After the importance of activity coefficients to the phenomena of equilibrium in reactions, particularly between ions, had been established, the question of their influence on the velocity of chemical reactions came to the fore. The problem was solved by Brønsted in 1922 when he proposed the idea, which afterwards seemed so obvious, that regard should be had not only to the activity coefficients of the reacting ions, but also to the activity coefficient of the so-called critical complex formed by the latter. The concept of critical complexes had already been introduced by Arrhenius in 1889, and had been used again in an inspiring paper by R. Marcelin in 1915. Brønsted's assumption was verified through a great number of examples taken from literature. Its appearance released from many quarters a deluge of works, experimental as well as theoretical. In this connection Brønsted himself together with K. J. Pedersen took up a work on the catalytic decomposition of nitramide which led to quite unexpected results. For it appeared that the reaction was catalysed not only by hydroxyl ions, but also by certain anions and other kinds of molecules which it was not customary at the time to term bases. These findings indicated certain regularities: a most interesting relation between the strength of the bases and their catalytic properties, the

complete explanation of which has hardly yet been given. But what was even more important: the work led Brønsted on to the thought that the definitions of acids and bases used up to then were not adequate. In 1923 before the publication of the nitramide work he, therefore, proposed new definitions of these concepts, which are so very important to chemistry, by defining acids as charged or uncharged molecules which may split off protons, and bases as molecules which may take up protons. Quite a similar definition was at the same time proposed by T. M. Lowry, and on account of the many advantages of the new view it was soon accepted. Although the setting up of a new definition was a purely formal matter, it proved, however, to place many problems in a new and much clearer light. Indeed, rarely has a new definition in chemistry entailed such great scientific advances. Also to elementary teaching the new and very simple definitions became of great value.

The fields of work which were opened up by these pioneer works from the beginning of the Twenties gave Brønsted and his numerous Danish and foreign collaborators enough to do for some ten years, but towards the end of this period, in the Thirties, Brønsted began to devote his attention to problems in connection with the newly roused interest of chemists in high molecular substances. Most characteristically one of these works was published in the volume issued in celebration of S. P. L. Sørensen's septuagenarian birthday in 1938, Sørensen's main subject having for a long time been the study of the physicochemical behaviour of the high molecular albumins.

From this group of works it is possible to get a certain although very incomplete insight into Brønsted's method of working. He begins to form more or less intuitively what I would call a semi-quantitative theory for the phenomenon, after which he works out the details by means of experiments planned under guidance of the provisional theory. On the other hand, to my knowledge, he never felt any inclination to dive deeply into the statistical theories which on many points play such a great part in the treatment of the properties of high molecular substances. Perhaps for this reason, but perhaps also because his intuition took him far in advance of his contemporaries, this group of works has not called the same attention as his works from the Twenties in spite of many interesting observations and important general views. Among other things he points out the very remarkable fact that the solubilities, particularly of high molecular substances, show discontinuity when plotted as functions of the composition of the solvent, i. e. that a substance is markedly soluble, *e. g.* in spirits slightly exceeding a certain alcohol content, but insoluble when the alcohol content falls below the same value.

An offspring of these works was a purely thermodynamic study on mixtures of low and high links in the paraffin series, carried out together with J. Koefoed

and published in the communications of the Royal Danish Society of Sciences and Letters (1946). The work, which was to be the last experimental work Brønsted published, is equally distinguished by the purity of the investigated substances, which was attained by means of the apparatus designed by Dr. A. Klit, the elegant methodical way in which the experiments were made, and the simple form in which it was contrived to render the results. As an example of his simple and efficient technique it may be mentioned that he solved the problem of weighing volatile substances only in contact with glass and mercury simply by suspending under the scale of a balance a glass bulb which was connected through a thin and very flexible capillary with the other part of the apparatus so that the presence of the capillary only impaired the exactness of the weighings immaterially.

From the middle of the Thirties till his death Brønsted moreover worked almost passionately on the problem of the best possible formulation of thermodynamics. In 1912 he had written a little text-book on elementary physical chemistry *Outlines of Physical Chemistry*. As an emergency measure it had been mimeographed in several impressions, but in the middle Thirties a new edition had become urgently needed, and this gave rise to Brønsted's work on the formulation of thermodynamics. With its 175 pages the old text-book is very compendious, but accompanied by the lectures it was satisfactory, and for subsequent use its lapidary style was an advantage. In his lectures Brønsted rendered his subject so elegantly that his students very often did not realize how hard it might be until they grappled with the problems afterwards at home. In the main outlines of his presentation of the fundamental principles he mainly followed the usual methods, but working on the new edition of his book, he was increasingly dissatisfied with them, the more so as on studying the classical presentations he found several examples of untenable reasoning. His ideal was to represent thermodynamics on the sole basis of axioms confirmed by experiences concerning macroscopic systems, the very ideal which must necessarily have been that of the founders of classical thermodynamics. In working out his ideas, however, he was gradually differing much from the classics and took a road which recalls Ostwald's approach to the problem, in order to get to the classical expressions in the form given by J. W. Gibbs in 1878. The latter procedure decidedly meant a modernization. For in the decades around the beginning of the new century so-called reversible cyclic processes were used, also in Brønsted's 'Outlines' to deduce thermodynamic relations. To carry out these reversible cyclic processes rather complicated idealised machines very often had to be designed, *i. e.* it was tried to replace Gibbs' mathematical operations by tangible physical ones. The method is intelligible and comparatively easy, particularly for beginners.

As soon as other systems than the very simplest ones are dealt with, it becomes, however, too cumbersome, and text-books were increasingly reverting to Gibbs' form, which Brønsted knew from Gibbs' 'Works'. This book, in Ostwald's translation, had been in his possession from his youth.

It is told about Gibbs that he left a pile of unpublished manuscripts which on examination proved to be manuscripts of lectures on the basic assumptions of thermodynamics worked out anew each year, and actually in his famous work of 1878 these assumptions: the energy principle and the entropy principle are taken as granted, and he does not attempt a presentation of them. In view of this we understand better that, feeling bound to render a logically unassailable representation of the fundamental principles of thermodynamics, Brønsted had to devote so much work, as in actual fact he did, to a task which seemed to his contemporaries thankless.

In his representation he uses certain words, especially the words work and heat in meanings sometimes deviating from the meanings given to them by physicists. This necessarily involved difficulties, and gave rise to very heated controversies, in this country notably in the physics periodical *Fysisk Tidsskrift*. Brønsted's arguments were characterized by the personal responsibility he felt towards the views he considered right or most expedient. If his opponents suggested, as suggest they would, in the argumentation that they acted as representatives of a collective, for example the physicists, he opposed it in caustic terms. The proposition which perhaps most staggered Brønsted's colleagues was that heat cannot be converted into work. The basis of this statement which so sharply shows the break with the classical formulation, is to my impression the following train of thought: It is well known that no work can be derived from one calorimeter, but from a system consisting of two calorimeters of different temperatures a certain amount of work can be gained, a certain quantity of entropy being transported by means of a reversible process from the calorimeter of the higher temperature to that of the lower temperature. As the amount of work gained only depends on the difference in temperature and the transported amount of entropy, but is independent of whether at the same time small positive or negative amounts of heat are supplied to the two calorimeters, it is natural to ascribe a certain potential thermal energy to the system, and it is this potential energy which is decreased through the process by exactly the amount constituted by the work gained. My own impression is that the language into which Brønsted thus tries to translate the more accustomed representations has considerable pedagogical advantages on account of its simplicity, but the text-book, particularly the last edition (1943), was very difficult in approach, notably as regards the introductory chapters. In the commemoration publication of the

University of Copenhagen of November 1946 he presented his views for the last time in a clarified form. Moreover this paper gives a very interesting contribution to the thermodynamic treatment of systems which are not in equilibrium. This field of problems, the theory of which is still rather undeveloped, is of great importance *e. g.* to reaction-kinetics, and so to biology.

It is still left for me to mention that Brønsted's love of living nature has also found expression in his scientific work, characteristically enough in one of his first and in the very last of his works. The former was a comprehensive work with C. Wesenberg-Lund on the hydrography of the lake 'Furesøen', and the latter a short note equally fascinating in subject and form in *Naturens Verden* (*The World of Nature*) which relates of an ingenious 'Regimentation in the Insect World', an observation from his last holidays.

Finally only this: In spite of help from those nearest to him, his family and his collaborators, I feel that I have only most imperfectly been able to give a picture of J. N. Brønsted, his straight, clean-cut and charming personality. His death, which came unexpected on the 17th December, 1947, after a short illness, was a hard blow to his friends and colleagues abroad and in this country, and we shall remember him as one of our great models.

J. A. Christiansen