Kamerlingh Onnes Memorial Lecture.

DELIVERED ON FEBRUARY 10TH, 1927.

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There can scarcely be a doubt entertained respecting the reducibility of all elastic fluids of whatever kind into liquids; and we ought not to despair of effecting it in low temperatures and by strong pressure exerted upon the unmixed gases.—JOHN DALTON (October, 1801).

An investigator should be almost a monomaniac, possessed of one idea only : to pursue and try to achieve but one purpose, and nothing else. Then, whether he makes a new discovery or not, he will have found satisfaction. But in no other case.—H. KAMERLINGH ONNES.

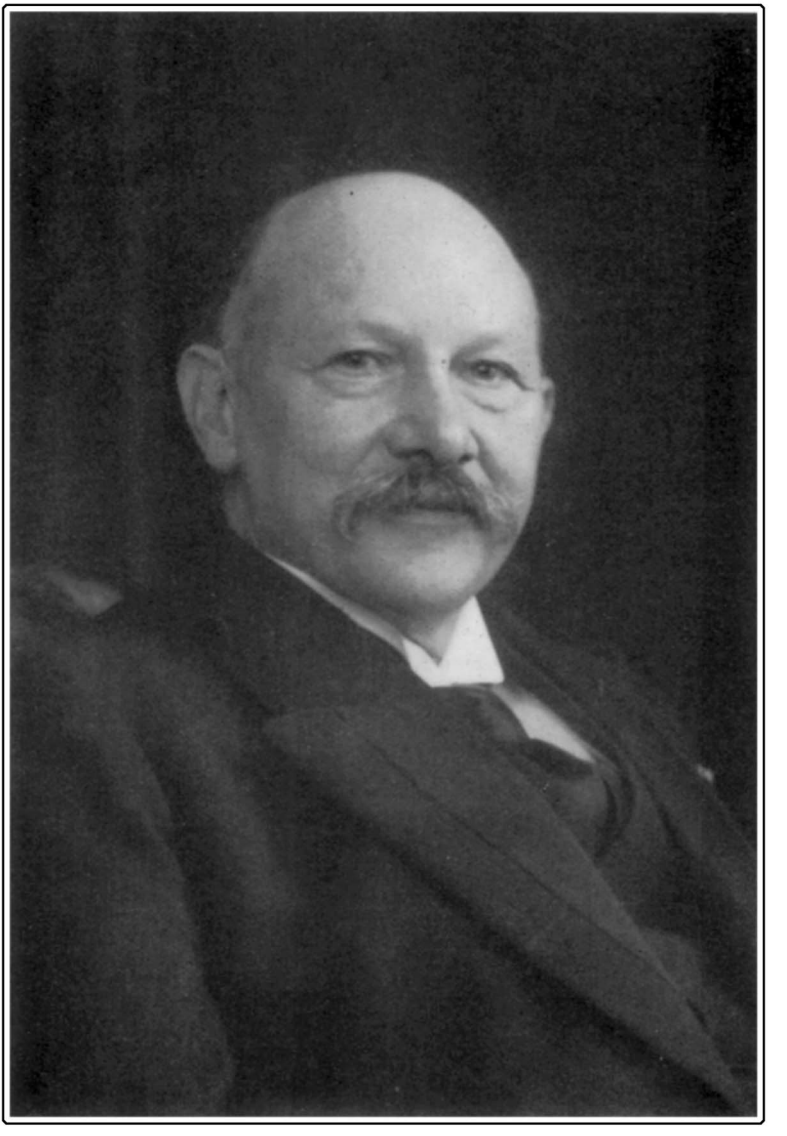
Je pense que tous ceux qui, en collaboration avec M. ONNES, ont travaillé à Leyde y ont connu des jours heureux.—MADAME CURIE.

LADIES AND GENTLEMEN,—

In 1885 the celebrated Swiss botanist Alphonse de Candolle wrote his enthralling work " Histoire des Sciences et des Savants." He closed one of the chapters of this book—the one in which, with the materials then at his disposal, he indicated to the country of Huygens the place which, about 1870, it occupied in the domain of natural science—with these very reassuring words : " Si mon analyse est vraie, la Hollande se relèvera. L'éclipse actuelle serait momentanée, comme celle de l'Angleterre à la fin du dix-huitième siècle. . . . Il existe encore tant d'excellentes influences en Hollande, qu'on peut espérer raisonnablement un retour de l'ancien éclat scientifique du pays." (" If my analysis is true, Holland will rise again. The actual eclipse is but temporary as the one in England at the end of the 18th century. . . . There are still so many excellent influences in Holland, that one can reasonably hope for a return of the ancient scientific lustre of this country.")

When treating the problems studied by de Candolle, we should now choose other data and criteria, and consequently a new work like de Candolle's is at the present moment a desideratum; but so much is certain, the prophecy pronounced in the sentences quoted has completely come true. This is in no small degree owing to the man whom the Chemical Society elected to its honorary Fellowship in the year 1920, and whom other scientific societies in this country —to mention only the Royal Society and the Royal Institution— honoured with the highest distinctions.

The communications from the Physical Laboratory of the University of Leyden give us a clear insight into what Heike Kamerlingh Onnes has done for science. But the Jubilee Volumes dedicated to him by his friends and co-workers in 1904, in commemoration



HEIKE KAMERLINGH ONNES.

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of the day when, twenty-five years before, he obtained his Doctor's degree, and in 1922, when he had held his professorate for forty years, are valuable documents in the history of science, which would make a Memorial Lecture superfluous had they not been published in a language which is spoken and read by few only.

Thus the task which has been laid on me becomes a labour of love, because I am allowed to sketch to you the life of my deeply regretted friend, and to recall to your memory some of his great deeds, deeds which signalise him as a man who must be numbered among the " primi inter pares " for all time.

First of all, a few particulars about the period prior to the day (November 11th, 1882) when he was appointed professor at Leyden; we may call this period his youth, for the new professor had not yet attained his thirtieth year. He liked to speak of his youth, of which he always retained the most pleasant memories.

" My father was the owner of a tile factory at Groningen (Heike was born there on September 21st, 1853) and was continually at work to develop his factory and to apply the newest machinery. In his spare hours in the evening he read much and I remember him, sitting before me with his favourite periodical, the *Revue des deux Mondes*. He liked to philosophise and to theorise, and in his walks with us—often with me alone; I was the eldest—many problems were considered and adapted to my level.

" And my mother? When I was sixteen and got up in summer at five o'clock to prepare my school tasks, I often found mother at work in the garden. She had artistic tastes; her father had been an architect.

" My parents had not much intercourse with other people. The business men had different tastes, liked a good dinner, were not averse to a good glass, and talked shop. Among the men of science (Groningen is a university town) my parents had few friends. Therefore we remained at home, read much, talked about art, and developed ourselves consciously, so to say. It was our delight to go for long walks in the country. Sport, as we understand the term now, was hardly known; nowadays for many young people sport is an intentional aim.

" In my parents' house all was made subservient to *one* central purpose: to become *men*. And only when a deep inner culture goes hand in hand with refined good breeding, so that nothing is neglected, and manifests itself also in neat and careful dress, may we expect that the result of such an education will be to form men, in the best and widest acceptation of the word. Has it not been a blessing that I was educated in a family where such ideas obtained? "

In September, 1865, Heike became a pupil of the Hoogere Burger-

school at Groningen, a school which in many respects may be compared to the American High School. The registers of the school relate, not in dry figures, but in glowing terms, that Heike always excelled in zeal, assiduity and knowledge. And also among his school fellows—than whom there are no better judges—the memory lives that Heike was the cleverest pupil of the school. At the time the director was van Bemmelen, later on Professor of Chemistry in the University of Leyden, and Onnes has expressed in feeling terms his gratitude for the influence which van Bemmelen exercised on his pupils.

The school records further tell us : September, 1869, removed to the fifth class (the highest); passes an excellent final examination in 1870; matriculates a short time afterwards to study science at the University.

Our student soon showed that he knew how to combine business with pleasure by joining the Groningsch Studentencorps (Corporation of Students). His club fellows quickly became aware that Heike had completed a great part of his daily task when they had hardly awakened from their sleep. When, in March, 1871, the Utrecht University opened the envelope containing the name of the prizeman to whose essay : " A Critical Investigation of the Methods of Determining Vapour Density and of the Results obtained thereby, with respect to the Relation of the Nature of the Chemical Compounds and the Density of their Vapours," the gold medal had been awarded, the name proved to be

HEIKE KAMERLINGH ONNES
Student in the University of Groningen.

The writer had not yet attained his eighteenth year.

From the way in which the subject matter of this prize essay was treated we see that Onnes was attracted by the study of chemistry, but his inclinations evidenced themselves more clearly after his cand. phys. examination (November 9th, 1871), which he passed with honours; he resolved to leave the country for some time and follow a course of studies with that master-mind in Chemistry who had reaped so many laurels on the banks of the Neckar. So he passed the winter term of 1871 at Heidelberg with Bunsen, the physico-chemist by the grace of God whose humorous sayings were well known to many generations of students and still form the lighter side of the literature of science.

Was it Bunsen's calorimetric investigations, published in 1870, which drove Onnes in 1871 to the birthplace of spectrum analysis? These investigations led to the rediscovery of the ice-calorimeter, which had already been described by Hermann of Moscow in 1834.

Certain it is that our student showed great interest in calorimetric methods in general. This is seen from his essay written in answer to a prize question from the Senate of the State University at Groningen : " A Critical Survey of the Methods of Determining the Quantities of Heat which are set free by Chemical Reactions and Dissociations and of the Results obtained by Different Investigators." Although for this essay Onnes got a silver medal (October 10th, 1872), the opinion of the Senate is not unqualified : " several times serious physical and chemical errors are found," but, on the other hand, it is stated " that he often shows great ingenuity and clever resourcefulness."

Soon we see his inclination for physics cropping out more strongly. At first he worked under the guidance of Bunsen and Kirchhoff; later on, we find him more frequently in the laboratory of Bunsen's friend and co-worker, of the man of whom A. W. von Hofmann said : " Auf meinem langen Lebenspfade bin ich keinem begegnet, bei welchem, wie bei Kirchhoff, höchstes Vollbringen gesellt gewesen wäre mit fast demutsvoller Bescheidenheit." (" During my long life I have never met anyone who, like Kirchhoff, joins the highest power of performance to almost meek humility.")

The " Seminarpreis," awarded to our candidate, which was a great honour, enabled him to work in Kirchhoff's laboratory, a privilege which was granted to two students only. Here Onnes gave himself heart and soul to experiments with Foucault's pendulum, and this investigation became later the starting point for his thesis (" New Proofs for the Axial Changes of the Earth "), which he wrote in his own country. One needs only to glance at the preface of this thesis to see how gratefully the author recalls the time spent at Heidelberg, guided by the man who not only had opened new worlds to mankind, but who had also been endowed with a talent for theoretical and practical investigation, and was a first-rate teacher besides.

Onnes's wanderings ended at the close of his stay at Heidelberg (April, 1873), where Gabriel Lippmann and Arthur Schuster were among his fellow-students. On his return to his native town Professor R. A. Mees became his mentor.

The fact that our student twice obtained the prize for an essay must not lead to the erroneous idea that he belonged to the genus of " plodders." In the Students' Almanacs of the Groningen University mention is made of the fact that Onnes was a very good horseman, and so well liked by his fellow members of the Students' Corporation that they elected him Rector. In their club building, Kamerlingh Onnes's memory is perpetuated by a memorial stone, on which his name is carved, placed there by the gratitude

of his fellow members for the fact that it was especially owing to Onnes's organising talents that the building was brought under direct management. We also read in those annals of students' joy and students' grief that the then Rector took an active part in the movement against a Government measure, at that time under consideration, to abolish the Groningen University.

On June 6th, 1876, Onnes passed his " doctoraal " examination with honours, but the last stage in his academical studies, his Doctor's degree, to be got after he had maintained a thesis, only came a few years later. This is not to be wondered at when we consider the size and the subject of his thesis, which he maintained on Thursday, July 10th, 1879, at Groningen. The Faculty thought its contents and treatment so excellent that they did not require the candidate to leave the room at the end of the examination, as is the custom in Holland, but unanimously and without discussion awarded him the Doctor's degree with great honours (magna cum laude).

When we read the preface of this thesis attentively, we find in it the programme which the young scientist had traced for himself, a programme to which he adhered to the end of his days. " When writing this thesis," he says, " I always tried to take to heart the lesson which the young student in science may find in the Memorial Lecture on Gustav Magnus, written by Helmholtz : ' Gegenwärtig scheint es mir, als wenn immer mehr und mit Recht die Ueberzeugung Boden gewönne, dass in dem entwickelteren Zustande der Wissenschaft nur *derjenige* fruchtbar experimentieren könne, der eine eindringende Kenntnis der Theorie hat und ihr gemäss die rechten Fragen zu stellen und zu verfolgen weiss ; und andererseits, dass nur *derjenige* fruchtbar theoretisieren könne, der eine breite praktische Erfahrung im Experiment habe.' (' It seems to me that nowadays the conviction gains ground that in the present advanced stage of scientific investigation only *that* man can experiment with success who has a wide knowledge of theory and knows how to apply it ; on the other hand, only *that* man can theorise with success who has a great experience in practical laboratory work.') "

Before taking his doctor's degree, Onnes had fixed his abode in the town where van Leeuwenhoek had lived, and where he filled the post of assistant in Bosscha's laboratory (1878). The four years he spent there were years of hard work ; he was required to give Professor Bosscha's course of lectures, and his laboratory work was an excellent training for the future experimenter, as he himself testifies at a later period. The reports of the annals of the students, who were not accustomed to make a secret of their opinions, show us how much his lectures were appreciated by his audience.

A scientist with a career like Onnes's was obviously the right man to fill the vacancy caused by the retirement of Ryke, professor of experimental physics at Leyden. So we see Onnes, on October 11th, 1882, in the Hall of the University, in the chair, to deliver his inaugural lecture in which he sketched the importance of quantitative investigation in physics. This day was the beginning of a new period in his life, but it was also for Onnes the dawn of his triumphal progress through the realm of low temperatures.

Time is lacking to describe this triumphal progress in detail. But for one short moment I wish to dwell on the above-mentioned lecture of 1882 and on the one delivered by Onnes as " Rector Magnificus " of the University of Leyden : " The Importance of Accurate Measurements at very Low Temperatures." Even at the present day these addresses have a great fascination for the reader. We do not know which excites our admiration more : his prophetic eye or the unequalled energy he displayed at a ripe age in accomplishing the programme he had at one time evolved. If we want completely to understand the contents of these addresses, we must first of all try to realise the progress of physics, especially of thermodynamics, about 1875.

Two years earlier a man had obtained his doctor's degree at Leyden, after maintaining a thesis : " On the Continuity of the Gaseous and Liquid States," whose work elicited a year later the remark of Clerk Maxwell (in a lecture delivered to this Society on February 18th, 1875) : " . . . but his attack in this difficult question is so able and brave that it cannot fail to give a notable impulse to molecular science. It certainly has directed the attention of more than one inquirer to the study of the Low-Dutch language in which it is written."

We know now, from a letter from Andrews at Belfast to James Thomson (February 5th, 1874), that this view was correct : " P. S. Bessie and I are hard at work on Diderik van der Waals," and a few months later Andrews writes : " My dear Thomson. . . . I am deep in the Dutch paper and also occupied with my own results, which I believe will turn out more important than I supposed. But I miss you sadly."

Fourteen years later the paper of van der Waals was translated into English under the auspices of the Physical Society in London.

The experimental testing of the equation of state, given by van der Waals in his thesis, together with the one of the law of corresponding states, published by van der Waals in 1880, formed the first part of Onnes's programme.

In later years he tells us : " This law had a special charm for me, because I was of opinion that it was based upon the stationary

mechanical similitude of the substances considered. From this point of view the study of the divergences in substances of simple chemical structure with low critical temperature seemed to me of great importance. Precision measurements at low temperature must be very attractive in my opinion. For this purpose, it was necessary to dispose of large apparatus with which the measurements could be made at a constant temperature, and it was indispensable to construct suitable temperature baths, baths which could also be used for numerous other investigations."

Thus, as soon as Onnes had entered upon his new sphere of activity, the foundations were laid of an institution in which the investigations in question could be taken in hand—the Cryogenic Laboratory of Leyden, which, in consequence of the results attained, was soon to become an international centre of research.

The efforts of Onnes and his co-workers met with stupendous success. In 1904 liquefied air and oxygen formed the boundary line of the low temperatures which could be obtained with cryostats; two years later hydrogen could be made in large quantities. Eight years before, Dewar had liquefied this gas in the laboratory of the Royal Institution in this city. The reason why so much time elapsed between the moment when Dewar could wire to Onnes: "Hydrogen liquefied," and the application at Leyden was that Onnes wanted to have at his disposal large quantities of liquids for his cryostats.

When we read the papers on the investigations in the Leyden Laboratory we are struck again and again by the great appreciation which Onnes had for the men who were working in the domain which he had chosen for his life-work, and he continually admits that he owes much to their researches. In his address of 1904 he says: "In the meantime, an entirely new path has been struck by Dewar with respect to investigations at low temperatures. He taught us to make glass vessels, beakers, bulbs, and glasses in which liquids with boiling points at very low temperatures could be kept and transported. These vacuum vessels have double walls which are silvered on the inside, whilst the space between them is exhausted to the utmost. The access of heat from without is now diminished to such a degree that the liquid does not evaporate perceptibly. By means of this invention we gained the desired free disposal of refrigerants like liquid oxygen. Dewar's magnificent invention may be called the most important appliance for operating at extremely low temperatures. The open vacuum flasks are for the permanent gases what the steel bottles, tested at 250 atmospheres, are for the coercible gases. In fact, the moment when a vacuum glass containing liquid oxygen was offered to the Prince of Wales at the meeting

of the Royal Institution marks a new era in low-temperature research."

The words which Henry E. Armstrong used in his most fascinating address dedicated to the memory of James Dewar may be unconditionally applied to Onnes : " His object was never merely to liquefy gases. He was never the mere artificer, but always the philosopher seeking to penetrate into the far distant region of the ultimate zero of temperature." This very fact made Onnes's creation at Leyden the place where investigators from all parts of the world could carry on their research work. Thus this building, distant but a few steps from the spot where, two centuries before, Boerhaave had expounded to his students Boyle's " Experimental History of Cold," became the place where physics in their entirety, physical chemistry, physiology, could be studied at the lowest point of temperature.

" Wer zählt die Völker, nennt die Namen,
Die gastlich hier zusammen kamen ? "

(" Who counts the nations or knows the names of all who were hospitably received here ? ")

These words of the poet would make a suitable inscription, not only for the Cryogenic Laboratory, but also for Onnes's artistic house, where so many scientists could and did find relaxation from their strenuous labours.

Science owes much to Lavoisier's wife for the share she took in her husband's work, but no less praise is due to Elisabeth Byleveld, who, since September, 1887, shared the sweets and bitters of Onnes's life. Besides her duties as a mother, which she fulfilled with the greatest tenderness, she always guarded her husband from the troubles of daily life as much as lay in her power and she took the greatest care of his ailing health. Onnes himself says : " She has toiled for me, has always been ready to put her own wishes in the background, has received my guests, and taken care of them."

All who have stayed in her hospitable home know that when her husband had finished his daily task in the hyper-arctic regions of science, he found in her companionship the warmth necessary to stimulate his energy for new problems. And new achievements were not wanting, even up to the last days of Onnes's life; the unending flow of communications from the physical laboratory of the University of Leyden testifies this. In these communications are the results of thermodynamic, magnetic, magneto-optical, radioactive and electric investigations at the lowest temperatures. In this hour I recall to your memory one of the most remarkable and far-reaching achievements of Onnes and his staff, the one which

more than any other entitles him to the epithet of " gentleman du zéro absolu." The day is December 10th, 1913, the anniversary of the death of Alfred Nobel. A select crowd has met in the Great Hall of the Royal Academy of Music at Stockholm, where those to whom Nobel prizes have been awarded are to receive the insignia from the hands of the King of Sweden. As is seen from the following lines, Onnes is among the laurelled :

HEIKE

KAMERLINGH ONNES

for hans undersökningar öfver kroppars egenskaper vid läga temperaturer hvilka bland annat ledt till framställningen af flytande helium.

Stockholm den 10 December 1913.

TH. NORDSTRÖM,
Kungl. Vet. Akad-s preses.
CHR. AURIVILLIUS,
Kungl. Vet. Akad-s sekreterare.

(For his investigations on the properties of substances at low temperatures, which investigations, among other things, have led to the liquefaction of helium.)

The next day he mounted the platform and sketched the " Leiden und Freuden " (disappointments and joys) of the years that lay behind him. After pointing out that the theories of van der Waals and more particularly his " law of corresponding states " had guided him, he surveys the results attained by Wroblewsky, Olszewski, Pictet, Linde, and Dewar at low temperatures, and in imagination he leads his audience through the Leyden Cryogenic Laboratory. He introduces them to his numerous co-workers, among whom Crommelin has especially distinguished himself in the technical part of the work, and finally depicts to them the way in which helium was liquefied : " The limit of what was possible was reached, as had been foreseen when the plans were formed. The experiment (July 10th, 1908) began at half past six a.m. and ended at half past nine p.m. When at half past six p.m. the first liquefied helium was perceived, not only had the apparatus been strained to the uttermost, but the utmost had also been demanded from my assistants. But for their perseverance and their ardent devotion, every item of the programme would never have been attended to with such perfect accuracy as was necessary to render this attack on helium successful. In particular I wish to express my great indebtedness to Mr. G. J. Flim, who, as chief of the technical department of the Cryogenic Laboratory, not only assisted me in

leading the operations, but also superintended the construction of the apparatus according to my direction and rendered me the most intelligent help in both respects.

" It was a wonderful moment when the liquid, which looked almost immaterial, was seen for the first time. It had not been perceived when it flowed into the glass; its presence could be detected only when the glass had been filled. Its surface stood out sharply defined like the edge of a knife against the glass wall. I was overjoyed when I could show liquefied helium to my friend van der Waals, whose theory had been my guide in the liquefaction up to the end."

And when, later on, Onnes himself relates that on this memorable day his wife fed him, beginning at three o'clock, by putting bits of bread into his mouth, there rises up before us the image of Caroline Herschel, your compatriot, who read to her brother, Sir William, when he was polishing his mirrors, and—to use her own words—" was constantly obliged to feed him by putting the victuals by bits into his mouth."

But, Ladies and Gentlemen, read the " Communications " for yourselves; the description of the journey to the nadir of temperature, and especially the famous discovery by Onnes (1913) of the supra-conductivity of metals at very low temperatures, will awaken your interest as much as the most thrilling novel. According to the electron gas theory of metallic conduction, one might have expected that the resistance of a metal would diminish continuously with fall of temperature, or even that the resistance at very low temperatures might begin to rise sharply, owing to a sort of freezing of the electrons. Onnes made the startling discovery that the resistance of certain metals suddenly falls to zero (or to an extremely low value, at a temperature varying with the nature of the metal) a few degrees above the Kelvin zero point.

Even before the verdict of the scientific world had assigned the Nobel prize to Onnes, Dutch scientists had given him a token of their profound veneration. Not one of the numerous company which had gathered in the Great Hall of the Amsterdam University on November 18th, 1908, on the occasion of the Annual General Meeting of the Ancient Association of Physics, Medicine, and Surgery, but will think with emotion of an event in the history of science at which he was then assisting. For on that day van der Waals and Kamerlingh Onnes were to be given a mark of the high appreciation which was felt by the whole scientific world; to each of them was to be presented the medal of honour, the highest mark of distinction at the disposal of the Association, to Onnes for the

liquefaction of helium, to van der Waals for his " law of corresponding states."

" Expressed in mathematical terms," thus van der Waals addressed Onnes, " this law may be formulated in this way : If we consider different substances at temperatures which are an equal number of times their critical temperatures, and under pressures which are an equal number of times their critical pressures, the volumes are each an equal number of times the critical volume.

" Elsewhere I have expressed this differently, in words that can be more easily understood : all substances form one single genus. If we compare, for instance, height with temperature, breadth with pressure, and length with volume, we can say that all substances are copies of one another. If one substance has a critical point, such a point must appear in all the others. But whereas, in individuals belonging to the same genus, the differences in height, breadth, and length are but slight, these differences may be very great with temperature in the different substances. Thus the critical temperatures sometimes diverge in the proportion of 1 to 1000.

" Now it was a question whether helium, the discovery of which has taken place in recent years only, also belongs to this common genus, whether this dwarf also has a well-formed shape. We owe it to you, highly esteemed Kamerlingh Onnes, that now we know this for certain. Only you could investigate it in your cryogenic laboratory, which is unequalled for organisation. You conducted this investigation systematically. By carrying out measurements of pressure and volume at the lowest possible temperature, you were able to determine the so-called Boyle point, *i.e.*, the temperature at which, with very great volume, the substance follows Boyle's law. For all substances, the Boyle point is rather more than three times higher than the critical temperature, according to the equation of state 27/8 times the critical temperature.

" Strictly speaking, the question was now settled : Helium too possesses this very same remarkable point; moreover, the critical temperature of helium, being rather more than three times lower than the Boyle point, was also known. Dewar had already announced that helium has a reversion temperature for the Joule–Kelvin effect. But this lies rather more than six times higher than the critical temperature. So you had halved the distance which separated actual results from the critical temperature of helium. But you would not stop here; you wanted to see not only the front and face of the well-formed shape, but its heart also. You wanted to reach the critical temperature itself and to liquefy the substance. And on the memorable 10th of July, after a long day's

work, surrounded by a staff of well-trained observers, you achieved it after careful preparation.

" First of all, you deduced, from the value found for the Boyle point, that the critical point would lie about 6° above absolute zero. Then, assuming the well-formed shape, you calculated how much helium you would require, considering the size of your apparatus, to what temperature you would have to cool it at first by means of hydrogen, and to what pressure you would have to submit it, so that by free expansion it could cool itself to below 6°. Having considered everything, you worked the summer day through, until, long after sunset, you succeeded in liquefying helium. You have made it possible to approach much closer to the absolute zero than could be done up to this time, an achievement which is of the highest importance for many scientific problems in which the influence of low temperatures has to be studied.

" It is therefore with a feeling of admiration for the results you have attained, with a feeling of veneration for your character as a man and an investigator, with a feeling of gratitude on account of science in Holland—because, as Korteweg said at the Royal Academy of Sciences, you have made the heart of every Dutch scientist thrill with joy and with a feeling of warm friendship—that I present to you this commemorative medal in the name of the Association for the Advancement of Physics, Medicine, and Surgery."

Van der Waals spoke a true word when he gave utterance to his feelings of veneration for Onnes's character as a man and an investigator. An incident in the previous history of the liquefaction of helium proves this, an incident which should serve as an example for all scientists : On March 5th, 1908, Onnes wired to Dewar in London : " Converted helium into solid. Last evaporating parts show considerable vapour pressure, as if liquid state is jumped over." On April 16th, Onnes wrote to the editor of *Nature* : " . . . The prosecution of the experiments has shown that what I observed in expanding the gas was *not* the evaporation of *solid* helium, but solution phenomena of solid hydrogen in gaseous helium. I have communicated to the Amsterdam Academy a note on my experiments, which at the moment leave the condensation of helium a yet undecided question." With unflagging zeal Onnes set to work again : on July 10th of the same year the problem was solved : helium had been liquefied.

The results attained could not but stimulate our untiring investigator to new labours. First and last his maxim is " *Inferior !* "

In a paper " On the Lowest Temperature yet obtained. An Introductory Paper to a General Discussion on the Generation and

Utilisation of Cold," read before the Faraday Society and the British Cold Storage and Ice Association on Monday, October 16th, 1922 (proof subject to revision), he summarised his newest conquests in the words : " Taking into account the uncertainty of the extrapolation, it will be better to say that the lowest temperature yet attained is some hundredths of a degree below 0·9K."

Onnes was obliged to leave the last stage of the work on which he had set his heart, the solidifying of helium, to one of his most brilliant pupils, whom he also recommended as his successor. At least five times (for the first time in 1908) Onnes tried to attain the result, but he never succeeded. Only a few months after his death (he passed away on February 21st, 1926) this refractory substance was subjugated by Keesom.

The plans which Onnes had already formed when he became professor at Leyden and grew to greater proportions as his work progressed (" Es wächst der Mensch mit seinen grössern Zwecken " . . . man grows with his growing projects . . .) required, not only a talented experimenter, but also a man with great organising ability. And Onnes had been gifted in this respect also. As such he rendered an invaluable service to the craft of instrument-making by founding the Society for the Promotion of the Training of Instrument-makers (1901). He gave new life to the traditions which arose in the workshop of van Mussenbroek Brothers at Leyden as early as the 17th century. Scientists constantly demand better instruments by means of which they can penetrate into the heart of Nature, and consequently greater demands are made on the makers of these appliances. Onnes's training school for instrument-makers, annexed to the Cryogenic Laboratory, was not only a training school for his own mechanics by which he was enabled to surmount many difficulties that presented themselves in his investigations; it became an establishment at which the laboratories in Holland have an excellent opportunity of providing themselves with first-rate workmen, and which has given many an excellent instrument-maker to the laboratories in Europe as well as to institutions beyond the Atlantic.

From what I have told you about Onnes's work you must have gathered that what he accomplished may be considered a stupendous achievement even for a man in normal health. Such a task is the more remarkable because Onnes had always to contend with his bronchial weakness. It is sad to read in the letters which he wrote from time to time to his friend van der Waals how much he was handicapped by his weak health, but the indomitable energy which urged him on to new problems awakens our admiration. Notwithstanding these reverses, which often retarded the progress of his

work, he was always happy. To van der Waals he wrote on September 11th, 1912, a few days after his silver wedding :

LEYDEN, *Sept. 11th*, 1912.
HUIZE TER WETERING.
HAAGWEG.

" DEAR FRIEND,—We deeply regretted that you could not come to Leyden yesterday as we had so much hoped. We should have liked to thank you in person for the kind letter, written in the name of all of you, and for the fine flowers with which you added lustre to our reception. For the time being, our room was a flower garden for the bride at her silver wedding.

" Our silver wedding was an event the commemoration of which had for a long time been looked forward to as a day which would fill us with heartfelt thankfulness for the many blessings we had received in the twenty-five years which lie behind us. So you will understand that we celebrated this day with thankful hearts and that we shall always look upon it as a pleasant milestone on the road which lies behind us.

" Which of us, Betsy,* Albert,† or myself, was most affected by these feelings is hard to say. All of us are equally conscious that our gratitude can never be great enough for the supreme happiness and prosperity which have been showered upon us. As for the prosperity, the measure of it can be realised best by me, because after our marriage the cares which I had known before diminished. When I re-read mother's letters, written in those most care-ridden years, it is as if I look back upon a totally different world, and it seems to me that only now I realise how appalling were the difficulties with which we had to contend—always hopefully after mother's example—until at last they gave way. When I think of that time, our present prosperity makes me doubly thankful. And as for the happiness we enjoy, although it has been mixed with affliction—the sad loss of our parents is still a source of sorrow—we have been favoured above many, because we have been allowed to possess them for so long a time in mutual love. And while gratefully accepting all this abundant happiness, a feeling of modesty and diffidence comes over us. When we thought of our future we felt the need of lifting up our hearts, and therefore we were deeply moved when Albert, who executed the recitative, and Harm ‡ with the two nieces who accompanied, received us at breakfast in the family circle of brothers and sisters with a solemn aubade.

* His wife. † His son. ‡ His nephew.

" May your wish ' that we shall long be spared for each other, every one of us labouring to the best of his ability '—which is also our fervent hope—be fulfilled. Once more our best thanks, with cordial greetings from all to all. In the name of our old friendship,

Cordially yours,
H. KAMERLINGH ONNES."

All who realised the important part which nowadays is played by temperatures below freezing point welcomed with satisfaction the co-operation between technics and science which was brought about by the institution of the " Association internationale du Froid " (1909), in which Onnes also took an active part. About ten years later it was reconstructed under the name of " Institut international du Froid." It was there that for the first time the epithet of " gentleman du zéro absolu " was applied to Onnes, whilst in his own country his popularity appears from a cartoon in which he is given the sobriquet of the " Freezer." Whoever reads the annual reports of the " Institut international du Froid " will agree that, contrary to the prevailing idea, low temperature had not impaired Onnes's energy and rate of reaction when it was necessary to promote the interests of the Institute. Is it to be wondered at that numerous learned Societies in his country and abroad, borrowing Saurin's line under the bust of Molière :

" Rien ne manque à sa gloire, il manquait à la nôtre "

have awarded their highest distinctions to Onnes. This was done also by this Society. He valued such marks of distinction very much, as may be seen from a passage in a letter to his friend van der Waals, in which he congratulates him on his election as corresponding member of the French and Prussian Academy of Sciences. Onnes says : " . . . the proof that slowly your work is being understood must be a source of great satisfaction to you."

At the commencement of my discourse I mentioned the beautiful international Jubilee volume which was presented to Onnes on November 11th, 1922, on the occasion of the fortieth anniversary of his professorate. On that memorable day all vied with one another as to who should be the first to show him, beside appreciation of his scientific labours, admiration for his amiability which had engendered love in the hearts of all who made his acquaintance. The staff of his laboratory, too, wished to give expression to their feelings. When visiting the Cryogenic Laboratory at Leyden, you

will notice a memorial stone of grey marble, in which are carved these words :

> " On this spot, on the 10th of July, 1908, Helium was liquefied for the first time by Dr. HEIKE KAMERLINGH ONNES.
>
> The entire staff of the laboratory has presented to him this memorial on the occasion of the 40th anniversary of his professorate.
>
> November 11th, 1922."

On this festal day an amazed audience admired the rare phenomenon of a fountain of liquid air. And, while reminding you of that day, I must not omit to mention the words spoken by Onnes about the cordial relations that existed between him and H. A. Lorentz :

" Now that I am speaking about friendship," thus he said, " I also think of my older friend Lorentz. We began our studies at the same time, and I can glory in a friendship of more than fifty years, a friendship which was shared by our mutual households. It has always been a great privilege to work with such a man as Lorentz. First he preserved my health by giving several of my lectures, which had the additional advantage of allowing me more time for my work in the laboratory. And later on, when he was called to Munich, it was by his efforts that Kuenen came here, who, as I have said before, succeeded in making the laboratory for the greater part what it actually is."

It is as if I still hear his voice when, on February 8th of last year, one day before my departure for America, he telephoned to me, wishing me a prosperous voyage and expressing the hope to see me again in good health on my return. Fortunately, he was spared a long sick bed; no sooner had I set foot ashore on the other side of the Atlantic than the sad tidings of his death reached me.

When we see how scarce really noble characters are among the living, and, on the contrary, how plentiful among the dead, according to biographies and epitaphs, we cannot wonder that the world in general refuses to believe in the existence of such characters, either among the living or the dead. And yet in Kamerlingh Onnes we had a man in whom it is difficult to discover qualities which one would have wished different. He was not only the " gentleman du zéro absolu," but, as my friend Donnan has said, " a gentleman in every sense of the word, and one of the first gentlemen of European science."

Thus Kamerlingh Onnes has lived his life—a life, although long, yet too short for my friend himself, too short for his family, too short for science. Many blessings fell to his lot and, although grief was not spared him, the benefits prevailed. He found love and friendship; he had an intellectual life, rich in discoveries, as is given but to few. Love, friendship, discoveries, and also honour. For Kamerlingh Onnes was not one of those whose merits are recognised at a ripe age only. He was an unknown scholar for but a short number of years. Very soon his life became one triumphal progress. And is it not his greatest triumph that in spite of all the marks of esteem which were showered upon him by all the world he remained a simple, genial, and kind-hearted man.