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THE
INSTITUTE OF CHEMISTRY
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GREAT BRITAIN AND IRELAND.

FOUNDED, 1877. INCORPORATED BY ROYAL CHARTER, 1885.

Patron: H.M. THE KING

“LUDWIG MOND, F.R.S.: 1839-1909”

a Lecture by

Professor F. G. DONNAN, C.B.E., D.Sc., F.R.S.

*given before the Royal Institution of Great Britain on
15th March, 1939, and redelivered (with the con-
currence of the Managers of the Institution) before the
Institute of Chemistry, on 12th May, 1939.*



30, RUSSELL SQUARE, LONDON, W.C.1

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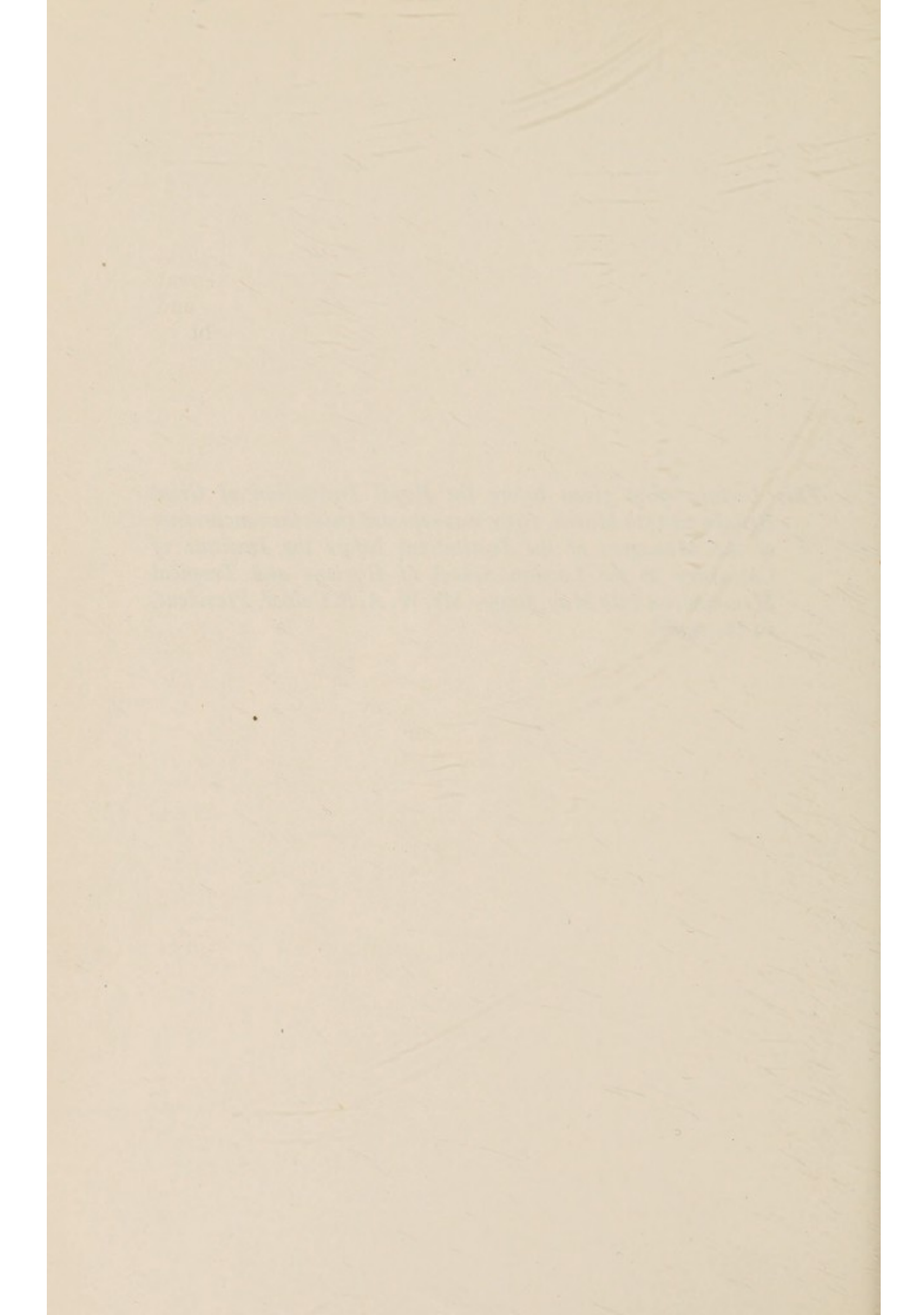
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This Lecture—first given before the Royal Institution of Great Britain on 15th March, 1939, was repeated (with the concurrence of the Managers of the Institution) before the Institute of Chemistry at the London School of Hygiene and Tropical Medicine, on 12th May, 1935—Mr. W. A. S. Calder, President, in the chair.



LUDWIG MOND MEMORIAL LECTURE

By F. G. DONNAN, C.B.E., D.Sc., F.R.S.

WE meet here this evening to commemorate, on the occasion of the centenary of his birth, the life and work of Dr. Ludwig Mond, M.R.I., F.R.S., eminent investigator, creator of great industries, princely benefactor of Science, great patron and lover of Art. To him the Royal Institution owes a debt of gratitude that cannot be measured in words or counted in gold. Ludwig Mond cared little for words or gold but much for deeds, and I rejoice to think that, if he were alive to-day, he would regard some part of that debt as repaid by the deeds of the famous Davy-Faraday Laboratory which he founded and endowed with such magnificent generosity in 1896. For many years the Davy-Faraday Laboratory has been a component and essential part of the Royal Institution, the home of its researches, and the nucleus of its creative activities. Under the leadership of Sir William Bragg it has raised the fame of the Royal Institution to the heights attained by Humphry Davy and Michael Faraday. The Davy-Faraday Laboratory can be compared only with the great research institutes founded by Carnegie and by Rockefeller in the United States, and with the equally great ones of the Kaiser Wilhelm Gesellschaft in Germany. In consonance with the fundamental idea of Ludwig Mond, the Davy-Faraday Laboratory embodies the truest spirit of a free democracy, inasmuch as it opens its doors to any competent and earnest investigator, and gives him every possible aid and facility in the pursuit of his researches. More than a score of the men who have worked within its walls have subsequently made a name for themselves in science.

In the mind and in the action of Ludwig Mond the dream of Francis Bacon came true. As in the case of Benjamin Disraeli, it required a great Jew, with the divine fire burning brightly in his spirit, to express and to embody in action the somewhat vague hopes and aspirations of the British race.

If Ludwig Mond had done nothing more than this, his name would ever be remembered with honour and respect in the annals of science. But he did much more, and in the temple of scientific fame he occupies a distinguished personal place.

Picture to yourselves Friday evening, 3rd June, of 1892. In the famous Lecture Theatre of the Royal Institution stood Ludwig Mond, describing his famous discoveries of the metal carbonyls, and, with the aid of his friend and assistant, Carl Langer, demonstrating their formation and their remarkable properties. He had now made an important discovery in pure science,—something worthy of his famous teachers, Kolbe and Bunsen. He, Ludwig Mond, already the creator of a great industry and immersed in affairs of great complexity and importance, had now contributed in an important way to the advance of pure chemical science. To him, the man of science, this was a great joy. Let us rejoice this evening that the elusive goddess had deigned to smile, and bestow on him the key to one of her secrets. For he was worthy of this good fortune and counted it for much.

Moritz Baer Mond, the father of Ludwig, was born in the village of Ziegenhain in Germany. At the age of 17 he went as an apprentice to the silk mercer of Cassel, Aaron Levinsohn, who had married Eva Müller. Moritz Mond, a young man of great energy and strength of character, soon won the favour of his employer and went to live with the family. In time he took charge of the business and married Henriette, one of the three daughters of old Levinsohn. Mr. Hector Bolitho, in his very interesting *Life of Alfred Mond*, first Baron Melchett, has painted a charming picture of the cultivated life in the big, old gabled house in Cassel. Eva Levinsohn spoke Italian and French and wrote poetry. Of an evening Moritz Mond would sit with the family, listening to Eva playing the violin, or her husband reading Goethe aloud. Frequently friends would come in, new duets would be tried on the piano, and fine literature read aloud and studied. It was in this happy and cultured home that Ludwig Mond was born, on 7th March, 1839, the second son of Henriette and Moritz, their first son having died at an early age. The boy Ludwig inherited determination and strength of character from his strong-willed and forceful father, whilst from the gentle Henriette, who loved to read Rousseau and Goethe, he derived that fineness and imaginative delicacy of mind that characterise the artist and the investigator. When his schooldays were over, he went in 1855 to study chemistry under Hermann Kolbe at the University of Marburg, proceeding in the following year to the University of Heidelberg, where he spent three years studying chemistry under the great Robert Bunsen. This was a rare piece

of good fortune for young Ludwig, for under the training and influence of Bunsen, who took a great interest in him, he gained that love of chemical science and that habit of precise quantitative investigation and disciplined logical thought which were to characterise him throughout his life. Though devoted to his chemical work, the young Ludwig was full of the joyous spirit of youth. As Hector Bolitho relates, he climbed the hills and explored the woods of the beautiful Neckartal. He hunted and he danced, and as an honoured member of the famous fighting corps, Rhenania, took a successful part in the duels of the Mensur. No doubt he held his own at the Kneipe, and took a lusty part in singing the fine old part-songs of the Kommersbuch.

Ludwig Mond did not take his Doctor's Degree at Heidelberg, probably or possibly for want of money. Many years afterwards, when he was 55 years old, he was destined to return to his Alma Mater to receive from her the Doctorate *honoris causa*.

Faced with the necessity of earning his living, nothing is more remarkable in his career than the early and successful appearance of his pre-eminent ability in applying scientific principles to the solution of technical problems. Already in 1857 he had paid a visit to his uncle, Adolf Löwenthal, in Cologne. Löwenthal was a pioneer of German electro-plating and galvanoplastic work, and had a good business. But in a few days young Ludwig Mond had found a way of increasing the profits, by utilising to good account certain discarded by-products, namely, zinc sulphate and nitric acid.

When, in 1860, his last semester at Heidelberg was finished, he went to live with his uncle at Cologne. For a number of years this hospitable house became his head-quarters, and in many respects a second home. Here he met his young cousin, Frida Löwenthal, whom he married in 1866.

It seems that Ludwig Mond's first post was as a chemist in a factory at Mombach, near Mainz, where acetic acid was manufactured by the dry distillation of wood. He was very soon successful in working out a profitable process for the manufacture of verdigris, and, as Mombach was not very far from Cologne, he was able to visit his aunt and uncle and his cousin Frida almost every Sunday. Happy is he who can combine verdigris with romance, for the affection between Ludwig Mond and his young schoolgirl cousin steadily grew during these happy months.

Then he went for a time to work at a Leblanc soda works at Ringenkuhl. This was an important step in his career, for it led him to study the problem of recovering sulphur from the calcium sulphide in the alkali waste of the Leblanc process. Returning to Cologne in May, 1861, he went to a works at Ehrenfeld (a suburb of Cologne) to assist in the process of manufacturing ammonia from waste organic matter, especially leather. As Ehrenfeld was near his uncle's home, Ludwig Mond continued his investigation of the sulphur-recovery problem, in a room fitted up as a laboratory. Sulphur, not verdigris, was now mingled with romance, for soon he and Frida Löwenthal became secretly betrothed.

Ludwig Mond's process for the recovery of sulphur from Leblanc alkali waste consisted in the atmospheric oxidation of the material, combined with lixiviation of the soluble (calcium) salts of the sulphur acids so formed. On treatment with hydrochloric acid, free sulphur is produced. The process was patented in France in December, 1861, and in England in August, 1862. Its discovery and successful development constituted the first step in Ludwig Mond's fortune. It brought him to England in 1862, where he demonstrated his process in the works of John Hutchinson and Company at Widnes. He found, however, that it was not entirely suited to large-scale operation and economy of labour, so he patented an improvement in September, 1863, which consisted in carrying out the oxidation in the "black-ash" lixiviating vats, by blowing air through the waste and repeating the operation after one or two washings with water.

Returning to the Continent in 1864, he undertook the construction and management of a Leblanc soda works at Utrecht, remaining in Holland for three years. It is interesting and important to note that the man who was destined to kill the famous Leblanc soda process had first made an accurate and comprehensive study of it, and knew every detail and every defect.

In 1866 Ludwig Mond travelled from Utrecht to Cologne and married Frida Löwenthal. This was the greatest good fortune of his life. They had known each other since she was a little girl of ten years. In her home she had been familiar with science and scientific technical problems from earliest girlhood, and had already assisted Ludwig in his work on sulphur recovery, carried out in her father's house. To the end of his life she continued to take a deep and active interest in all his work.

The good fortune that had come to another great chemist, Antoine Laurent Lavoisier, came now to Ludwig Mond.

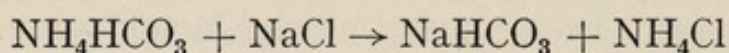
In 1867 he arrived in England, became a British subject, and rejoined Messrs. Hutchinson, in whose works he perfected his sulphur-recovery process and supervised its introduction into many others. Mond's process depended for its success on the control of the degree of oxidation, so as to obtain the correct balance of the different salts before acidification, and on successive oxidations and lixiviations. A 50 per cent. recovery was achieved. It was very successful, but was eventually superseded by the Chance process. Frida and Ludwig Mond went to live in "The Hollies," a house in the village of Farnworth near to the Hutchinson works. Their first baby was born in September, 1867, and was named Robert. Another baby came in October, 1868, and was called Alfred. I must refer you to the interesting story which Hector Bolitho tells of life at "The Hollies" during the years 1867-73.

During his period of work with Messrs. Hutchinson, Ludwig Mond made the acquaintance of John Tomlinson Brunner, who was in the commercial department of the firm. They soon became close friends. Brunner was the son of a Swiss citizen, the Rev. John Brunner, who had come to England and founded a successful school at Everton, near Liverpool. John Brunner was an acute man of business and finance, but also, like Ludwig Mond, a man of high intelligence, though in a different way. It was a kindly fate that brought these two men together, for they formed an irresistible combination of scientific genius, financial wisdom, inflexible determination, and courage of the highest order. Little did they realise in the early years with Messrs. Hutchinson how soon the mysterious call of Destiny would demand of both the utmost use of all their qualities.

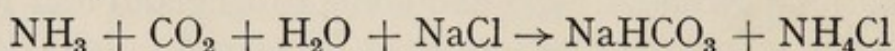
In an extremely interesting paper published in 1885 (*J. Soc. Chem. Ind.*, 1885, 4, 527), Ludwig Mond has himself given an account of the origin of the ammonia-soda process. It appears that the great French physicist, Fresnel, was the first to suggest it. The principal credit seems due, however, to the British chemists, Harrison Gray Dyar and John Hemming, who took out a patent on 30th June, 1838, and worked the process in a certain form for some time at Whitechapel, London. Time does not allow me to give an account of the numerous patents that were taken out, and the equally numerous attempts that were made to work the process in a profitable way. On account

of various difficulties, amongst which may be mentioned the loss of ammonia, all attempts failed, until Ernest Solvay, a Belgian chemist, succeeded in overcoming a good many of the difficulties by means of new types of apparatus, and, in partnership with his brother Alfred, started business as Solvay et Cie, with a capital of £5,440. The small works which they built at Couillet, near Charleroi, began operations in 1865.

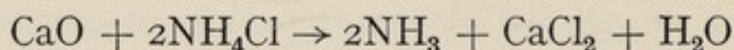
Perhaps I may mention at this point that the ammonia-soda process consists essentially of the reaction (in aqueous solution)



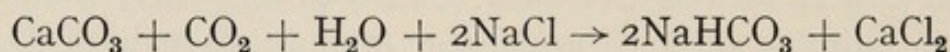
Owing to its relatively low solubility, the bicarbonate of soda, NaHCO_3 , separates as a fine crystalline precipitate, and so causes the reaction to go on. We have here a beautiful example of the principles introduced into chemical science by the great French chemist, Claude Louis Berthollet, the friend and adviser of Napoleon. Doubtless it was the influence of Berthollet which led to the pioneer investigation of Fresnel. In practice, the ammonium bicarbonate is formed by the solution in the brine of ammonia and carbon dioxide gases, so that the foregoing reaction may be written



The carbon dioxide is obtained by the heating of limestone (CaCO_3 essentially), whilst the lime obtained in this way is used to recover the ammonia by means of the reaction



The total reaction may be written in the form



Ammonia acts only as an intermediate, whilst the only waste product is a solution of calcium chloride.

I have written all these reactions in their simplest form, i.e., without regard to the ionic theory or the formation of carbamate. When the process is treated from the point of view of physical chemistry, it forms one of the most beautiful examples of homogeneous and heterogeneous equilibria.

Ludwig Mond and John Brunner were ambitious young men. We can picture in our minds many a long evening at "The Hollies," when the possibilities of the future were eagerly discussed. Mond, the man of science and the already experienced chemical technician, was probably the imaginative leader in

these discussions, but he had the inestimable advantage of a friend whose acute mind was well versed in the technique of accountancy and the costing of chemical processes on an industrial scale. It seems that the two friends at first formed the project of establishing a fertiliser works in the London area, but for various commercial reasons this plan was dropped. Then they conceived the idea of erecting a Leblanc alkali works in the neighbourhood of Manchester. Concerning the prospects of such an enterprise, Mond asked the advice of a friend of his who had a Leblanc works in Belgium. It appears that this sagacious person suggested that, before embarking on this project, Mond should look into the degree of success obtained by Ernest Solvay's resuscitation of the ammonia-soda process. The result of this excellent piece of advice was that Mond visited Solvay in 1872, and made a careful study of his plant and the technical and commercial results so far obtained. This examination convinced Mond that a brilliant future awaited the process. Brunner was of the same opinion, so the two men entered into partnership and obtained a licence to work Solvay's process in England. They knew that, underground in Cheshire, there existed vast quantities of the brine they wanted. So with some difficulty they obtained sufficient capital to enable them to purchase, from Lord Stanley of Alderley, the Winnington Park Estate, which adjoins the canalised River Weaver, a tributary of the Mersey, and to erect a small works thereon. This choice of site was most sagacious, for limestone could be brought from the Derbyshire quarries, near Buxton, some forty miles away, whilst the River Weaver enabled their products to be sent to all parts of the world with only one transshipment from barge to steamer at the Liverpool docks.

Winnington Hall consisted of two buildings, Winnington Old Hall, an ancient baronial mansion whose history went back to Domesday Book and, in close juxtaposition thereto, the new Hall, a fine eighteenth-century mansion built about 1784 in the Adams' style. For some time these had been rented to a seminary for young ladies, kept by Miss Margaret Alexis Bell, where Ruskin was wont to visit and to lecture to them about Art. The horrid desecration of this genteel Victorian paradise by the presumed belching furnaces and smoking chimneys of a chemical works called forth the maledictions of that exponent of aesthetic beauty. No doubt Widnes and the Leblanc soda process justified his anger, but had he lived to see, as I have seen, the green lawns

and bright flowers that would come to surround the works of Brunner and Mond he might have changed his mind.

Ludwig Mond and his family made their home in Winnington New Hall, whilst after much reconstruction (due, amongst other things, to the presence of dry rot) the old black and white Hall became the home of John Brunner and his family. The new ammonia-soda works started operation in 1873. For the next seven years, Mond and his partner Brunner fought a titanic battle against every sort of difficulty. The engines supplied to them were very imperfect, incrustations blocked up pipes and other apparatus, whilst the liquors caused much corrosion of metal parts. It is related that everything that could break down, broke down, and everything burst, that could burst. Night and day the two partners worked amongst their men. What sleep they could snatch was often to be had only in the works. They were continually haunted by the spectre of failure due to a rapidly vanishing capital. But the genius of Ludwig Mond finally triumphed over all difficulties and, by 1880, the manufacture of carbonate of soda had become a technical and commercial success, and could well be termed the Mond-Solvay ammonia-soda process.

The practical working is attended by many difficulties, the principal one being the formation of very coherent deposits, known in the industry as "scales." Thus, the sodium bicarbonate scales and clogs up the vessel in which it is formed, whilst the impurities in the brine, consisting of small quantities of calcium and magnesium salts, form complicated scales by interaction with ammonia and carbon dioxide. As if that were not enough, the vessel in which the distillation of ammonia is carried out scales heavily and persistently with a deposit of calcium sulphate. These formidable troubles, combined with the necessity of producing an easily filterable precipitate of sodium bicarbonate, suitable for efficient separation on rotary vacuum filters, and the imperative necessity of avoiding so far as possible any loss of the expensive ammonia gas during distillation, transport and brine absorption, had up to the time of Ludwig Mond's work rendered the ammonia-soda process either commercially unprofitable, or very precarious, to say the least of it. All these problems were tackled by Mond with characteristic energy, and solved by the use of scientific method, applied with high and trained intelligence and great practical ability. Precipitates which would handle well and cause the minimum

of blocking were regularly obtained by strict attention to the measurement and control of pressures, temperatures, and concentrations. Better designed apparatus and a technique of regular change and cleaning were of the greatest assistance, whilst Mond saved ammonia, in characteristic fashion, by giving the workmen and foreman a direct financial interest in the efficiency of its recovery.

Time does not permit me to deal with the highly important improvements which Ludwig Mond introduced in Ernest Solvay's process. I can only refer to his introduction of the continuously operating "distiller" (ammonia still), which supplanted the awkward batch method originally employed by Solvay, and to his improvements in the "finishing" plant, wherein the bicarbonate of soda was converted into "ash" in two stages, i.e., by driving off the water, ammonia, and some carbon dioxide in one machine, and then calcining to soda ash in an open hearth furnace.

On 1st January, 1881, Brunner and Mond sold the works at Winnington and Sandbach to a limited company with a nominal capital of £600,000. It was stipulated in the Articles of Association that John Tomlinson Brunner and Ludwig Mond should each hold the office of managing director for life. A new and improved plant was erected at Winnington and began work in February, 1882.

Of a successful industrial enterprise it can rarely be said that the fight with continuous change and improvement is ever ended. So it was with the continuously expanding and developing works of the new Company. It is not for me to tell a story that is known to all the world. But Mond and Brunner had now won their great battle with fate, and the famous firm of Brunner Mond & Co. was well launched on its great career. A splendid account of its origin and development, entitled *The First Fifty Years of Brunner Mond & Co., 1873-1923*, was written by John I. Watts for the Jubilee celebrations in 1923.

It was my great good fortune during the War to get to know a few of the men who had collaborated with Ludwig Mond and John Brunner in the famous days of Brunner Mond & Co. Amongst these I might mention Roscoe Brunner, Sir John Jarmay, H. Glendinning, and A. W. Tangye.

Since, even with the greatest care, ammonia is an expensive item in the process, Ludwig Mond had turned his attention as early as 1879 to the problem of obtaining ammonia from the

nitrogen of the air. When the success of the ammonia-soda process was assured he attacked this question with great vigour. With the help of Joseph Hawliczek, all the known processes were examined, but the only one found to be at all suitable was that of Margueritte and Sourdeval, in which the nitrogen is fixed as barium cyanide by a heated mixture of barium carbonate and carbon. When the resulting product is treated with steam, ammonia is obtained and barium carbonate regenerated. Mond designed apparatus for carrying out this process on a fairly large scale, but he was reluctantly compelled to abandon it, since the clay retorts he employed could not withstand the high temperature, namely, 1200° – 1400° C., required for the formation of cyanide.

The next step in this quest led to results of great importance and reveals in striking fashion Mond's high ability as a scientific investigator. In a process patented by Rickmann and Thompson, it was claimed that, when air and steam are passed through a deep coal fire, a certain amount of the nitrogen of the air is converted into ammonia. Mond found that some ammonia was certainly obtained by this method. However, when he subjected the same coal to a current of steam in an externally heated tube he got double the amount of ammonia! It was clear that the ammonia came from the nitrogen contained in the coal, and not from that in the air. Large-scale experiments convinced him that this method could never become economic, so he conceived the brilliant idea of burning the coal in gas producers in a mixture of air and steam. By this method a valuable power gas is obtained, which can be employed for heating purposes in foundries and small furnaces or for generating power in gas engines, and owing to the reduction of temperature effected by the carbon-steam reaction the thermal dissociation of the ammonia is so greatly reduced that one-half of the nitrogen of the coal is obtained as ammonia. So was born the Power Gas Corporation, and the South Staffordshire Mond Gas Company, with its central station at Tipton, near Dudley Port, supplying compressed Mond power gas in pipe-lines to 160 works.

In his Presidential Address to the Society of Chemical Industry in 1889, Ludwig Mond stated that, if one-tenth of the 150 million tons of coal annually consumed in England at that time were treated by his process, the production of sulphate of ammonia would be large enough to supply the whole of Europe, and would render us independent of Chilean nitrate for fertiliser

purposes. In these famous investigations Mond was at first assisted by G. H. Beckett, Karl Markel, and Adolf Staub. Later, he derived most valuable help from Mr. Herbert Humphrey, particularly in connexion with the development of gas engines and the use of Mond gas therein.

In 1884, Ludwig Mond and his family moved from Winnington Hall to a house in Park Crescent, London. After a short time there he purchased the fine mansion known as "The Poplars" at 20, Avenue Road, Regent's Park. This house, with its beautiful garden, soon became and long remained a centre of cultured life, in which Ludwig Mond and his wife entertained in the most delightful way scientific, musical, and artistic men and women. Here in the course of years he made his famous collection of pictures by early Italian masters, a collection which was ultimately given to the nation of his adoption. In order to escape the London fogs, he spent most of the winters in Rome, where he purchased the house known as the Palazzo Zuccari. Beautiful pictures were also collected here, and, as Professor Nasini has related, the Palazzo Zuccari became a centre of artistic and scientific culture in the Italian capital. Mond assembled here a very fine and comprehensive library of art. The house with its library and artistic treasures was ultimately bequeathed to the Kaiser Wilhelm Gesellschaft, of which Mond was a distinguished member, as a centre for the study of Art. I understand that many of the pictures and other artistic treasures have now been removed to the Palazzo Venezia, whilst the house itself is employed as an office of some sort.

Having established two great industries, and with his fine houses in London and Rome, it might have been thought that Mond, now at the age of 56, could well afford to rest on his hard-won laurels. The very opposite happened. He set up at once a research laboratory at the Poplars, utilising at first, for this purpose, hay lofts and other outbuildings. The tale of what happened at the Poplars laboratory during the twenty-five years, 1884-1909, forms, I think, one of the most wonderful stories in the whole history of science and industry, for, from the hay lofts of 20, Avenue Road, came a series of entirely unexpected scientific discoveries of high importance, and a great new metallurgical industry of an entirely novel sort.

Carl Langer, a pupil of Victor Meyer, came to Ludwig Mond as a research assistant and collaborator in 1884, and was closely associated with him until his death. I mention his name here

as Langer took a prominent part in the discoveries which I now describe.

Two lines of investigations converged on the same problem, namely, the removal of carbon monoxide. I shall not try to take them in exact chronological order. In the ammonia-soda process the chlorine of the salt goes to waste as calcium chloride, whereas, in the older Leblanc process, this chlorine is utilised as hydrochloric acid or as bleaching powder. Indeed, in its battle with the ammonia-soda process, these so-called by-products became more important, commercially, than the alkali. The fertile and active mind of Ludwig Mond conceived the idea of working out a chlorine by-product process for the ammonia-soda industry. His method consisted in starting with dry solid ammonium chloride, obtained from the process liquor by the Jarmay refrigeration method, volatilising it by heat, and passing the hot vapour over a heated oxide, such as nickel or magnesium oxide, when the metallic oxide combines with the hydrogen chloride of the dissociated vapour, forming the corresponding metallic chloride, whilst the ammonia passes on and is recovered. If now a stream of hot dry air be passed over the heated metallic chloride, chlorine is set free and the original metallic oxide regenerated. It is necessary to use valves for the purpose of this process, and Mond found that nickel was the best metal for their construction, since this metal showed a high resistance to the extremely corrosive action of the hot vapour of ammonium chloride. In the laboratory at the Poplars everything went well, but in the plant erected at Winnington the nickel valves became leaky, and were found by Langer to be coated with a black deposit of carbon. Where was the snag? It was traced to the use of the lime-kiln gas, which was used to blow out the ammoniacal vapours, before the air was passed over the hot mass of pellets in the second stage of the process. For this purpose pure carbon dioxide had been used in the laboratory. The lime-kiln gas, mainly carbon dioxide, was found to contain a small amount of carbon monoxide, owing to the presence of organic matter in the limestone. So carbon monoxide was the nigger in the fence, and must be removed. I may mention at this point that Ludwig Mond's by-product chlorine process attained a considerable development at the Winnington works, the nickel oxide pellets being replaced by those of magnesium oxide admixed with a suitable binder. It was, however, ultimately replaced by Hoepfner's process, in which the calcium

chloride liquor is treated with the zinc oxide and carbon dioxide. The ensuing reaction may be represented by the equation $\text{CaCl}_2 + \text{CO}_2 + \text{ZnO} \rightarrow \text{CaCO}_3 + \text{ZnCl}_2$. Chlorine gas and metallic zinc are then recovered by the electrolysis of the zinc chloride. For many years Brunner Mond & Co. supplied the market with very pure metallic zinc obtained in this manner. The success of this process was due to the work of several men, amongst whom I might mention George P. Pollitt—now Lieutenant-Colonel Pollitt, D.S.O.

Now let us turn to the other line of investigation. Here again we see the active mind of Mond at work. He had conceived the idea of realising the dream of the electro-chemist, of converting the chemical energy set free as heat in gaseous combustion directly into electrical energy. So he set Carl Langer to work on the problem of the gas battery. They achieved quite a respectable measure of success. Slabs of porous clay or gypsum damped with sulphuric acid constituted the electrolyte, whilst the electrodes were sheets of perforated platinum foil covered with platinum black, and pressed against opposite sides of the porous slab. On one side was air, on the other hydrogen. The secret of their success lay in the fact that the platinum black was not wetted with liquid, which at once destroys its powers of gas absorption. A seven-plate battery, containing $9\frac{1}{2}$ grams of platinum, gave 5 volts at a current of 2 amperes, and had an efficiency of 50 per cent. However, when Mond and Langer tried to use producer gas instead of hydrogen, its content of carbon monoxide (and hydrocarbons) destroyed the absorptive power of the platinum black for hydrogen. A remedy was, however, at hand. Their earlier difficulty with the carbon monoxide in the lime-kiln gas had led to experiments which showed them that hot carbon monoxide is converted by contact with nickel into solid carbon and carbon dioxide gas. So they found that when the producer gas plus steam was passed over finely divided nickel at a temperature of 400°C ., the carbon monoxide was completely converted into solid carbon and carbon dioxide, and all "poisonous" gas removed.

Now, picture to yourselves a dramatic scene, the scene of a new discovery and the birth of a new compound and a new industry. Carl Langer is going on with further experiments on the (catalytic) decomposition of carbon monoxide by finely divided metallic nickel in order to ascertain if a definite compound

of carbon and nickel is formed. The undecomposed carbon monoxide is poisonous, so it is burning with a pale blue flame at the Bunsen burner exit of the apparatus. Carl Langer's assistant goes home early and leaves him to shut down the experiment by turning off the flame that heats the nickel. To his surprise, he notices that, as the nickel cools, the pale blue flame becomes a greenish-yellow. Arsenic hydride due to impure sulphuric acid? Langer heats the glass tube through which the gas passes to the burner. A metallic mirror is produced on the glass. But it is *nickel*, not arsenic. Carl Langer's mind leaps to the truth, and nickel carbonyl, a new compound of a strange new character, is discovered (1888). It turned out to be a liquid of the molecular formula $\text{Ni}(\text{CO})_4$, boiling at 43°C . and freezing at -23°C . Scientific papers communicated to the *Journal of the Chemical Society*, in the years 1890 and 1891, by Mond and his collaborators, Carl Langer and Friedrich Quincke, described the formation and properties of nickel tetracarbonyl, and two carbonyls of iron, the liquid penta-carbonyl, $\text{Fe}(\text{CO})_5$, and the solid diferro hepta carbonyl, $\text{Fe}_2(\text{CO})_7$. It was shown later that the correct formula for this latter substance is $\text{Fe}_2(\text{CO})_9$. They could obtain no other metallic carbonyls at that period. In the later years of his life, Ludwig Mond returned to the investigation of the metal carbonyls, employing the high-pressure methods developed at the Royal Institution by Dewar and Lennox. In a paper published in the *Journal of the Chemical Society* in 1910, in the names of Mond, Hirtz and Cowap, the formation of carbonyls of cobalt, ruthenium and molybdenum were described, using pressures of 100 to 450 atmospheres.

This was the swan-song of Ludwig Mond, broadcast to the world after his death, which occurred on 11th December, 1909. Would that we all could leave this world with such a valiant song of noble effort, such a melodious message devoted to the cause of truth. As Lord Kelvin said, Ludwig Mond, in his discovery of the volatile metal carbonyls, had "given wings to the heavy metals."

I might mention at this point that the work on the gas battery led Ludwig Mond to devote great attention to the absorption of hydrogen by platinum and palladium. The development of the great nickel process forced the laboratory at the Poplars to drop research on the gas battery, but for a number of years Mond collaborated with Ramsay and Shields in an extensive investigation of the absorption problem, the results of which were published

in several very interesting papers communicated to the Royal Society.

I should also like to mention the important part taken by Robert Mond in the later investigations on the metal carbonyls. To him and Mr. Wallis is due the discovery of the nitrosyl carbonyls.

Let us now return to the busy laboratory at the Poplars. Mond perceived that his discovery led at once to a new method of separating nickel from cobalt. But about the year 1890 it became clear to his mind that the volatilisation of nickel as the carbonyl could lead to a new technical process for manufacturing nickel from its ores, since by this method the nickel in a highly pure form could be separated from cobalt, copper, and iron. At once he and Carl Langer set to work. Again, the laboratory of 20, Avenue Road hummed with intense activity. A complete model laboratory plant was constructed, and fully realised the hopes of its designers. In 1892, Mond and Langer constructed an experimental pilot plant at Wiggin's Nickel Works at Smethwick, near Birmingham, in order to test the process on a larger scale. The difficulties were, indeed, great, but several years of patient, systematic work overcame them. The famous Mond Nickel Process was now a viable child of robust and sound constitution. Ludwig Mond, now a man in his middle fifties, saw the vast possibilities that lay open to him, and did not hesitate to face another herculean labour. Although Carl Langer was put in charge of the works, he relates that Mond spared himself in no way, and took a leading part in everything. He bought two nickel-ore deposits near Sudbury, in the northern part of Ontario, sank mines, built metallurgical plant, and constructed railways and hydro-electric power stations. In all this strenuous work of construction and organisation in Canada he was assisted by his two sons and by Dr. B. Mohr. Under the efficient supervision of Langer, the nickel-extraction works were constructed at Clydach, near Swansea, in South Wales. Already in 1910, after ten years of existence, the undertaking had made great advances, and was marketing yearly 3,000 tons of nickel of the highest purity (99.9 per cent.). To-day the Mond process produces one-third of the nickel consumed by the world. Most of it is taken by the steel industry.

Time does not permit me to say more than a few words about the details of this great and important industry. The nickel-copper sulphide ore, after concentration by flotation, is furnaced in Canada with nitre cake and coke. The molten sodium sulphide

so formed dissolves most of the copper as a complex sodium cuprisulphide in one liquid phase, whilst the second coexistent liquid phase contains most of the nickel sulphide. The total melt is run out of the furnace, and after solidification the two phases are readily separable by mechanical means (Orford Process). The concentrated nickel sulphide matte so obtained is roasted and converted largely into oxide in Canada.

After these and other preliminary treatments we come to the Mond process at Clydach. The purified nickel oxide is first calcined to remove any remaining sulphur. The product is then reduced to metal in the "reducer" at 350° – 450° C. in a current of water gas, the hydrogen acting as the principal reducing agent. In the "volatiliser" the metallic nickel, kept at about 60° C., is carried off as gaseous carbonyl in a current of the water gas, now much enriched in carbon monoxide. Finally, in the "decomposer" the nickel carbonyl is broken down at a temperature of 180° C. The carbon monoxide passes on and re-enters the gaseous cycle, whilst the nickel is deposited on nickel pellets in the form of small spheres which are kept in continuous motion. Needless to say, the materials are also in motion (of a different sort) in the reducer and the volatiliser. The whole series of operations forms one of the most beautiful examples of an exactly controlled and scientifically developed chemical (manufacturing) process. To a certain extent, pressures very considerably higher than atmospheric are employed in the most modern developments at Clydach.

If Ludwig Mond had done nothing more than this in his life, his name would go down to future ages as the creator of one of the most important and most scientific industries in the history of civilisation. Very great honour is also due to Carl Langer and the many chemists and engineers who have assisted him, and who continue to supervise and improve the process. Amongst these I should like to mention Mr. Wallis, who had been closely associated with the research work of Ludwig and Robert Mond, and who is now Chief Chemist of the Clydach Works.

I may permit myself only two further remarks concerning the Mond Nickel Process. As is now well known, considerable amounts of valuable precious metals are recovered as by-products. In recent years, through the influence of Sir Alfred Mond, who later became the first Baron Melchett, the Mond Nickel Company was merged with an important American group, to form the International Nickel Company.

The great results which Ludwig Mond achieved, both in pure science and in industry, were recognised throughout the world. The honours bestowed on him by Universities and learned Societies form a very impressive list.

One of the first four Honorary Secretaries of the Society of Chemical Industry in 1881, and elected President in 1888.

Fellow of the Royal Society in 1891.

Doctor of Science, *honoris causa*, of the University of Padua in 1892.

Doctor of Science, *honoris causa*, of the University of Heidelberg, in 1894.

Foreign Member of the Reale Accademia die Lincei of Rome in 1899.

Doctor of Science, *honoris causa*, of the University of Manchester in 1904.

Medal of the Society of Chemical Industry in 1906.

Doctor of Laws, *honoris causa*, of the University of Oxford in 1907.

Honorary Member of the German Chemical Society in 1908.

Honorary Foreign Member of the Royal Society of Naples in 1908.

Foreign Member of the Prussian Academy of Sciences in 1909.

I do not know of any other chemical manufacturer, however eminent, who has been so signally honoured by the learned world.

He received the Grand Cordon of the Crown of Italy in 1908.

Mond's gifts to science and learning were magnificent. I cannot pretend to give a complete list, so must content myself by quoting from the memoir which Carl Langer wrote in 1910 for the German Chemical Society:—

Davy-Faraday Laboratory	..	..	..	..	£125,000
Royal Institution, London	..	..	..	..	5,000
Royal Society	..	..	..	..	50,000
Royal Society (for the International Catalogue of Scientific Publications)	..	..	..	..	14,000
Heidelberg University	..	..	..	..	50,000
Munich Academy of Plastic Arts	..	..	..	..	20,000
Chemische Reichsanstalt, Berlin	..	..	..	..	10,000
Cannizzaro Foundation, Rome	..	..	..	..	7,500
Children's Hospital, London	..	..	..	..	14,000
Lister Institute, London	..	..	..	..	7,500
Physiological Institute, London	..	..	..	..	3,000

The Mond Laboratory at Cambridge University, which the Royal Society was enabled to establish owing to his munificence, is now one of the world's great centres of physical research. In the Address of Commemoration of their Foreign Member, Ludwig Mond, which Professor Nasini presented to the Reale Accademia dei Lincei in Rome on 3rd April, 1910, he refers to the "conspicuous grants received from him by the Chemical Institute of the University of Rome and my Institutes of Padua and Pisa."

Ludwig Mond was a most enlightened and far-seeing employer, and an industrial pioneer who was always deeply interested in the welfare of his workers. Brunner Mond & Co. was the first

company to reduce the hours of work from 12 to 8, and to give an annual week's holiday with full pay to all who deserved it. They took care that their people were decently housed, and provided with recreation clubs and sports fields. No wonder that Mond was both loved and respected by his men. In his Memoir published in the *Journal of the Chemical Society*, John I. Watts relates the following incident about him:—"During his absence in Rome in 1903, a report reached England that he had died, and obituary notices appeared in some of the papers. The news was quickly shown to be false and, on his next visit to Winnington, the workpeople met him in a torchlight procession, presented an illuminated address of welcome, and made Winnington Park gay with fireworks."

I had not the privilege of knowing Ludwig Mond, but, at the meeting of the British Association at Liverpool in 1896, I heard him give his Presidential address to the Chemical Section. The subject was the production of chlorine. Mond gave a masterly account of the history and present state of this great branch of chemical industry. The address was of particular interest on account of the description which he gave of his own investigations and their technical results.

Although Ludwig Mond became a rich man, his interest did not lie in the accumulation of wealth. What really attracted him was the strict and quantitative application of the principles of chemical and physical science to the improvement of technical (chemical) processes, and the cheapening of manufacture by high efficiency of construction and operation. Therein lay the great satisfaction of his mind, and at least one deep joy of his spirit.

He was blessed with a wife such as few great men are destined to possess. With her sympathy, her knowledge of science, and her trained intelligence, she stood by his side, a faithful helper and adviser in the great enterprises and adventures of his life. Of her he might well have said—*Fons et origo boni*. She died on 16th May, 1923, at the age of 75.

His two sons, Robert and Alfred, gave him great help in various parts of his work, and he lived to see them both grow to manhood, and to trained and highly intelligent activity in many spheres of life: Alfred, in 1895, and Robert, in 1897, became Directors of Brunner Mond & Co. I must not fail to mention the great help which Emile S. Mond gave to Ludwig Mond, and to several of his enterprises, amongst which I would particularly mention, besides Brunner Mond & Co. (elected Director in 1906),

the Mond Nickel Company and the South Staffordshire Mond Gas Company. It is sad to think that Alfred, Robert, and Emile are all gone. I had the great good fortune to know both Robert and Emile well, and I shall ever remember them with deep affection. We can all rejoice that Violet, Lady Melchett, Lady Mond, and Mrs. Emile Mond live to comfort and delight our hearts, and that Henry Mond, the second Baron Melchett, and the grandson of Ludwig, carries on the great tradition as a Director of Imperial Chemical Industries.

The mournful French saying, *Tout passe, tout lasse, tout casse*, may be all too true of this fleeting human existence, but it has no application to the valiant deeds of a great life such as that of Ludwig Mond, which will go down to future ages in the history of science and human endeavour, coeval with our race and our civilisation.

In the preparation of this lecture I have to thank many friends for valuable help: Lord Melchett, Dr. Slade, Major Freeth; Mr. Wallis, Mr. Haig, and Mr. Simon of the Mond Nickel Company; Dr. Cocksedge and Mr. Fletcher of I.C.I. Alkali; and Mr. H. J. Pooley, General Secretary of the Society of Chemical Industry. I fully realise the insufficiency, and probably also the inaccuracy, of this attempt to do any sort of justice to my theme, but my all too inadequate study of the life-work of a great man has been, for me, a source of much inspiration and pleasure.

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