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Ludwig Mond — father of metal carbonyls — and so much more (7 March 1839–11 December 1909)

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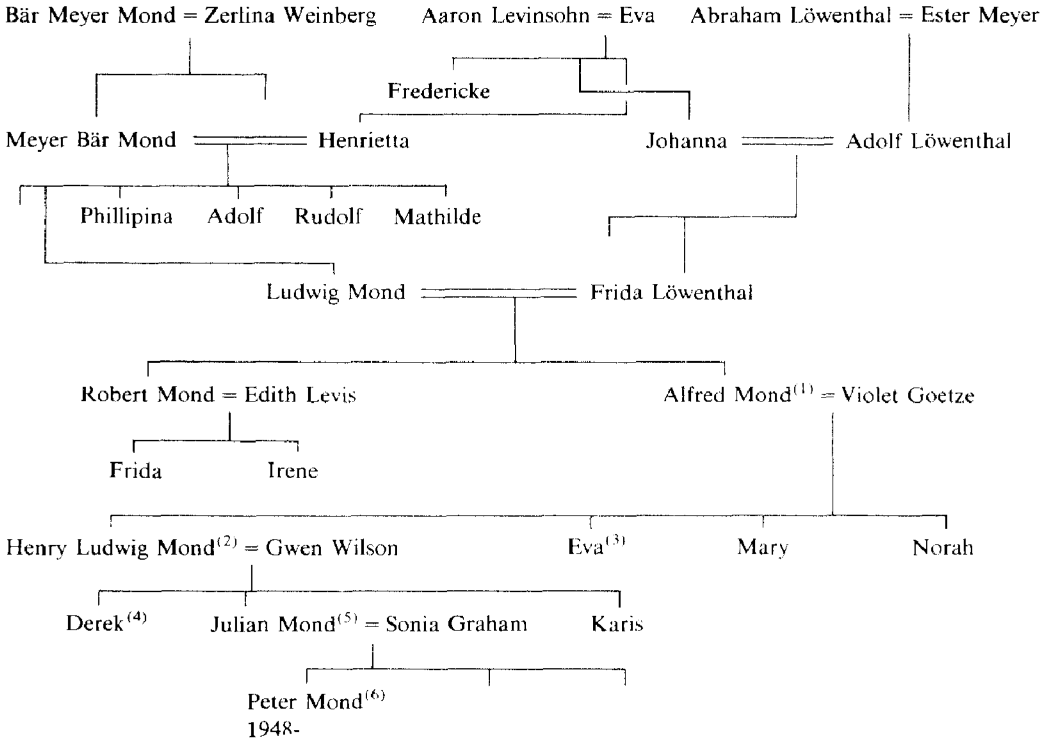
Several books and many articles have been written about the lives and achievements of Ludwig Mond and his family [1–4]. In an article of this brevity it is feasible only to produce a selective precis that attempts to justify the title.

Ludwig Mond was born one hundred and fifty years ago to Henrietta (née Levinsohn) and Meyer Bär (Moritz) Mond. The abbreviated family tree illustrates some ancestors and selected descendants. In the village of Ziegenhain near Kassel in the latter half of the eighteenth century lived Bär Meyer Mond, a reasonably well-off merchant in his sixties. He had outlived two wives, but he had no sons and it worried him greatly that no son would say the Jewish funeral prayer over him on his death. He did, however, find a third wife, a young (and we are told, pretty!), lady by the name of Zerlina Weinberg. For Meyer she produced two sons, the elder was Meyer Bär (Moritz) who was eleven when his father died, and presumably carried out his father's wish for kaddish. At 17 Moritz left the village for Kassel with letters of introduction to take up an apprenticeship with the silk merchant Aaron Levinsohn, who made the dresses for the Court Theatre. Moritz lived in the Levinsohn household which, in contrast to his village life at Ziegenhain, was well-off, lively and cultured. Aaron had no sons, but three daughters, Fredericka, Johanna and Henrietta. Moritz chose Henrietta for his bride, and very rapidly they became trusted to run the business in Kassel. Sadly their first son died in infancy, but a second son Ludwig was born 7 March 1839.

Grandfather Levinsohn lived long enough to foster Ludwig's interest in all things cultural and scientific. Between 1853 and 1857 Ludwig attended first the Polytechnic School at Kassel where he acquired a good knowledge of the chemistry of that time. Subsequently he spent some time with Kolbe at Marburg and then moved to study with Bunsen at Heidelberg. Mond was so grateful to Heidelberg that in later years, he made several generous gifts to this old University. In addition he wished to commission an oil painting of Bunsen, but the old Professor flatly refused to make the time for the artist's sittings. Not to be outdone, Ludwig knew that his old teacher spent a little time each day at the same corner table of the college dining room over his lunch. Mond arranged for the artist to spend each lunch time unobserved behind a leafy screen, capturing the old man for posterity.



(1) Created Baron Melchett 1928
(2) 2nd Baron Melchett
(3) Marchioness of Reading
(4) Killed in action 1945
(5) 3rd Baron Melchett
(6) 4th Baron Melchett, no heir at this time

Fig. 1. Partial family tree of Ludwig Mond.

There was a problem for the student Mond at Heidelberg, in that Moritz Mond begrudged the money for fees and sustenance for the study of chemistry by what had become his somewhat spendthrift son.

Fortunately by this time his mother's sister Johanna had married a chemist, and it was Adolf and Johanna Löwenthal who partially supported Ludwig at Heidelberg. Nevertheless Ludwig still became heavily in debt and left his University before he took his degree. It is, however, pleasing to record that Mond did eventually get his Heidelberg degree at age 57, as an honorary doctorate in 1894.

In Fig. 1 a partial family tree of Ludwig Mond is shown.

When he left Heidelberg Ludwig went to live with his Uncle Adolf Löwenthal at Cologne, where he was pioneering electroplating and the electrochemical industry. Ludwig was cared for by his Aunt Johanna and repeated his father's enterprise in becoming espoused to the daughter of the house, in this case his first cousin Frida, then only 13 years old. Ludwig next went to work for a chemical manufacturer at Mombach near Mainz and raised profits there to the great delight of his employers. He was soon on a salary of 700 Gulden, free room, wood and light and 10% of the profits. In the early 1860's he moved around a succession of companies in Germany and Holland establishing a reputation as what we might today describe as a consultant. At this time he worked on his own process for the recovery of sulphur from alkali waste, and resolved to attempt its exploitation in England. He visited Manchester and negotiated the sale of his process to John Hutchinson at Widnes. It was not until two years later, however, that he moved to England permanently.

In 1866 Mond married his cousin Frida, and they lived briefly in Cologne before their emigration to England, whence he became a partner at Hutchinsons. He purchased the 'Hollies' in Farnsworth and was what may be described as 'comfortable'. Ludwig and Frida's first son Robert was born in 1867 and a second son Alfred in 1868, more of these later.

In 1872, after discussions with John Brunner, Mond visited Ernst Solvay in Belgium. The ammonia soda process had given problems in trials in France, Germany and England, but Mond believed the method could be perfected. He bought a licence for the process and formed a partnership with John Brunner. They bought Lord Stanley's house and estate at Winnington Hall and the Monds and the Brunners set up home in one half each in 1873. In their planning they were not unaware of the nearness of coal, the port of Liverpool via a navigable river, a railway line, and limestone from Derbyshire.

Mond perfected the ammonia process by sheer attention to detail and the insistence on high quality feed stocks. He virtually lived on the plant, solving problems as they arose. Even when he slept in his bedroom in the Hall, there was a bell-pull on the wall outside below, so that a workman could arouse Ludwig at anytime if a difficulty arose on the plant. Soda started to flow in quantity, and it was one of Mond's great pleasures to run the grey-white crystals through his hand as they emerged from the process.

It was not an immediate commercial success story, however; in 1874 they made 838 tons of soda and lost about £5 on each ton. Mond was not happy, and impending ruin advanced daily. There were 6–7 uncertain years, during which Mond by hard work, successive inventions and improvements brought the works around to a commercial success. By 1881 Ludwig's main problem was the doubling and redoubling of the size of his plant.

Brunner and Mond retained a controlling interest in what became the biggest alkali works in the world. They were immensely wealthy and became important men in the land. Brunner was elevated to the baronetcy, but although he had become a British citizen Mond is believed to have steadfastly declined any honour. He was, however, pleased to be elected to the Fellowship of the Royal Society, as also eventually were both of his sons.

Mond ventured into many other aspects of the chemical industry with the Power Gas Corporation, Brimsdown Lead Works, South Staffordshire Mond Gas Company, etc., but by 1889 he had moved to London. He wanted a garden big enough to walk in, and yet be near enough to Euston Station to be able to get by train with ease and speed to his beloved Winnington. "The Poplars" at 20 Avenue Road at the north end of Regents Park became his London house, with the Palazzo Zuccari in Rome as a much loved second home. At "The Poplars" Ludwig converted and extended the stables to create an extremely well-equipped laboratory which became the research pulse of Mond's many interests and endeavours. Elder son Robert was involved in the work with Carl Langer who had previously worked on the chemistry of carbon monoxide with Victor Meyer, along with a young German assistant Friedrich Quincke. In the lifetime of the Avenue Road laboratory over forty chemical patents were registered from that address by Mond.

The discovery of nickel carbonyl would appear to be one of those curious meeting of the ways in science, and different recorders have given the likely pathways different emphases.

Mond knew of the first hydrogen cell constructed by Grove earlier in the century and had a long-term yearning to convert the hydrogen of his Mond gas directly into electricity, as in Grove's gas cell. Parenthetically Sir John Grove (Lord Justice Grove), in addition to being a leading lawyer, was a distinguished electrochemist and Secretary of the Royal Society. The construction of a 'gas battery' was one of Langer's many projects, and in his work he found that the presence of carbon monoxide in his hydrogen supply rapidly spoiled the effectiveness of his platinum black. Back at Winnington, traces of carbon monoxide in the carbon dioxide stream were attacking the nickel cooks of the reaction vessels. From all this arose Mond's desire to investigate the effect of carbon monoxide on nickel, essentially with the aim of removing carbon monoxide from gas mixtures. There are many and variable accounts of the discovery of nickel carbonyl. Ludwig Mond's own account [5] is reproduced later in this volume. Complementary to this are the accounts by Alfred Mond [2], Carl Langer [6] and J.M. Cohen [1]:

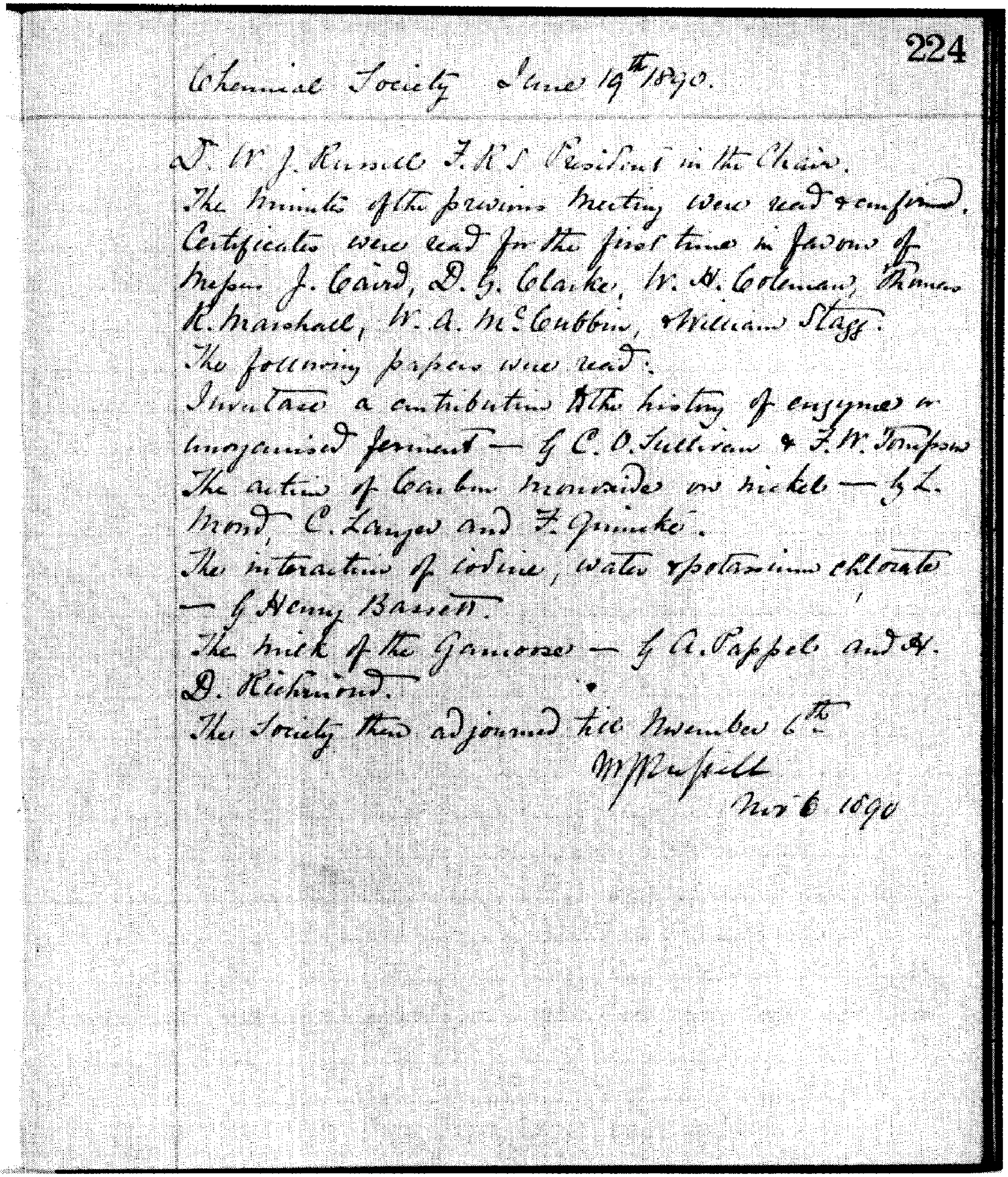
"My father and Dr. Langer were working together upon another problem and in order to purify the gas they wanted for their purpose, they passed carbon monoxide over reduced nickel. They were burning it at the end of a glass pipe in order to prevent it from escaping into the room.

One day, much to their astonishment, they found this flame burning an extraordinary green colour. Nobody could make out what it was, and when they held up the procelain dish to cool it down they got a nickel mirror. Nobody had ever heard of a gas and metal forming a gaseous compound. Some might have dismissed it as a scientific curiosity, but they, scientific men, immediately saw there was a new phenomenon, investigated and found it was nickel carbonyl... a combination of gas and metal previously never heard of in science. That seemed to be an interesting scientific discovery, but of no particular industrial or commercial value. The gas was difficult to obtain, it was poisonous and it had many disadvantages, including danger to operatives if it escaped; but my father's technological mind was not satisfied until he had developed from that new fact the best and cheapest way of refining nickel from complex ores..." (Alfred Mond in ref. 2, page 100.)

"Diese Versuche waren schon längere Zeit im Gange, als wir durch einen Zufall das Nickelcarbonyl entdeckten. Wir behandelten, wie schon oft zuvor, in einem Verbrennungsrohr Nickel mit Kohlenoxyd und leiteten die entweichenden gase, um sie unschädlich zu machen, in einen Bunsen-Brenner. Mein Assistent, der diese Versuche überwachte, ersuchte mich, den Apparat abzustellen, da er früher nach Hause gehen müsse.

Enige Zeit nachdem ich die Erhitzungsflammen abgestellt hatte, bemerkte ich, daß die Flamme des Brenners, in welchen das entweichende Gas einströmte, eine eigentümliche grünlich-gelbe Färbung zeigte, die stärker wurde, als sich das Rohr abkühlte. Mein erster Gedanke war, das Arsen in Kohlenoxy vorhanden sein müsse, da dasselbe mit gewöhnlicher Schwefelsäure dargestellt war; ich erhitzte daher das Glasrohr, durch welches das Gas in den Brenner geleitet wurde, um einen Arsen-spiegel zu erhalten. Der Spiegel trat auch sofort auf, bestand aber nicht aus Arsen, sondern aus Nickel!" (Carl Langer in ref. 6.)

"So Dr. Langer, joined by now by a young German, Friedrich Quincke, was detailed to make an elaborate study of the action of carbon monoxide upon nickel, to see whether he could identify the evanescent compound that was responsible for



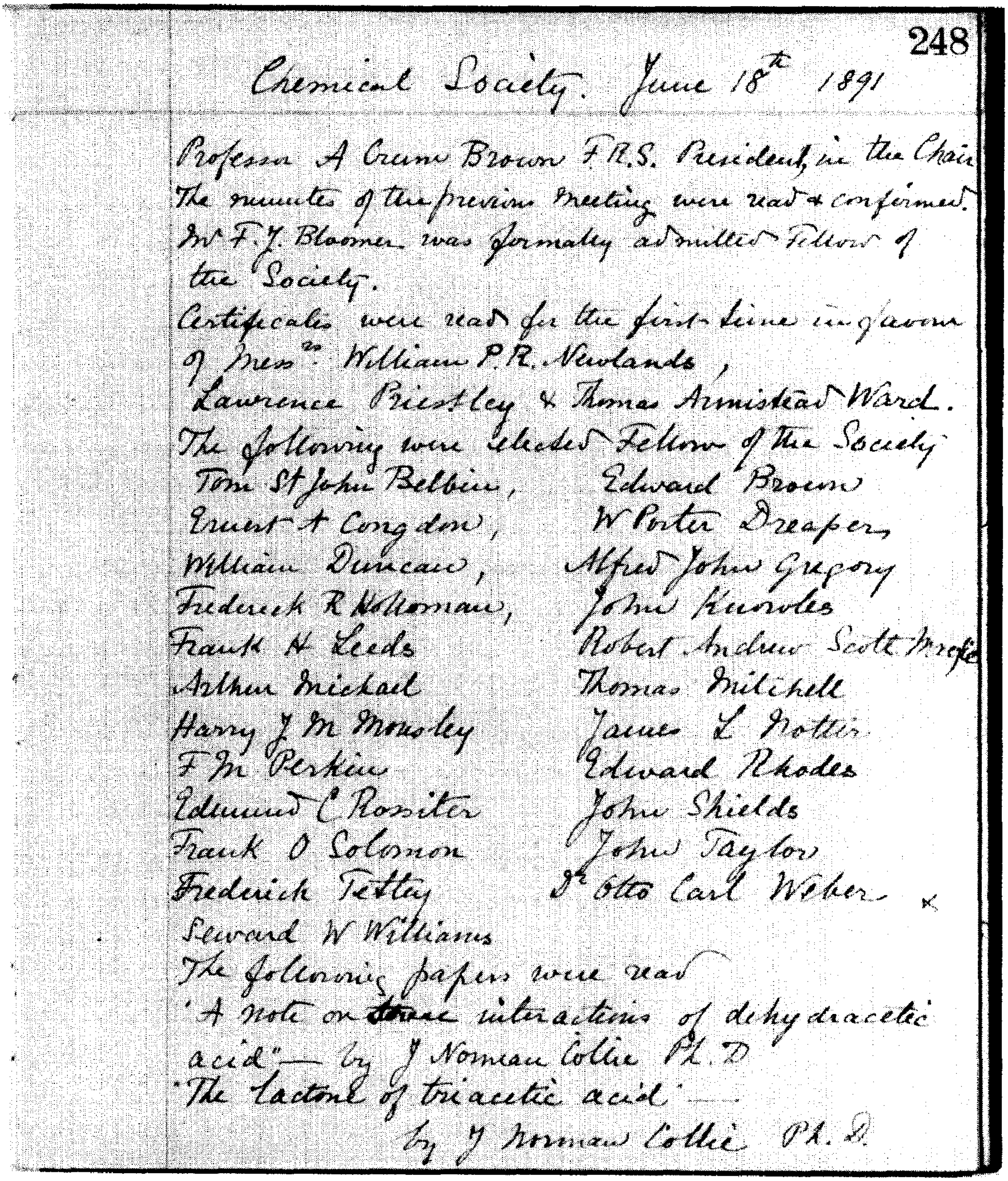
224

Chemical Society June 19th 1890.

Dr W. J. Russell F.R.S. President in the Chair.
The Minutes of the previous meeting were read & confirmed.
Certificates were read for the first time in favour of
Messrs J. Caird, D. G. Clarke, W. H. Coleman, Thomas
R. Marshall, W. A. McCubbin, & William Stagg.
The following papers were read:
Invertase a contribution to the history of enzymes or
unorganised ferments — by C. O'Sullivan & F. W. Tompson
The action of Carbon monoxide on nickel — by L.
Mond, C. Langer and F. Quincke.
The interaction of iodine, water & potassium chlorate
— by Henry Bassett.
The milk of the Gamoose — by A. Pappel and H.
D. Richmond.
The Society then adjourned till November 6th
W J Russell
Nov 6 1890

Fig. 2. Minute-book of meetings of The Chemical Society: Page 224 dated 19 June 1890.

the catalytic action. In the course of these experiments a combustion tube was set up, in which finely divided nickel was treated with pure carbon monoxide made by the action of sulphuric acid on a formate. To keep the poisonous carbon monoxide out of the atmosphere of the laboratory, the tail-gases from the combustion tube were passed through a glass jet and there burned. The experiment was started each


248

Chemical Society. June 18th 1891

Professor A Crum Brown F.R.S. President in the Chair
The minutes of the previous meeting were read & confirmed.
Mr F. J. Bloomer was formally admitted Fellow of the Society.
Certificates were read for the first time in favour of Messrs William P. R. Newlands, Lawrence Priestley & Thomas Armistead Ward.
The following were elected Fellows of the Society

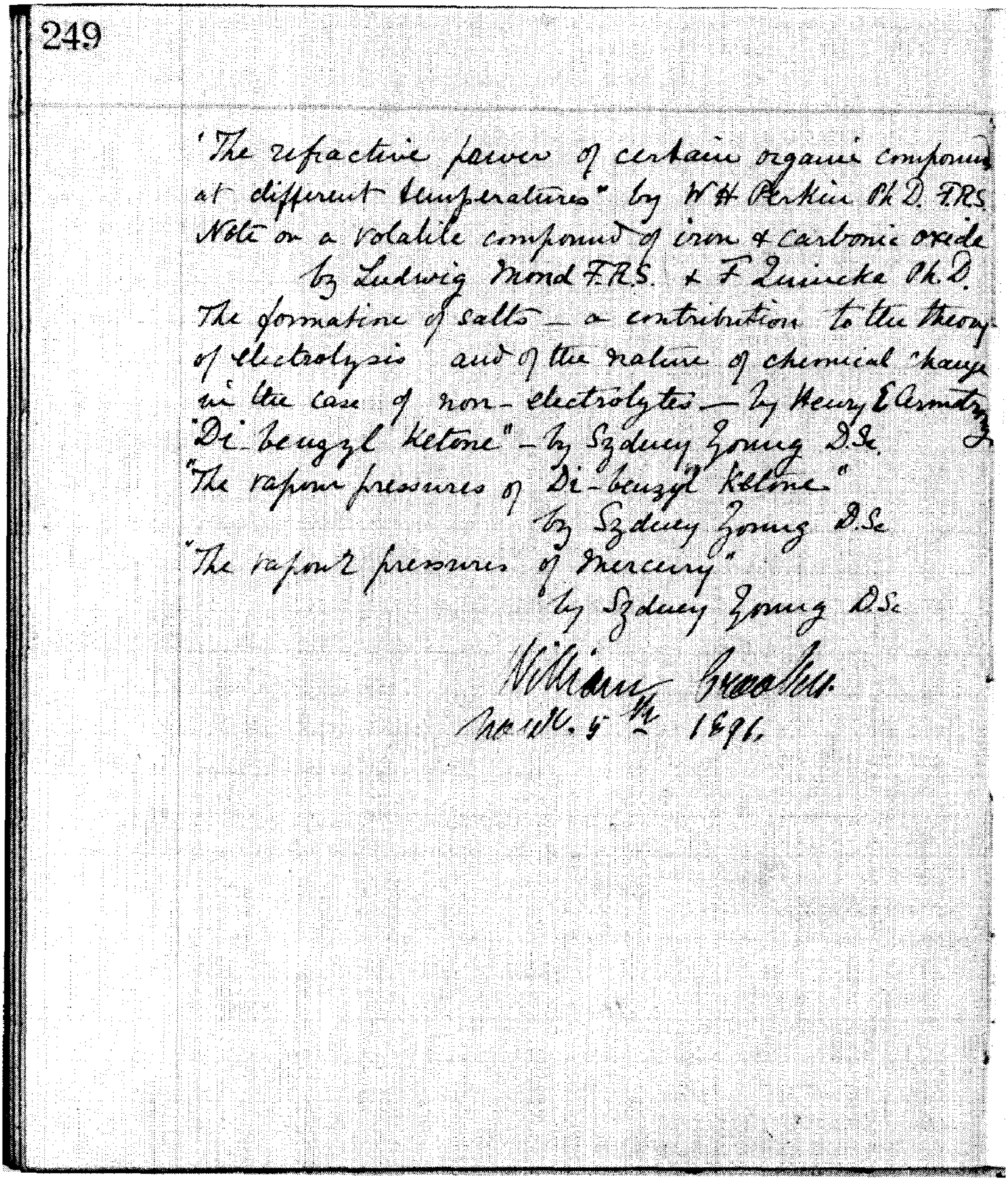
Tom St John Belbin, Edward Brown
Ernest A Congdon, W Porter Dreaper,
William Duncan, Alfred John Gregory
Frederick R Holloman, John Knowles
Frank H Leeds, Robert Andrew Scott Macfie
Arthur Michael, Thomas Mitchell
Harry J M Moseley, James L Notter
F M Perkin, Edward Rhodes
Edmund C Rossiter, John Shields
Frank O Solomon, John Taylor
Frederick Tetley, Dr Otto Carl Weber ×
Seward W Williams

The following papers were read
"A note on ~~some~~ interactions of dehydracetic acid" — by J Norman Collie Ph.D
"The lactone of triacetic acid" — by J Norman Collie Ph.D.

Fig. 3. Minute-book of meetings of The Chemical Society: Pages 248 and 249 dated 18 June 1891.

morning and shut down each night, the nickel being allowed to cool off in the stream of carbon monoxide before the whole apparatus was shut down.

One evening in 1889, however, the assistant who usually remained behind to close down the experiment, had gone home early, and Langer himself was waiting for the flame to die down and the last of the carbon monoxide to be burnt before locking



249

"The refractive power of certain organic compounds at different temperatures" by W H Perkin Ph D. F.R.S.
Note on a volatile compound of iron & carbonic oxide
by Ludwig Mond F.R.S. & F Quincke Ph.D.
The formation of salts — a contribution to the theory of electrolysis and of the nature of chemical change in the case of non-electrolytes — by Henry E Armstrong
"Di-benzyl Ketone" — by Sydney Young D.Sc.
"The vapour pressures of Di-benzyl Ketone"
by Sydney Young D.Sc
"The vapour pressures of Mercury"
by Sydney Young D.Sc
William Crookes
Nov. 5th 1891.

Fig. 3 (continued).

up. It was the first time that he had done so, and he was quite unprepared for what he saw. For as the apparatus cooled he saw, to his great surprise, the flame of the jet grow luminous and increase in brightness until the temperature fell below the boiling point of water, when the flame faded again. Furthermore, from its usual lambent blue the flame had turned a sickly green.

Ludwig Mond was called at once to witness the strange phenomenon, and together they stared in silent wonder. At first both thought of the arsenic that might be present in the sulphuric acid. Arsenic was known to form a volatile hydride that would tinge the flame with green. But that was readily tested – a cold porcelain tile was thrust into the flame and was immediately coated with a shiny mirror, not unlike, but significantly different from, the spots left by arsenic in Marsh's test; and when the neck of the combustion tube was heated, a bright mirror formed on the glass and the luminosity of the flame disappeared. The mirrors were analysed and appeared to be nickel, but such was the improbability of so heavy a metal as nickel forming a volatile compound that Ludwig would not believe his own tests, and postulated an unknown element in the nickel. Both the carbon monoxide and the nickel were then purified as carefully as possible, but still the phenomenon occurred. It was not, one feels, until the gaseous nickel carbonyl had actually been frozen to a mass of needle-shaped crystals that Ludwig could really believe that he had, in Lord Kelvin's words, given wings to a heavy metal." (J.M. Cohen, ref. 1 page 283).

Mond and his co-workers had made one of the great and truly seminal discoveries of science. The Chemical Society records [7,8] the reading of a paper, "The action of Carbon Monoxide on Nickel" by L. Mond, C. Langer and F. Quincke on 19 June 1890, with subsequent publication [9] in the Society's Journal (Fig. 2). Nickel carbonyl was first isolated the previous year in 1889, and the closest date we can assign comes from the opening sentence of Mond's address [10] to the British Association for the Advancement of Science at its Cardiff Meeting of 1891, — "The existence of a volatile compound of nickel and carbonic oxide was first discovered in my London laboratory in October 1889, in the course of an investigation ..." The next metal carbonyl was discovered virtually simultaneously by Berthelot and by Mond. On 15 June 1891 Marcelin Berthelot read a paper [11] before L'Académie des Sciences at Paris entitled, "Sur une combinaison volatile de fer et d'oxyde de carbone, le fer carbonyl, et sur le nickel-carbonyle", in which he reports the formation of iron pentacarbonyl.

The literature [12] records a paper "Note on a Volatile Compound of iron and Carbonic Oxide " [13] read by Mond and Quincke to the Chemical Society also on 15 June 1891. It would appear, however, that this first recorded date [12] is a misprint, as a subsequent account of this meeting [14] and the Meeting Minutes of the Society [15] (Fig. 3) both date this Mond lecture as 18 June 1891. Thus to Berthelot [11], by three days, must go the credit for the first report of iron carbonyl along with the correct formulation. Mond subsequently [16–18] reported the correct formula for iron pentacarbonyl along with the dinuclear carbonyl which he recorded as $Fe_2(CO)_7$. There is little doubt however that he had made di-iron enneacarbonyl, $Fe_2(CO)_9$, — "The liquid ferropentacarbonyl undergoes no change when kept in the dark, but when it is exposed to light for several hours in a sealed tube, gold-coloured tabular crystals are formed, and the pressure in the tube rises very high" [18]. In mitigation for an erroneous formula, we must note that Mond does himself express concern at an iron-only analysis on a very small sample.

Mond summarized [19] his work and thinking on metal carbonyls in 1892 in a Discourse to the Royal Institution, and subsequently claimed metal carbonyls of cobalt, ruthenium and molybdenum in a posthumous paper [20] in 1910. In the hundred years since Mond's discovery the metal carbonyls and their derivatives have become a rich vein of endeavour in all branches of chemical research, and known metal carbonyl complexes now number tens of thousands.

Mond perceived that the volatilization of nickel as a pure gas could lead to a process for the separation of nickel from its ores. By 1892 a complete model laboratory plant was constructed at 20 Avenue Road, which realized the hopes and aims of Mond and Langer, and in 1892 they constructed a pilot plant at Wiggins Nickel Works at Smethwick near Birmingham, and in 1895 after many difficulties, brought the Mond Nickel Process to commercial viability producing pure nickel at the rate of about 3000 lbs per week.

Mond offered to sell his process to several English and Canadian companies including the Canadian Copper Company but after two years of negotiations they rejected the idea for several reasons, among which was the unsuitability of the Canadian climate for the process! Eventually Mond decided to mine and refine nickel on a large scale. The search and negotiation for suitable ore bodies is in itself a saga of heroic proportions, and eventually at a meeting in the Palazzo Zuccari in Rome, Mond came to agreement on Canadian Properties held by the 'wild man' prospector Ricardo McConnell. Mond visited Canada in person in 1899 and saw for himself the sinking of shafts and the construction of railways and metallurgical plants, and negotiated the purchase of further holdings. The keystone of the operation however was to be the new nickel carbonyl plant. This was to be built near Swansea, with good dock access for the Canadian ore, excellent anthracite coal, and both river and canal for water and transport, along with a work force with generations of metallurgical experience.

It was Langer, Robert Mond and Mohr who toured the Swansea area in a landau and eventually chose a suitable site; and Mrs. Langer cut the first turve of the Clydach plant on Monday 12 February 1900. The estimated cost of construction was £250,000, the contractors were Walters and Johns of Morriston with consulting engineer W.D. Rees of Swansea [21].

The plant began production in 1902, and after an initial closure to remedy problems which caused the poisoning of several workers, it has produced nickel continuously up to the present time; and there is now a second carbonyl refinery in Canada. There is still a fine bronze statue of Ludwig Mond in the square at Clydach, and both the plant and local bus stop are still known to the locals as the 'Mond'.

Mond was a highly paternalistic employer, and housing, recreation, sport and club facilities were all financed and encouraged. If he could return now for a look at Clydach he would still find all of these activities, but he would probably be most of all entranced by the sheer size of the individual kilns along with the fully computerized control of all operations and the television monitoring of all key points on the plant.

Mond probably more than any other individual influenced the growth of the chemical industry both in Britain and worldwide, by his use of modern scientific concepts and engineering practices of the highest possible standards. He was honoured as a member or honorary graduate by many national academies and universities throughout Europe. With his huge wealth he was generous in the funding of a very wide range of institutions among which were the Royal Society of London, Heidelberg University, Munich Academy of Arts, Chemische Reichsanstalt Berlin, Cannizzaro Foundation Rome, Children's Hospital London, Lister Institute London, University of Rome, University of Padua and the University of Pisa.

Of particular importance was his purchase of a long lease on Lord Albermarle's mansion in London in order to endow the Davy–Faraday Laboratory adjacent to the Royal Institution. This world famous research establishment continues to flourish in the premises provided by Mond with such foresight. In addition, Mond's benefactions to the arts include the superb collections of paintings and books donated to such galleries as the Palazzo Venezia in Rome and the National Gallery in London.

Ludwig's elder son Robert continued to research on metal carbonyls, and with Wallis [22] opened the field of metal carbonyl nitrosyls in 1922. Sir Robert Mond became additionally a noted Egyptologist. Younger son Alfred [2] was a founder of ICI and also entered politics as a Member of Parliament, achieving Cabinet rank as Minister of Health in the government of David Lloyd George in 1921. Sir Alfred Mond was created Baron Melchett in 1928, and members of the Mond family have been active in the Liberal, Conservative and Socialist parties of British politics right up to the present day [23].

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