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Chapter 2

THE LIFE AND SCIENTIFIC WORK OF HENRI MOISSAN

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Introduction

The extraordinary progress achieved in scientific and technical fields during the 19th century was based on the work of only a small number of investigators by today's standards. Naturally, the importance of the contribution made by each one reflected individual preoccupations, intelligence and efforts. Some made a deep impression during their lifetimes and their influence is still clearly felt today. Moissan was one of the most brilliant.

Childhood and adolescence

Born in Paris on 28 September 1852, Ferdinand Frédéric Henri Moissan came from a family of modest origins: his father, François Ferdinand Moissan, born in Toulouse in 1825, was employed by a railway company (Compagnie des Chemins de Fer de l'Est) and his mother, Joséphine Théodorine Almédorine Mitel (or Mitelle), born in Chécy near Orléans in 1828, worked as a seamstress. The Moissan family moved from Paris to Meaux in 1864 and stayed there until the Autumn of 1870. This was the period of the Franco-Prussian war, when fears of their town being occupied by the enemy led many inhabitants of Meaux to seek refuge in the capital, where they believed they would find greater security.

Henri Moissan's adolescence was therefore spent in Meaux, where he entered the town's college in 1864. His parents being of modest means, he was unable to go through the extended educational programme and was entered for special secondary education, a cycle of studies which contained neither Latin nor Greek; consequently, it did not lead to the baccalauréat examination, but served as a preparation for commercial careers. He left the college in July 1870 with only a basic school-leaving certificate to his credit. At the college, Henri Moissan was remembered as a student of sharp intelligence, interested in mathematics and physical sciences. However, he failed to take much interest in his studies and occasionally was caught playing truant. On leaving college he became an apprentice with a Mr. Godaillier, a watch and

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clock maker in Meaux, and this would have become his trade too if it had not been for the war of 1870 and the return of the Moissan family to Paris. Being 18 years old during the siege of the capital, Henri Moissan was recruited into the army and in December 1870 took part in the Avron Plateau engagement, one of the operations designed to relieve enemy pressure on Paris.

Immediately after the surrender of Paris and signature of the armistice with Germany, Henri Moissan decided to direct his efforts towards pharmaceutical studies with the aim of reconciling his interest in the sciences, particularly chemistry, with the need to achieve a professional position which would be both honorable and interesting from the scientific point of view. Not having taken the baccalauréat examination, he was not eligible to prepare for the diploma of pharmacist, second class. From February 1871 to the end of June 1874, therefore, he worked as a trainee at the Baudry Pharmacy in the rue Saint Martin, Paris. He then entered the Ecole Supérieure de Pharmacie in Paris for three years of theoretical studies which, at that time, were a normal follow-up to the practical experience in a pharmacy and gave official recognition to the cycle of pharmaceutical studies.

Initial research

Henri Moissan had maintained contacts with several of his friends in Meaux, particularly the Plicque brothers (Jules and Théodore), fellow students at Meaux College with whom he corresponded at length during the period 1872 - 8. This correspondence has come down to us and reflects the years of his youth. One of these letters, addressed to Théodore Plicque on 27 February, 1872, a year after he started work at the Baudry Pharmacy, provides insight into the long and tiring days that very few students would accept now but which in no way altered Henri Moissan's even temper and good humour. Living at that time in Noisy le sec, a town in the north-east suburbs of Paris, he used to leave the family home at 6 a.m. and did not return before 9.20 p.m. after a hard day's work, as witnessed by the statement "unfortunately for the state of public health, but fortunately for Mr. Bastien (Baudry?), we sold an enormous amount of medicines".

The future career of Henri Moissan was overwhelmingly influenced by his relationship with Jules Plicque, who had also moved to Paris. From 1871 to 1872, Jules Plicque was a student at the Edmond Frémy School of Experimental Chemistry at the National Natural History Museum. Afterwards he remained in this establishment, working in P. P. Dehérain's laboratory on plant chemistry, particularly with regard to defecation and carbonation slurry from sugar beet juice, used as vegetable fertiliser. As a young research worker just as fascinated by chemistry as Henri Moissan, Jules Plicque often talked about research being carried out in the Museum laboratory. His enthusiasm was such that Moissan, who found only limited interest in work as a pharmaceutical trainee, joined his friend at the Museum, where he registered as a student at the Frémy school for the 1872/73 academic year. Did he, at this time, hesitate between the continuation of his pharmaceutical studies and the prospects of a career as an industrial chemist? This may well be. Nevertheless, he did not abandon his course of training in the pharmacy but pursued it at the same time as carrying out research into plant physiology under the direction of Dehérain. It is quite possible, although no documentary proof has ever come to light, that Baudry had felt early on that Moissan had an aptitude for chemistry and encouraged this by allowing regular attendance at the Museum and partial or even total abandonment of his practical pharmaceutical training, while continuing to provide the certificates necessary to maintain Henri's enrolment at the School of Pharmacy.

Fascinated by his work in the laboratory, and encouraged by Dehérain, who had noted his brilliant aptitude for research, Henri Moissan decided to return to the normal programme of traditional studies with the aim of afterwards obtaining his university degrees. The year 1874 saw his success in the baccalauréat examination, as well as his first published works on variations in the respiratory activity of various plant organisms, research which he pursued for several years afterwards. Having obtained his university degree, Moissan began to prepare for the diploma of pharmacist, first class. He passed the examinations with flying colours and obtained this diploma in 1879, after having defended a thesis entitled *On the Amount of Oxygen absorbed and Carbonic Acid emitted during Plant Respiration*; this brought together the various researches he had undertaken in Dehérain's laboratory.

Until the opening university term of 1879, when he was appointed a physics tutor at the Institute of Agronomy where Dehérain also taught, Moissan had practically no income other than that from the lessons he managed to give. In other words, the years spent at the Natural History Museum from 1872 to the end of 1879 were difficult times. During this period, Moissan served his year of voluntary service in a military medical unit in Lille (commencing November 1875); and in 1877 he obtained the title of Bachelor of Science. Letters addressed to Jules Plicque clearly reveal that the time spent in Lille was extremely difficult for Henri Moissan, who was little attracted to military life; it nevertheless proved profitable from the scientific point of view. This is clear from a letter to Plicque sent from Lille on 20 September, 1876 which reveals that Moissan, while keeping up to date with the latest developments in plant physiology by reading the various agronomic publications, had started his work on iron oxides. This letter therefore provides proof that Moissan came to the decisive turning point in his research career as early as his period of military service. It was then that he entered the field of inorganic chemistry, which he was to restore to its proper importance for his own greater glory. No precise information has become available on the reasons for this move from plant chemistry to inorganic chemistry. We can simply put forward what appears to be a reasonable assumption: when called for military service in November 1875, Moissan had already completed a year of studies at the School of Pharmacy and had been deeply impressed by Riche's lectures on inorganic chemistry, hence this passage from the Eulogy that he later dedicated to Riche:

Fig. 2.1. Moissan (second from the left) and his friends Béclère, Walther and Siredey (from left to right), during their military service in Lille (1876). (By courtesy of the Faculty of Pharmacy, Paris).

"I very well remember that the sight of Mr. Riche warmly explaining the beauties of chemistry in his clear and concise manner filled me with great enthusiasm and, in my own heart, I thought I would be very happy to be able to teach in the same way".

Moissan's studies on *Metallic Oxides from the Iron Family* were to form the subject of his Doctor of Science thesis in 1880. Having discovered a new allotropic variety of magnetic iron oxide, he recognised this polymorphism in nickel and manganese oxides. These results quite naturally led him to study the various forms of chromium oxides and salts. He took a particular interest in the salts, and it was during this research that, in 1879, he gave an account of the first process for obtaining pure chromium by distillation of its amalgam in a flow of hydrogen.

Senior lecturer and head of practical studies at the Ecole Supérieure de Pharmacie (Higher School of Pharmacy) in Paris with effect from 1880, Moissan was appointed associate professor at that same school in 1882, following a competitive examination where he presented a thesis entitled *Cyanogen Series*. That year also saw his marriage to Marie Léonie Lugan, daughter of a pharmacist in Meaux, whom he had met at the home of his friends the Plicques. This marriage produced an only boy in 1885, Louis Moissan, who later became a chemical engineer and who, as a reserve officer with the 102nd infantry regiment, was killed in battle on 10 August, 1914.

Isolation of fluorine

In 1884, Henri Moissan turned his attention to the isolation of fluorine. The background to his researches, including the demonstration by Frémy some 30 years previously that immediately it was formed, fluorine attacked all materials in contact with it and could not be collected, has already been described (Chapter 1). After having carefully studied the results of his predecessors and the causes of their failures, Moissan first thought it would be easier to isolate fluorine from metalloid compounds, by analogy with what was known of chlorine. This formed the basis of the authoritative research he carried out on phosphorus fluorides. The only compound known at that time was phosphorus pentafluoride, which Thorpe had prepared in 1875 from phosphorus pentachloride and arsenic trifluoride. Moissan prepared phosphorus trifluoride using various processes, first by heating dry lead fluoride with copper phosphide and later by more convenient halogen-exchange processes ($PCl_3 + AsF_3$; $PBr_2 + ZnF_2$). After determining the physical properties of purified phosphorus trifluoride, he made a particular study of those reactions of this gas which seemed likely to lead to the isolation of fluorine. For example, he passed electric sparks through a mixture of phosphorus trifluoride and oxygen, and also pyrolysed the trifluoride over red-hot platinum sponge in a platinum tube. The first reaction gave only the new compound POF_3, but the latter provided phosphorus pentafluoride and a trace of an oxidising gas believed to be fluorine but which proved impossible to collect. From the results of these and other experiments, Moissan concluded that the only feasible way of isolating this element was *low-temperature* electrolysis of certain fluorine compounds. Electrolysis had been tried previously by Davy, the Knox brothers, Gore and Frémy, but had been carried out either on hydrated substances or at high temperatures with molten salts (see Chapter 1).

Moissan began by attempting the electrolysis of liquid arsenic trifluoride, carefully dehydrated, in a platinum crucible (the cathode); a platinum wire along the axis of the crucible served as the anode. A small gaseous sheath appeared around this wire and possessed the property of decomposing potassium iodide. In order to increase the electrical conductivity of the arsenic fluoride, Moissan added potassium fluoride. However, close observation revealed no external gaseous emission; bubbles of gas were released at the anode but rapidly disappeared, and the trifluoride was transformed into arsenic pentafluoride. This unsuccessful research also had the inconvenience of being particularly disagreeable; arsenic fluoride is a toxic gas that is difficult to handle, and Moissan had to interrupt his research programme several times for health reasons. In no way discouraged, he then undertook the electrolysis of anhydrous hydrofluoric acid. Faraday, Davy, Frémy and Gore had observed previously that the anhydrous acid was not a conductor of electricity; nevertheless, Moissan decided to attempt the experiment.

Anhydrous hydrogen fluoride generated by heating potassium bifluoride was condensed directly into a small U-shaped platinum tube (9.5 cm high and 1.5 cm diameter) cooled in a bath of evaporating methyl chloride (b.p., −24 °C). Each arm of the tube was closed off by means of a fluorspar plug, leaving a passage for a platinum electrode. A delivery tube was fitted to each arm, one for hydrogen and the other for the so-much-expected fluorine. Electrical current was supplied by 50 Bunsen elements which were normally used to operate the projector in the neighbouring ampitheatre. Having switched on the current, Moissan was delighted to note the escape of a gas from the anode compartment which combined with silicon when cold, producing brisk flames. This occurred towards midday on Saturday, 26 June, 1886, in the presence of Rigaud, Troost's assistant, and Friedel, professor at the Faculty of Science, who were there by chance. *For the first time, a significant quantity of fluorine had been prepared.*

On the following Monday, 28 June, Debray announced Moissan's success to the Academy of Science and read the following short note from Moissan entitled *Action of an Electrical Current on Anhydrous Hydrofluoric Acid.*

"Anhydrous hydrofluoric acid, prepared in accordance with Frémy's process and with all the precautions indicated by him, was placed in a U-shaped platinum tube and subjected to electrolysis by means of an electrical current produced by a battery with 50 Bunsen elements. Operating at −50 °C, the results were:
At the negative pole: Release of easily-distinguished hydrogen. At the positive pole: A continuous flow of gas with the following properties: in the presence of mercury, complete absorption with the formation of light yellow protofluoride of mercury; on contact with water, decomposition of the latter with the production of ozone.

Phosphorus ignited in the presence of this gas, producing phosphorus fluoride. Sulphur heated and melted rapidly. Carbon appeared to have no effect. Fused potassium chloride disintegrated when cold and gave off chlorine. Finally, crystallised silicon, washed by nitric acid and hydrofluoric acid, ignited on contact with this gas and burnt briskly, producing silicon fluoride. The platino-iridium electrode forming the positive pole was heavily corroded, while the platinum electrode of the negative pole was intact.

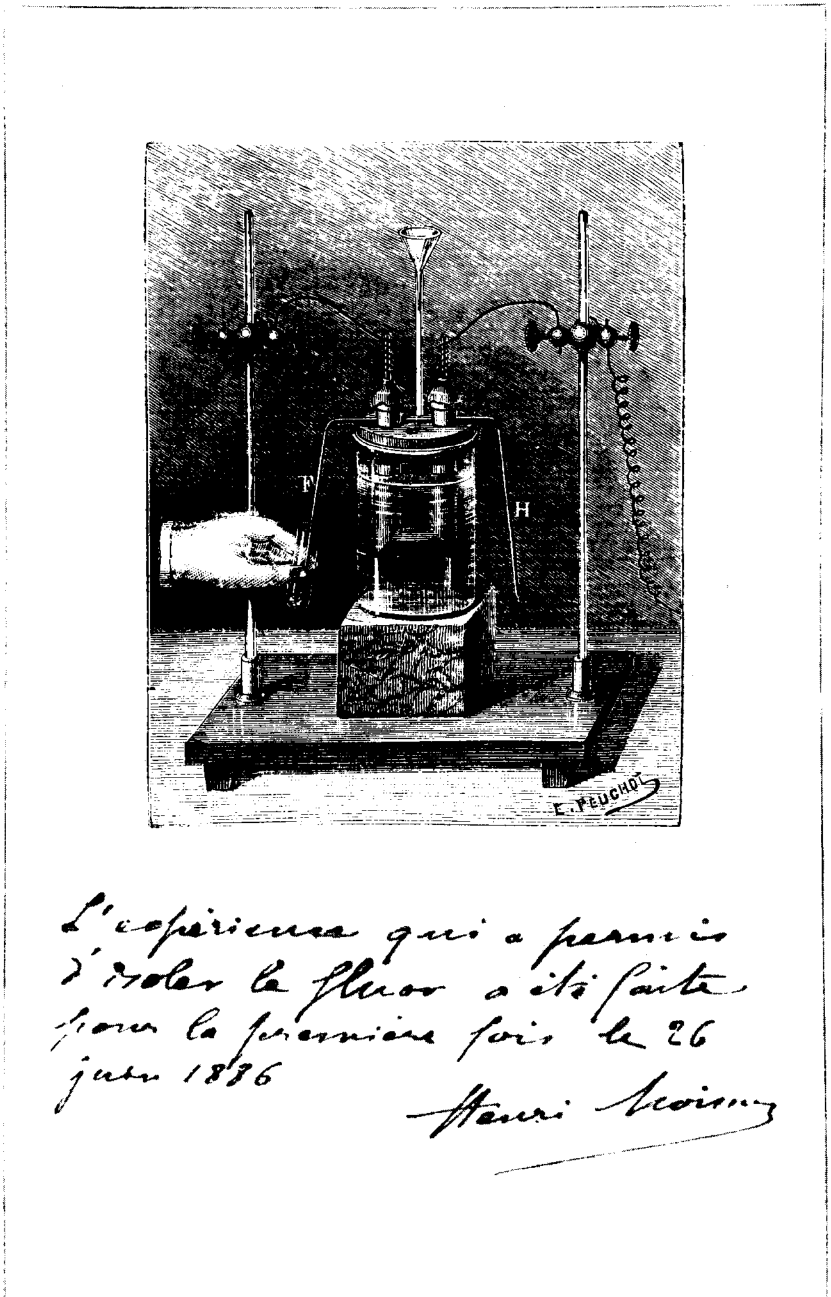
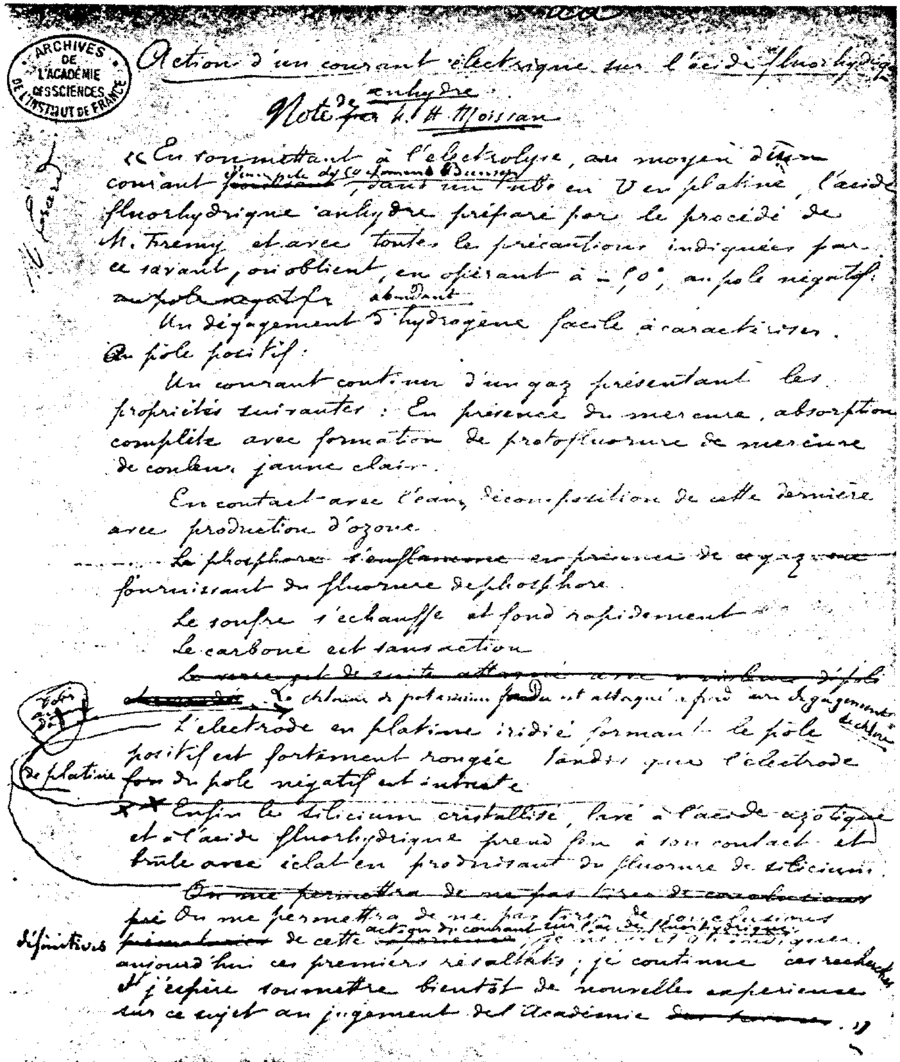


Fig. 2.2. Apparatus used for the preparation of fluorine (from *Homage to Professor Henri Moissan, 22 December, 1906*, brochure of 22 pp. printed by Lahure, Paris).



ARCHIVES DE L'ACADÉMIE DES SCIENCES DE L'INSTITUT DE FRANCE

Action d'un courant électrique sur l'acide fluorhydrique anhydre.

Note de M. H. Moissan

« En soumettant à l'électrolyse, au moyen d'un courant fourni par 90 éléments Bunsen, dans un tube en V en platine, l'acide fluorhydrique anhydre préparé par le procédé de M. Fremy et avec toutes les précautions indiquées par ce savant, on obtient, en opérant à −50°, au pôle négatif : un dégagement abondant d'hydrogène facile à caractériser.

Au pôle positif :

Un courant continu d'un gaz présentant les propriétés suivantes : En présence du mercure, absorption complète avec formation de protofluorure de mercure de couleur jaune clair.

En contact avec l'eau, décomposition de cette dernière avec production d'ozone.

Le phosphore s'enflamme en présence de ce gaz en fournissant du fluorure de phosphore.

Le soufre s'échauffe et fond rapidement.

Le carbone est sans action.

Le chlorure de potassium fondu est attaqué à froid avec dégagement de chlore.

L'électrode en platine iridié formant le pôle positif est fortement rongée tandis que l'électrode de platine du pôle négatif est intacte.

Enfin le silicium cristallisé, lavé à l'acide azotique et à l'acide fluorhydrique prend feu à son contact et brûle avec éclat en produisant du fluorure de silicium.

On me permettra de ne pas tirer de conclusions définitives de cette action du courant sur l'acide fluorhydrique. Je me contente d'indiquer aujourd'hui ces premiers résultats ; je continue ces recherches et j'espère soumettre bientôt de nouvelles expériences sur ce sujet au jugement de l'Académie. »

Fig. 2.3. First page of the handwritten note on the isolation of fluorine submitted by Moissan to the Academy of Science on 28 June, 1886 (by courtesy of the Science Academy Library).

I would hesitate to draw any definite conclusions from this action of the electrical current on the hydrofluoric acid.

N.B. It is effectively possible to make several assumptions concerning the type of gas given off; the simplest would be that we were in the presence of fluorine, but it could well be, for example, that it was a hydrogen perfluoride or even a hydrofluoric acid/ozone mixture active enough to explain the very energetic effect of this gas on crystallised silicon.

I have today simply indicated the initial results. I am continuing my research and hope to be able to submit new experiments on this subject for consideration by the Academy".

Moissan had accepted that, on the face of it, combustion of silicon in fluorine would occur with bright incandescence. For him, this was the perfect detector for fluorine gas. Since the silicon had behaved exactly as he had hoped, it is quite possible that identification of the anode gas as fluorine was more solidly established than Moissan was prepared to admit. On this subject, one of his colleagues later recounted the following significant anecdote:

'Madame Moissan was walking with her very young son in the Avenue de l'Observatoire, precisely in front of the wall of the amphitheatre in which her husband was working; she knew that, at that very moment, an important experiment was to be attempted and she anxiously awaited the result. A small window in the wall suddenly opened and she hastily approached it: "It works", cried Moissan joyfully'.

A Commission made up of Berthelot, Debray and Frémy was appointed to witness the electrolytic generation of fluorine. With the greatest care, Moissan prepared for the occasion a particularly pure batch of anhydrous hydrogen fluoride. This time, however, the current failed to pass through the cell, so the demonstration was a failure and the Commission left highly disappointed. Moissan then realised that small quantities of potassium fluoride had to be added to the hydrogen fluoride in order to make it conduct electricity. It was the accidental presence of this substance, carried in during preparation of the hydrogen fluoride, that had ensured the latter's conductivity and hence the success of the first experiment. The absence of potassium fluoride during the extra-careful preparation of the electrolyte for the demonstration to the Commission explains the failure of the second experiment. On its second visit, the Commission *was* able to witness the release of fluorine and admire the bright combustion on its contact with silicon, iron, manganese, arsenic and powdered antimony; it also observed the ignition of alcohol, ether, benzene, petrol and turpentine. The extraordinary chemical reactivity of fluorine was clearly demonstrated to everyone's satisfaction.

Moissan published a second note on 19 July, three weeks after the first and confirming the observations described therein. However, he was still afraid to say that this concerned fluorine: he feared possible confusion with a hydrogen perfluoride. It was not until a week later, at the July 26th meeting of the Academy of Science, that Moissan provided both qualitative and quantitative proof that "the gas given off by the electrolysis of anhydrous hydrofluoric acid or potassium hydrofluoride is definitely fluorine". He demonstrated that the fluorine contained no hydrogen "by passing the gaseous substance over a red hot iron. In the case of fluorine, the gas should be entirely absorbed; if, on the contrary a combination of fluorine and hydrogen has been prepared, the latter gas will be released .....". As L. Domange wrote recently:

"Thus ends the story of the isolation of fluorine. This isolation resulted from a century of efforts, starting with the work of Marggraf and Scheele on hydrofluoric acid and followed by a whole list of ingenious, patient and courageous scientists. Each one made a contribution to the knowledge of this special chemistry, allowing his successor to take a further step forward. There were numerous setbacks, some tragic like the suffering endured by the Knox brothers and the death of Louyet, some almost comical like the failure of Moissan's experiment before the distinguished Commission appointed by the Academy. The whole story bears witness to a marvellous adventure".

Progress in inorganic chemistry

The associate professorship which Moissan had obtained in 1883 was restricted by law to a period of tenure not exceeding five years. However, shortly after the isolation of fluorine, Moissan found himself appointed, by an Order of 30 December, 1886, professor in the chair of toxicology at the Ecole Supérieure de Pharmacie, following the death of the previous holder Jules Bouis. It may have been thought that this appointment would stop his move towards inorganic chemistry that had begun so brilliantly with the isolation of fluorine. Indeed, Moissan did effectively undertake some toxicological research into the anaesthetic properties of methyl and ethyl fluorides, pathogenic bacilli in some mineral waters, poisoning by carbon monoxide — a gas to which he was himself particularly sensitive — and the toxicity of opium fumes. However, though all this research was of unquestionable value, both where methods and results were concerned, it formed only a very secondary aspect of his activity throughout the 13 years during which he lectured on toxicology at the Ecole de Pharmacie. In fact, these functions provided him with the stability necessary for the development of his inorganic chemistry research and gave him complete independence where research facilities were concerned. However, the toxicology laboratory was only very small, consisting of just one office for the professor, a single room designed for the preparation of lectures, and a basement serving as a washery and store for the laboratory assistant. Moissan immediately modified this laboratory by splitting the main room in two horizontally, thus creating an extra floor and doubling the floor area. In the absence of laboratory benches, wooden tables were installed with picturesque shelving above; anyone with a working area of 2 m^2 was lucky, and all movement required care and dexterity. In spite of the drawbacks, numerous French and foreign students crowded into this laboratory and contributed to the rapid development of Moissan's research work.

A satisfactory laboratory was finally installed for Moissan and his students in 1896 in a building specially constructed for this purpose in the botanical garden of the Ecole de Pharmacie, between the two amphitheatres (it has now disappeared). Shortly afterwards, in 1899, Moissan succeeded Alfred Riche in the vacant chair of inorganic chemistry. He remained there for only one year, however, for in July 1900 he was appointed to the Faculty of Science, where he found even better working conditions.

Returning to the research work that followed the isolation of fluorine, Moissan concentrated exclusively on studying the properties of fluorine and its compounds until 1891. He improved the preparation of fluorine and systematically studied the effect of the element on most simple substances and a very wide range of compounds. In addition to metallic and metalloidal fluorides, he prepared fluorinated alkanes (methyl, ethyl and isobutyl fluoride, etc.). This work made him the leading research chemist in France. In 1888 he was appointed a member of the Academy of Medicine, and in 1891 he became a member of the Academy of Science, where he replaced Cahours in the chemistry section. He was then just 39 years old.

In 1890, having carried out an in-depth study of boron and its derivatives, Moissan began to direct his attention to an even more difficult problem than that of the isolation of fluorine: the preparation of artificial diamonds. While with fluorine he had been guided by the work of his predecessors, nothing similar existed for diamonds, where a large part of previous research had been kept secret. Moissan therefore had to use a very exacting method of approach, based on numerous preliminary tests. Finally in 1893, after four years of intense effort, he succeeded in obtaining small diamonds by rapidly cooling in water molten iron that had been saturated with carbon in an electric furnace. This experiment has since been repeated with varying success by numerous research scientists: Crookes in 1905, Parsons in 1907 and 1918, Ruff in 1917, Hershey in 1929, Kirchrath in 1942, and Reuter and Knoll in 1947.

Although there remains some controversy over whether diamonds were obtained during these tests, we can call upon the evidence of Paul Lebeau, one of Moissan's students and his principal assistant during these experiments. In a conversation with him about 30 years ago, he assured us that he had himself analysed by combustion the small diamonds obtained and found that they were formed of pure carbon. At that time, however, no more samples remained, so we were unable to confirm these results using more modern methods. Whatever the case, Moissan's remarkable series of experiments, while greatly increasing knowledge in several fields, formed the basis of high-temperature chemistry and technology.

The electric arc furnace operated for the first time in 1892 at the Ecole Supérieure de Pharmacie. It was powered by a current of 45 A and 40 V. Power was supplied by the small dynamo used for the projector in one of the amphitheatres and was driven by a voluminous gas engine of 4 HP. The furnace consisted simply of two superimposed blocks of chalk. A groove was cut in the lower block in which were placed the two carbon electrodes, from 8 to 10 mm in diameter. A small cavity in the centre of this block held a crucible of retort coal which was therefore located immediately below the arc between the electrodes. It was with this very simple device that Moissan succeeded in first preparing chromium, followed by most refractory metals. These initial tests provided a sufficient wealth of results for Moissan to immediately perceive the essential utility of high temperatures and the arc furnace as auxiliary aids to the chemist.

However, the power supply available at the Ecole Supérieure de Pharmacie was fairly weak and could be used only for experiments on small quantities of products. Moissan therefore searched around for power supplies adequate for his requirements. First of all he found hospitality at the Ecole Normale Supérieure, then successively at the Conservatoire des Arts et Métiers, the Gramme factory, the electrical power plant at the Gare de l'Est and the Continentale Edison company, before returning to the Ecole Supérieure de Pharmacie, where a high-power plant providing 1000 A at 60 V had been specially installed. Over the same period, the furnace was increased in size and perfected. The chalk blocks, difficult to obtain in the required dimensions, were replaced by limestone blocks, using an idea thought up by Sainte-Claire Deville. These blocks were prepared by stonemasons from the nearby Montparnasse cemetery, the whole operation being willingly organised by the marble mason Labatie. The arc imprisoned between the two blocks of limestone now allowed the highest temperatures (up to 3500 °C) ever reached until then to be attained, and enabled Moissan to carry out some quite outstanding scientific research which alone would have sufficed to make him world-renowned. He opened a new chapter in the history of science — that of high-temperature chemistry. This subject then developed very rapidly, particularly in industrial circles.

Moissan's research first of all demonstrated that substances considered to be infusible and unchangeable could all be melted or volatilised at a sufficiently high temperature; for example, chalk, barite, strontia and magnesium can be liquified, and even vaporised. At a temperature of 3500 °C, all substances are volatilised or dissociated. The action of carbon on metal oxides allowed Moissan to prepare refractory metals, some of which were merely indicated. With an excess of carbon, he obtained carbides — compounds which were mainly unknown at the time. With the introduction of acetylene for lighting, calcium carbide very quickly became an industrial product. The action of water on these various carbides produced an abundance of hydrocarbons which were studied in depth by Moissan and, above all, by his students. Silicides and borides were described at the same time as the carbides.

With effect from 1898, Moissan developed three new lines of research: studies on calcium, the chemistry of metal hydrides and investigation of solutions of metals in ammonia or alkylamines. Simultaneously, he returned to his work on fluorine and its compounds, aided by the discovery (1899) that a copper U-tube could be substituted for the original costly platinum cell body. It was now possible to generate fluorine at the rate of 5 l/h and manipulation of the gaseous element was greatly facilitated by the observation that glass is resistant to attack if moisture is carefully excluded. Of the numerous compounds prepared and studied, sulphur hexafluoride, made (in collaboration with Lebeau) by burning sulphur in fluorine, aroused much interest because of its composition and chemical inertness.

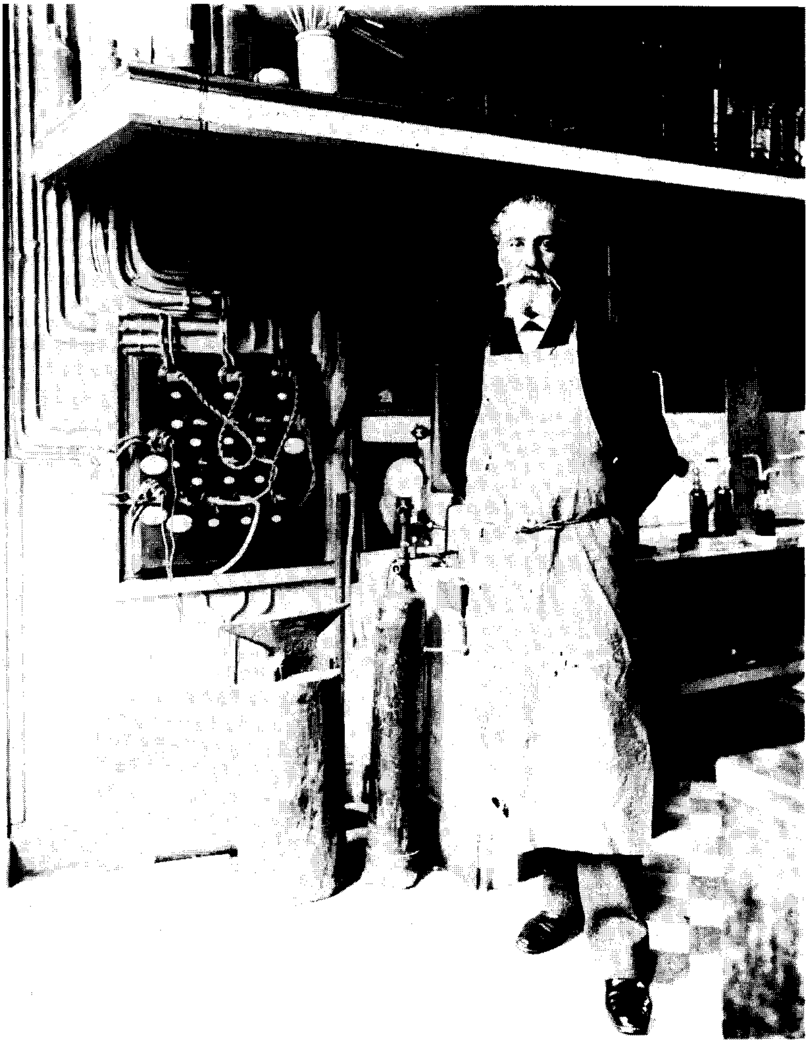


Fig. 2.4. Moissan in his laboratory *ca.* 1899 (by courtesy of the Faculty of Pharmacy, Paris).

The last days

On 6 February, 1907, after a day spent in the laboratory, Moissan returned home complaining of a pain in his side and general tiredness. A few hours later, he suffered a sharp attack of appendicitis and his condition deteriorated rapidly. At his bedside were three people with whom he had formed strong friendships during their military service together in Lille — Drs. Béclère, Siredey and Walther. They vainly attempted all they knew but, after a few days of mingled hope and anguish, Moissan passed away on

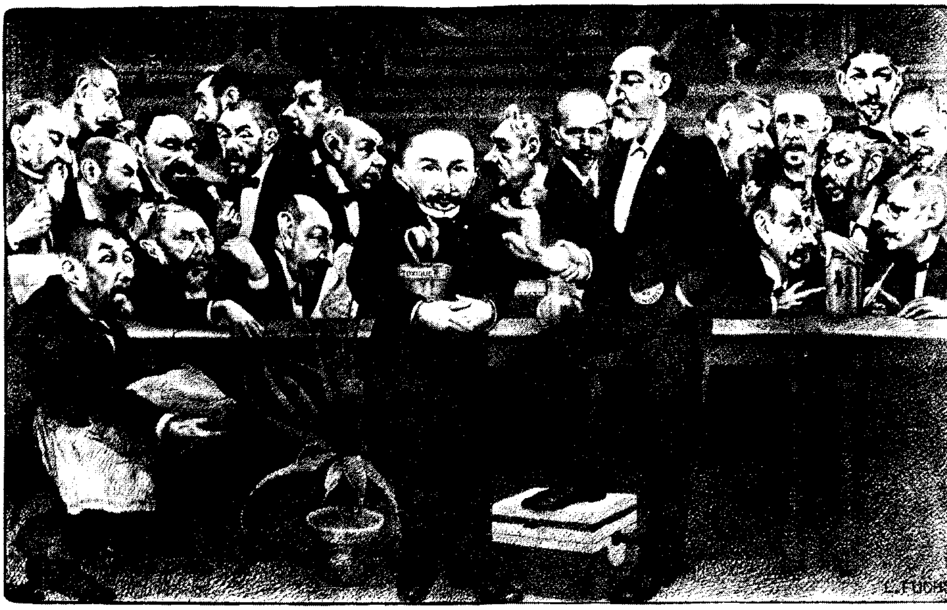


Fig. 2.5. Cartoon by L. Fuchs showing previous and current professors of the Ecole Supérieure de Pharmacie in Paris (early 1907) (by courtesy of the Faculty of Pharmacy, Paris).

15 18
2 5 9 14 16 17 21
1 4 8 11 13 20
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6

1. Bourquelot; 2. Guéguin; 3. Béhal; 4. Moureu; 5. Lutz; 6. Bouchardat; 7. Prunier; 8. Grimbert; 9. Guérin; 10. Perrot; 11. Gautier; 12. Guignard; 13. Coutière; 14. Radais; 15. Moissan; 16. Lebeau; 17. Jungfleisch; 18. Delépine; 19. Berthelot; 20. Villiers; 21. Tassilly; 22. Guerbet.

20 February. Thus he died at the comparatively early age of 54, just two months after having received the 1906 Nobel Prize for Chemistry ('for his investigation and isolation of the element fluorine, and for the adoption in the service of science of the electric furnace called after him'). His fame had already spread far beyond France: he was a member of most Science academies and honorary member of many foreign scientific associations. He had made enormous efforts to ensure the dissemination of his discoveries, attending numerous conferences abroad and welcoming French and foreign chemists to his laboratory, so his death was mourned internationally.

The researches carried out by Moissan took in the whole field of inorganic chemistry and led to a genuine re-birth of the subject. By demonstrating the power of experimentation, by introducing new methods and by creating a new approach to research, he showed that all existing knowledge could be reconsidered, modified and developed. He rehabilitated inorganic chemistry in the eyes of scientists the world over. Through his unflagging energy, his tremendous labours and his original thought, Moissan gave chemical science an incomparable lift that was felt throughout the world. The isolation of fluorine was just one small part of the enormous amount of work he accomplished. A small part, but one of lasting importance.

Moissan the man

Henri Moissan was a shrewd and cultivated man with a mischievous sense of humour. He was a knowledgeable lover of paintings and no style left him indifferent, provided the work was of high calibre. A great collector, he gathered together a whole series of contemporary paintings which were bequeathed to the city of Meaux by his son Louis and which now form practically the entire collection of 19th century paintings in the town's fine arts museum.

At 20 years of age, he formed a close circle of friends who cultivated the arts, sciences and literature. Like many young people of that time, he had toyed with the theatre in the belief that this could be a source of inspiration and success. He even wrote a comedy — *An Unexpected Marriage* — which he submitted to the Odeon Theatre but which was turned down by the selection committee. Moissan quickly realised that he was not destined to be a successful playwright and used to refer to this short-lived attempt in the following words: "I think I did right to study chemistry".

His attachment to various forms of culture, far from diverting him from his scientific preoccupations, in fact contributed to providing him with the equilibrium without which no great intellectual reflections can exist. It is for this reason that we have attempted here to describe the different aspects of the person, which would not have been possible by just a simple description of his scientific achievements.

Acknowledgements

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References

A. Béhal, "Hommage à Henri Moissan", (speech given at the inauguration of the Henri Moissan monument in Meaux on 4 October, 1931), *Chim. Ind. (Paris)*, (1932) 73.

M. Chaigneau, "Henri Moissan (1852 - 1907), Professeur de Toxicologie à l'Ecole Supérieure de Pharmacie de 1886 à 1899", *Rev. Hist. Pharm., 32* (1985) 332.

L. Domange, "Les débuts de la chimie du fluor", *Proc. Chem. Soc.*, (1959) 172.

A. Endrès and C. Viel, "Quelques vers et écrits de jeunesse d'Henri Moissan", *Rev. Hist. Pharm.*, *31* (1984) 5.

H. Gautier, "Henri Moissan (1852 - 1907)", *Bull. Sci. Pharmacol.*, (March 1907) 1.

P. Lebeau, "Notice sur la vie et les travaux d'Henri Moissan" (accompanied by a chronological list of Moissan's publications), *Bull. Soc. Chim. Fr.*, *3 - 4* (1908) I.

P. Lebeau, "Les découvertes de Moissan", (ceremonial session of the Société d'Histoire de la Pharmacie in the honour of Moissan, 18 May, 1946) *Rev. Hist. Pharm.*, (1946) 70.

P. Lebeau, "Moissan et l'expérience", (lecture given to the General Meeting of the Société Chimique de France, 23 May, 1952), *Bull. Soc. Chim. Fr.*, (1953) 135.

P. Lebeau, "Moissan et la pharmacie", (lecture given to the Academie de Pharmacie), *Report of the Annual Public Meeting held on 7 January, 1953*, pp. 42 - 3.

P. Lebeau, "Henri Moissan et son oeuvre", (lecture given on the centenary of Moissan's birth, 20 May, 1953) Institut de France (1953) p. 11.

H. Moissan, "Eloge de Monsieur le Professeur Riche", *Bull. Sci. Pharmacol.*, *2* (1900) 15.

J. C. Ruiz and C. Viel, "Henri Moissan, amateur avisé et collectionneur de tableaux", *Bull. Soc. Lit. Hist. Brie* (1985) 49.

C. Viel, "Quelques notes brèves à l'occasion du 75ème anniversaire de la mort d'Henri Moissan", *Rev. Hist. Art Brie et Pays de Meaux*, (1982) 69.

C. Viel, "Sur une correspondance inédite d'Henri Moissan avec ses amis meldois, Jules et Théodore Plicque", *Bull. Soc. Lit. Hist. Brie*, (1982) 97.

C. Viel, "Eléments de généologie concernant les familles Moissan et Lugan", submitted for publication.

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