Michel Eugène Chevreul

*Jaime Wisniak**

Resumen
Chevreul es un excelente ejemplo de que la vejez no es una barrera para una vida productiva. El vivió 103 años y hasta el último momento jugó un papel activo en la ciencia francesa. Sus contribuciones a la química de las grasas y a la física del color fueron fundamentales para entender los principios que las rigen. Su descubrimiento del círculo cromático puso la ciencia del teñido de los géneros sobre una base científica que condujo al desarrollo floreciente de la tapicería. Sus descubrimientos en el área de las materias grasas y la estearina puso a la industria de la velas en el camino hacia su desarrollo moderno. Chevreul determinó la naturaleza de las grasas y su saponificación, y aisló y preparó la mayoría de los ácidos grasos corrientes.

Abstract
Chevreul is an excellent example that old age is not necessarily an impediment to a fruitful productive life. He lived to be 103 years and to the very last minute was very active in French science. His contributions to the chemistry of fats and to the chemistry and physics of color were fundamental for the understanding of the principles that rule them. His discovery of the chromatic circle put fabric dyeing on a scientific basis that led to the flourishing development of tapestry, his discoveries related to fatty materials such as stearin put the candle industry on the road to its modern development. Chevreul established the nature of fats and their saponification, and isolated and described many of the commonly known fatty acids.

Chevreul is not a name that appears in standard books of Chemistry and Physics. No reaction or theory carries his name but his fundamental and applied research stands behind many common products like drying oils, soaps and candles. His work signals the understanding of the chemistry of fats. Here we will describe his life, his outstanding career, and his contribution to many facets of science.

Life and career
Several references give details about the life and work of Chevreul (Bouchard, 1932; Lemay and Oesper, 1948; Costa, 1960).

Michel Eugéne Chevreul was born on August 31, 1786, the son of Etiennette Magdeleine and Michel Chevreul a practicing surgeon. His father was a correspondent of the *Académie de Medicine* and a known advocate of the idea that medicine and surgery should join forces and not be hostile disciplines. His boyhood took place during the Reign of Terror (1793-1794) and was witness to many cruel events. In 1793 he was taken before a guillotine located very close to his home, to witness the execution of two young girls who had been accused of hiding refractory priests. He was also witness to the bloody battle *la Roche des Murs* between the Vendéans and the Republicans.

When Chevreul was old enough to go to school, all educational institutions had been disbanded, and for five years his parents had to recourse to private teachers. In 1795 the Convention modified the French educational system and established central schools (*Écoles Centrales*) in the capital cities of the departments. This action allowed Chevreul to enter, in 1799, the *École Centrale* in Angers, the replacement for the ancient University of Angiers.

Teaching at the *École* was divided in three sections. The first one covered literature, science, and technology, the second was exclusively scientific, and the third was devoted to grammar, history and law. Chevreul split his studies within the first two sections and complemented his education with courses on Greek, Italian, Botany, Mineralogy, Mathematics, Mhysics, and Mhemistry. His scholastic achievements were very high and included first prizes in Greek, Latin, Physics, Chemistry and Mineralogy.

In spite of the family medical tradition, Chevreul was not attracted by Medicine but by Chemistry. To realize his ambition it was necessary to go to Paris were Antoine Laurent de Lavoisier's (1743-1794) famed

* Department of Chemical Engineering. Ben-Gurion University of the Negev, Beer-Sheva, Israel 84105.
Correo electrónico: wisniak@bgumail.bgu.ac.il

[1] The *Muséum* was originally the *Jardin Royal des Plantes Medicinales*, it was renamed as such after its reorganization in 1793 by the Convention.

students; Antoine-Francois Fourcroy (1750-1809) and Louis Nicolas Vauquelin (1763-1829) were lecturing. Chevreul left the *École* in 1803 intent on being admitted to the *Muséum d'Histoire Naturelle*[1] and learn under Vauquelin. He was fortunate enough to carry a letter of recommendation from Joseph-Louis Proust (1754-1826), his townsman and close friend of Vauquelin. Vauquelin took Chevreul as his laboratory assistant and put him to work together with another assistant, Louis-Jacques Thénard (1777-1857). Chevreul also attended the *Collège de France* where he studied Mathematics, Physics, History, and ancient languages.

In 1804 Vauquelin was appointed professor of Applied Chemistry at the Muséum and took Chevreul as his unofficial assistant.

At the beginning of the 19th century research in Organic Chemistry was in a very rudimentary state. Organic materials were complex aggregates of diverse substances of which it was necessary first to resolve the native materials and separate them into their proximate principles before ultimate analysis could work with full effect.

His first activities under Vauquelin were the study of the coloring materials present in natural products. Chevreul was required to separate the natural dyes from the complex mixture of oils, resins, gums, etc., with which they were found in the plant. Within the period of 1807 to 1811 he was able to isolate brazilin from brazilwood, haematoxylin from logwood, quercitrin from oak bark, luteolin from dyer's wood, and morin from fustic (*Chlorophora tinctoria*). Chevreul also found that indigo was present in its reduced form in woad, and obtained the white crystals of reduced indigo by concentrating an alcohol extract of woad (*Isatis tinctoria*). He found that pure indigo could be converted into the white reduced form and then, by exposure to air, the white indigo would oxidize and recover its blue color. All these activities in the area of vegetable dyes would find their expression later when he joined the Gobelins.

In 1818 Chevreul married Sophie Davallet, the daughter of a retired tax official, they had only one son, Henri. Sophie died in 1862, during all her life she understood and supported the activities of her husband who was either a workaholic or had a more than normal sense of responsibility to his work. Chevreul would return to their home in l'Hays only for one day a week, the rest of the time he would spend working at the Muséum. Chevreul rarely left Paris, so absorbed was he in his research. He worked all his life and when asked the secret of his longevity he replied: "*Le travail est une des conditions essentielles pur une vie centennaire*" (work is an essential ingredient or a long life).

In 1816, when Louis-Bernard Guyton de Morveau (1737-1816) died, Chevreul's name was proposed to fill his vacancy at the *Académie des Sciences.* Chevreul declined the honor after learning that many academicians wished to nominate Proust, who was in a state of poverty. Chevreul was appointed to the Académie in 1826, after Proust's death. Chevreul was a member of the *Académie* for sixty-three years, being elected to the presidency in 1839 and again in 1867.

The *Societé Royale de Agriculture* admitted Chevreul to membership in 1832. He became president of this organization in 1849 and from this year until his death he served as president on alternate years.

In 1810 Chevreul received his first official position, that of assistant naturalist at the Muséum. Chevreul interest in natural history never waned and most of his work is in this domain. His first teaching appointment came in 1813 when he was made at the *Lycée Charlemagne.* He held this position until his resignation in 1828. The Czar Alexander I visited Paris in 1814 and offered Chevreul the directorship of the polytechnic school of Saint Petersbourg but Chevreul refused as a he felt that he should not leave his post during his country's occupation (actually, Chevreul never went abroad).

From 1821 to 1840 he was examiner of Chemistry at the École Polytechnique. His appointment, in 1824, as director of dyeing at the *Manufacture Royale des Gobelins* [replacing Claude-Louis Berthollet (1748-1822)], the national tapestry works of France, marked a new direction in his career. Chevreul spent sixty-one years at the service of the Gobeins, while retaining his activities as chemist and professor at the Muséum.

In 1830 Chevreul was appointed to the chair in Chemistry at the Muséum, in replacement of Vauquelin. He held this position for the rest of his life. He became director of the Muséum in 1864.

In 1826 he became a foreign member of the Royal Society of London.

Although Chevreul did not have students, many French and foreign scholars came to learn under his guidance, among them were Charles-Frédéric Gerhardt (1816-1856), Stanislao Cannizzaro (1826-1910), and August Cahours (1813-1891). He was also a close friend with Örsted, Davy, Berzelius, and Liebig.

Chevreul continued to work and to assist at the Académie meetings until he was 102. He read his last communication in May 1888. He declined considerably from this time and could speak only with pain. His only child, Henri, stayed with him and would accompany him on his daily excursion to view the construction of the Eiffel tower. On March 27, 1889, his son died, and a few days later Chevreul contracted a cold and collapsed suddenly. He died April 9, 1889, five months before the Eiffel tower was inaugurated. His state funeral at the Cathedral of Notre Dame attracted thousands of people who massed near the church in spite heavy rains. Chevreul ashes are buried at the cemetery of l'Hay.

Chevreul lived to the ripe age of 103 years. On the jacket of Bouchard's book (Bouchard, 1932) it is written that Chevreul witnessed in his own country four kings, two emperors, three republics, and four revolutions. When Chevreul was about eighty-five years old, instead of adding to this name on the tile pages some of his professional and academic titles, he wrote simply "*M. Chevreul, doyen des étudiants de France.*" No one suspected at that time that he would continue doing it for the next seventeen years.

Within his life Chevreul was married for forty-four years, worked for sixty-one years at the Gobelins, was a member of the Académie for sixty three years, was connected to the Muséum for ninety years, and collaborated with the *Journal des Savants* for fifty-seven years. In addition, he served twenty times as president and twenty times as vicepresident of the *Societé d'Agriculture.* An interesting fact is that Chevreul presented communications, which were printed in the *Comptes Rendu* in their entirety even when they surpassed the maximum number of pages fixed by the *Académie.* One academician once asked how he could be allowed to do the same and Jean Baptiste André Dumas (1800-1884), secretary for perpetuity of the *Académie*, answered him that the condition was very simple; it was only necessary to be 100 years old.

The centenary of the birth of Chevreul was celebrated on August 31, 1886; it was a great national event conducted in the presence of Jules Grévy, President of the Republic, and of scientific delegations from all over the world. Numerous discourses and honors were given to the centenarian by universities, scientific societies, and industries. For example, the American Association for the Advancement of Science made Chevreul an honorary member.

The principal ceremonies of the centenary were held at the Múseum where a statue of Chevreul was unveiled. A volume containing a complete bibliography of Chevreul's works was issued on this occasion; it was prepared by Godefroy Malloizel, a librarian at the *Múseum* (Malloizel, 1886). A medal was also presented to the centenarian and on the back was the dedication "*La Jeunesse Française au Doyen des Étudiants.*"

Scientific Work

We will now describe in detail some of the contributions of Chevreul to Chemistry, tapestry and textile dyeing, Psychology, and History.

Tapestry

At the beginning of the fifteenth century dyers settled at Saint Marcel, a suburb of Paris, on the banks of the Bièvre River. It is here that the name Gobelin first occurred, of a family that originated in Flanders or northern France. Jehan Gobelin, who ran a factory in the Faubourg Saint-Marcel just southeast of Paris, discovered a scarlet dyestuff and spared no expense to exploit his creation. His reputation and wealth grew rapidly due to his secret of scarlet dyeing. His good fortune excited the envy of some of his neighbors, and it was rumored that he had sold his soul for the secret of scarlet dyeing, but had succeeding ion cheating the Devil of his price.

The members of the family followed the profession of the founder and increased the business so much that eventually the Gobelins came to own most of the Faubourg Saint-Marcel suburb of Paris. Their success increased even more when the famous Flemish tapestry weavers Marc Coomans and François de la Planche (Franz van den Planken) settled in their workshops. The marriage of Marie Gobelin with Antoine de la Planche marked the foundation of the great tapestry workshops in the Gobelin's house (Varron, 1938). A street, a great avenue, and a whole quarter of the city of Paris have derived their names from the Gobelin family, now extinct.

Tapestry weaving on a very large scale started in the 17th century when the French government began to turn its attention to this flourishing industry. The French government centralized its scattered forces, and, according to the mercantile system of Jean-Baptiste Colbert (1619-1683), the various Parisian tapestry workshops were united under one head as a royal factory. The work of the weavers was protected by law from imitation; the workmen were given free board and lodging and pensions, and the material used by them was declared free from taxes. Colbert's decisions found expression on the establishment of the *Manufacture Royale des Gobelins* in 1667. Colbert introduced a new organization in which fixed salaries were abolished, the entrepreneurs were supposed to supply a certain number of pieces and these were paid for according to a fix scale. By Colbert's order, a painter was to be at the head of the organization (*Le Premier Peintre du Roy*). Interesting enough, after the Revolution the financial system of the workshop returned to its original form: payment became fixed again.

The reproduction of colors, shades, and half-shades in tapestry and other textiles was a serious problem. The weavers would split the colors into different shades, which they placed side by side as in a mosaic. Very few colors were available and each of the principal colors had but few shades. They were distinguished only by rough and ready standards. Artificial colors like aniline dyes were unknown and the colors used were of vegetable origin like indigo, or mineral origin like Prussian blue. In addition, the different colors reacted differently with time and the passing of the years produced many unexpected results.

The experiment, made already in the 18th century, of placing a chemist at the head of the dyeing department led to a revolution with the 1824 appointment of Chevreul to this post. Chevreul realized immediately that dyeing was done according to recipes and that to improve the process it was necessary to put it on a scientific basis. Chemical knowledge regarding dyes was unsatisfactory, the composition of the dyes was not completely known and the chemical principles were altered in an unknown manner in the dyeing operation.

Chevreul set up an experimental program to determine the character and properties of fibers, the mutual actions occurring between fibers and acids, bases, and salts, between fiber and organic dyes, and between combinations of these. He also analyzed the influence of mordents on the tone and stability of colors, bleaching, and preservation of colors, and the effect of water quality on the finished material.

His program called for providing an explanation for the following: (a) the cause by which textiles were dyed, that is, whether it was chemical affinity, surface adhesion, or interposition between filaments; (b) the conditions in which this fixation occurred, that is, the nature of the chemical reagents, their proportions, their time of contact, and the temperature; (c) determination of the exact color obtained; (d) influence of atmospheric agents such as water and sunlight on dyed cloth; and (e) the comparative effect of dyes on different clothes.

Chevreul's efforts crystallized in fourteen papers published in the *Mémoires de l'Académie*, from 1838 to 1864, a book (Chevreul, 1829-1830), and a course on the applications of chemistry dyeing, given every year from 1826 to 1840.

a) The contrast of colors (Lemay and Oester, 1948)

Chevreul next goal was the understanding of the visual problems related to the contrast of colors. A known phenomenon was the lack of vigor in the blacks used for shadows in blue and violet draperies. Black colors lost much of their intensity when they were painted on a blue or violet background. Chevreul found that much of the difficulty in tapestry production was not due to the dyes used, but rather to improper juxtaposing of colors.

After an intensive study of the phenomenon he realized that there were three classes of contrast: simultaneous, successive, and mixed. *Simultaneous contrast* was the modification in hue and tone experienced by colors seen simultaneously. According to Chevreul, this kind of contrast was ruled by the following laws: (a) If two colored objects were juxtaposed, each lost its own color and took on a new color resulting from a modification of its own color by the complementary of that which is contiguous to it. (b) The juxtaposition of two colors of different tones lowered the tone of the brighter and lightened that of the darker (c) If two contiguous colors were complementary, then the shade of each of them could no longer be modified by the complementary of its neighbor. The tones of both were heightened reciprocally. (d) If non complementary colors were brought side by side, sometimes a more pleasant harmony issued, and sometimes false and disagreeable shades resulted.

On the other hand, *successive contrast* was the phenomenon that occurred when one gazed at a colored object and then turned away. The image of the image now had a color complementary to the original. *Mixed contrast* involved looking at one color and then to another. One would see a color that was a mixture of the second color and the complementary of the first.

Chevreul published these results in a long memoir (Chevreul, 1883) and in book (Chevreul, 1839).

b) Chromatic analysis of colors

In order to solve the problem of the definition and representation of colors Chevreul proceeded to define a chromatic circle in which, out of three pigments of red, yellow, and blue, he was able to realize almost fifteen thousand shades or tones (actually 14440). Chevreul used as fundamental points of comparison three definite rays of red, yellow, and blue, each marked by Fraunhofer lines[2] (Joseph von Fraunhofer, 1787-1826). In this way he was able to derive from the chromatic circle of pure colors 1442 different tones all of which were perfectly defined, but only the trained eye of the dyer was able to distinguish. Chevreul believed that standard circles of colors should be preserved in the same way as standards of weights and measures were preserved (Chevreul, 1861).

Chevreul applied all his results to the production of the Gobelin tapestries and carpets and revolutionized the art.

c) Neo-impressionism

Chevreul's physical and chemical researches on colors had also impact on the fine arts. They became the basis for the neoimpressionism school of painters to develop their method of painting based on the application of separate touches of colors to the canvas and allowing the eye of the observer to combine them. Such optical mixtures were more intense than premixed colors; for example, red and yellow created a more intense orange as an optical mixture than the actual tube color of orange.

Chevreul realized that the negative and positive after-images were responsible for the subjective effects. The changes of color-value upon different backgrounds and the differences in the laws of pigment and of color mixture were afterwards applied to the color schemes of textile and other designs.

Chemistry of Fats

Chevreul's investigations of the Chemistry and composition of fats and oils constitute his most remarkable scientific contribution. He was led into this subject in 1811 when Vauquelin asked him to analyze a sample of a potassium soap made from pig fat. As an initial step Chevreul prepared a very diluted aqueous solution of the soap and observed that shiny crystals separated from it (*matiere nacrée*). Acid treatment of this fraction of the soap, followed by crystallization in alcohol, yielded a solid fatty that possessed the properties of an acid, a property that was in contrast to the neutral fat from which the soap was derived. He named this fatty substance *margarin* (from *pearl*).[3] In a later work he changed the name margarin to *margaric acid* (Chevreul, 1816) Chevreul pursued the study on fats from 1811 to 1823, and read his first paper on this subject in 1813 (Chevreul, 1813). Margaric acid (although misidentified as a pure acid) was the first of the several fatty acids that he was to isolate from natural fats. In a following paper (Chevreul, 1815; p. 80-107) Chevreul reported that from the dissolved part of the soap he had obtained a second acidic product, this one of a fluid character. He named it *fluid fat*, later redesignating it *oleic acid*. Having determined the results of the saponification process Chevreul went on to determine if the products of saponification were originally present in the fat. His results indicated that the fat was neutral before saponification and that after combination with alkali it produced the solid and liquid fatty acids and the sweet principle of Scheele [*ölsus*; Carl Wilhelm Scheele (1742-1786)] (Chevreul, 1815, p. 13-144). In a later work Chevreul named the sweet principle *glycerin* (Chevreul, 1823). In a few words, Chevreul elucidated the process of formation of soap and showed that fats are combinations of acids with glycerin.

Chevreul studied the saponification process using a variety of bases such as soda, baryta, lime, and metal oxides. He showed, contrary to what Fourcroy had claimed, that saponification also took place under vacuum and hence in the absence of oxygen. He also saponified fats from all available sources, including man, wild (dolphin and porpoise) and domesticated animals (pigs, cows, sheep, and goats), oils of vegetable origin, and the crystalline substance present in biliary calculi (cholesterine). Such origins are revealed in the names he coined for

[2] Fraunhofer's lines indicate the radiations that have been absorbed in the trajectory of light from the sun to the observer's eye, by the various elements existing as gases in the atmosphere. The set of lines constitute a series of very precise and fixed points that can be used to define the different portions of the spectrum.

[3] Wilhelm Heintz showed that Chevreul's margaric acid was probably a mixture of 10% stearic acid and 90% palmitic acid. This mixture possessed the melting point, crystalline form, and properties of margaric acid. Genuine margaric acid ($C_{17}H_{34}O_2$) was synthetized by Heintz in 1857 (Heintz, W., *Ann Physik*, **1857**, *102*, 257-289).

the new acids: *butyric* (butter); *capric, caproic* (goat); *delphinic* (dolphin); *phocenic* (turtle); etc. In the case of spermaceti he found that it was not a fat because it did not produce glycerin (spermaceti is actually a wax, cetyl palmitate). His investigation on the nature of spermaceti led him to purify cetin by repeated crystallization. Later he saponified it into cetic acid, which he now recognized was a mixture of margaric and oleic acids. Saponification of spermaceti led him to prepare cetyl alcohol.

Chevreul utilized his discoveries to develop a system of nomenclature for fats and derived products. The chemical substance in biliary calculi he called it *cholesterin* (from the Greek meaning bile + solid); spermaceti was to be *cetin* (from Greek for whale), the solid fat principle and the liquid fat principle were to be *stearin* (fat) and *elain* (oil; eventually he would change this name to *olein*). The acid from saponified was named cetic acid and the terms margarates, oleates, and cetates, were to be the generic names for the soaps, which these acids formed with bases.

A very important discovery was the fact that fats originating from very diverse sources (human, sheep, beef, jaguar, and goose) could all be resolved into stearins and olein and that their different consistency was due to the different proportions of the two components. This discovery explained why it was possible to have oils, butters, and fats of soft and hard structure, without assuming, as many chemical individuals as there were fats.

His copious research on the subject gave place eventually to a 500-page book summarizing the state of the art in the chemistry of fats (Chevreul, 1823).

Chevreul researches may be considered a great leap forward in putting soap making on a scientific basis. They led immediately to a very large increase of soap production in France, which was helped by the simultaneous large-scale commercialization of soda production. From Chevreul's theory of the constitution of fats, there was a swift elucidation of the details of fat splitting to prepare soaps and candles. The manufacture of improved stearin candles was also a direct application of his researches.

The great success that issued from his studies of fatty materials strengthened Chevreul's ideas regarding proximate analysis and the application of appropriate means of separating them without altering their nature. He conferred on proximate organic analysis a great measure of scientific rigor and certainty. It was clear to him that a proximate analysis should precede a useful ultimate analysis. To Chevreul belongs the credit for the conception of proximate principles as applied to well-defined materials, that display constant physical and chemical properties and which cannot be separated without being denatured. His doctrine was developed in his 250-page book *Considérations Générales sur l'Analyse Organique et sur ses Applications*, published in Paris in 1824.

Stearic Candles

The candle represents one of the most ancient and most useful forms of illumination. The excellence of a candle depends upon the nature of the wick and the combustible matter, and on the manner and extent to which these are apportioned. The plaited and pickled wick was first introduced in France in 1825. The early wicks, which were neither plaited nor pickled, did not bend over to the outer oxidizing region of the flame and consequently were not completely consumed; they required frequent snuffing to remove the char.

The Christian era created a tremendous demand for beeswax candles for religious services. Wax candles were expensive and tallow candles cheap but both were hardly satisfactory and gave an objectionable smell. Chevreul's experiments on the saponification of fats led him to believe that the product could be used for manufacturing new and improved candles. Initial experiments had shown him that the removal of glycerin from fats led to candles that were less greasy and had substantially increased hardness and illuminating power than those from untreated tallow.

In 1842 Chevreul approached Joseph-Louis Gay-Lussac (1778-1856) and persuaded him to jointly finance the building of a factory for the manufacture of stearic acid. Chevreul and Gay-Lussac proceeded to take two joint patents, one in France (Chevreul and Gay-Lussac, 1824) and another in England (Chevreul and Gay-Lussac, 1825). The English patent was registered under the name of Moses Poole, a patent agent who testified that the invention had been communicated a by a certain foreigner, resident abroad.

In their patents Chevreul and Gay-Lussac claimed the exclusive right to use fatty acids for lighting and for production of fatty acids by treating fats with alkali or acid. Their arguments were that "no one having yet applied to illumination fatty bodies saponified by means of alkalies or acids, we wish to introduce our patent for this application, that is to say to reserve to ourselves the exclusive right of preparing for illumination acids from fatty bodies, whether solid or liquid, which are obtained by saponifying with potash, soda or other bases, by acids or by any other means, fats, tallow, butters, and oils."

Basically the patented process consisted in saponifying the fat and separating the two layers. The lower layer contained a water solution of glycerin and the upper layer contained the salts of oleic, stearic, and palmitic acids. The liquid oleic acid was separated from the solid acids by pressure. The separation of the products was not so easy in practice and the first candles produced by this method were greasy and generally unsatisfactory. When the process was carried out with soda or potash, the soap was decomposed with hydrochloric acid. Separation of the sodium or potassium chloride produced was achieved by dissolving the fatty acids in alcohol. This was a very good laboratory procedure but not economic on a large scale. Chevreul and Gay-Lussac were unable to develop an alternative procedure and abandoned their rights after spending about 40,000 francs.

Although Chevreul and Gay-Lussac did not succeed in their endeavors to commercialize the discovery of fatty acids, the further development of the French industry for the manufacture of fatty acids candles is based on Chevreul's work. In recognition of these merits Chevreul was awarded in 1852 the Marquis d'Argenteuil prize for the encouragement of national industry (12,000 francs). The jury of the International Exposition of Paris of 1855 also recognized these merits and awarded him a grand medal of honor.

The interested reader is directed to the fascinating booklet written by Michael Faraday (1791-1867) about the manufacture of candles and their combustion (Faraday, 1920).

Paraffin wax was not introduced in candle making until 1854.

Psychology

There was a vogue in Paris during the 18th century of séances and table lifting. In 1853 the *Académie* appointed a committee of three, Jacques Babinet (1794-1872), Jean-Baptiste Boussingault (1802-1887), and Chevreul as chairman, to inquire into the phenomena of the divining rod and exploring pendulum which had been the subjects of recent memoirs to the *Académie.*

The interpretation of the dipping of the divining rod in locating water as an involuntary movement of the forked stick in the hands of the dowser, was known long before Chevreul. Some had argued that the force emanated from the devil. The same device was used to detect crime and a learned physician had once hypothesized that "the corpuscles exhaled in the transpiration of the body of a murderer differed in the pattern of their arrangement from that they would had not he perpetuated the crime." In Chevreul times it was thought that the effect of the divining rod was the result of the *organoelectricity*, which resided in humans (Jastrow, 1937).

The swinging pendulum was simply a weighed ball suspended at the end of a string. The observations noted that the pendulum swung one way for one kind of substance or influence, and in an opposite way for another. For example, if a string, with a bit of iron, sulfur, gold, or other metal suspended from it was held over the north pole of a magnet, the movement was from left to right and over the south pole from right to left. The direction of movement was dependent on the nature of the metal.

According to Chevreul, the movements of the divining rod were the result of subconscious reflexes governed by preconceived notions or by the appearance of the surroundings.

Chevreul experimented with the pendulum and explained it as the result of expectant suggestion; the pendulum would swing as you think it would or should. The pendulum swung so readily that the holder was unaware that he was giving the impetus. Chevreul concluded that "so long as I believed the movement possible, it took place, but after discovering the cause I could not reproduce it." This observation marked an important moment in the annals of suggestion. The swinging pendulum was a case of autosuggestion, as long as you believed the movement possible, it occurred.

Chevreul summarized his independent findings and the results of the committee investigations in a report to the *Académie* and a book (Chevreul, 1854). In these writings Chevreul appears as a spokesman for natural causes, as opposed to the recourse of occult, mysterious and supernatural explanations.

Philosophy and History of Science

In 1866 Chevreul published the first (and unfortunately the last) volume of his history of chemical knowledge (Chevreul, 1866), which was meant to include four volumes. In the first volume he discussed the purpose and field of chemistry, its relationship with other sciences, with natural history and with life itself; the classification of the sciences; and scientific abstraction versus art and literature. Chevreul dedicated this book to the memory of his wife (who had died four years before): 'A la mémoire de Mme. Sophie Chevreul, née Davalet. Reconnaissance de 44 anées de bonheur.'

Chevreul's incursion into Psychology led him to write a book on scientific method (Chevreul, 1870) where he stated that he always sought to establish general methods and principles and was never satisfied with making individual discoveries. He claimed that one of the principal functions of experiment was the testing of the validity of a preliminary induction based on the study of natural phenomena. All generalizations should be submitted to the rigorous control of experiments and observation.

At the time of publication of this book Pierre Maurice Duhem (1861-1916), another brilliant French scientist, was just nine years old. Eventually he would become one the most influential philosophers of his day because of his opposition to mechanistic modes of explanation and his development of a holistic conception of scientific theories. Duhem championed the idea that individual empirical propositions should not be tested in isolation but only in conjunction with other theoretical claims and associated hypotheses. He considered Physics to be non-explanatory, physical theories were not explanations but representations. Physical theories did not reveal the true nature of matter, but gave general rules of which laws were particular cases; theoretical propositions were not true or false but convenient or inconvenient.

In another publication on the history of Chemistry (Chevreul, 1878) Chevreul divided the historical development of Chemistry into four epochs, clearly identified by some remarkable events. The first epoch ended with the foundation of the museum of Alexandria (285 to 247 BCE). Although this period did not contain any authentic writing about Chemistry it contained the ideas on the nature of matter of the Greek atomists Plato, Aristotle, and their successors. The second epoch covered up to Johann Joachim Becher (1635-1682). It included the works of Plotinus (205-270 CE) and Geber (Jabir ibn Hayyan) in the ninth century, as well as sacred writings where nothing positive was said regarding science. The third period started in the tenth century and ended with Becher's book on Alchemy and corresponded to the alchemists' efforts to prepare the quintessence.[4] The fourth epoch included Becher and the phlogiston theory of George Ernst Stahl (1660-1734). The fifth and last stage began with Newton's writings in 1717, those of Étienne François Geoffroy (1672-1731) in 1718, and the chemical work of Antoine Laurent de Lavoisier (1743-1794). This period ended in 1794.

As mentioned by Metzger (Metzger, 1932), Chevreul did not justify why he decided to divide a continuous evolutionary phenomenon into discrete stages or why his second and third epochs overlap.

In summarizing his findings, Chevreul attributed a critical influence to Newton's philosophy on the formation and renewal of the chemical doctrine.

Another book that strongly attracted Chevreul's attention was Ferdinand Hoefer's (1811-1878) *Histoire de la Chimie*, published in two volumes between 1842 and 1843 Chevreul published in the *Journal des Savants* a long series of articles devoted to the analysis, criticism, and discussion of the book. Chevreul's review consisted of fourteen articles published within nine years (1843-1851) and covering some 191 pages. These essays were more a philosophical rather than a historical discussion of Hoefer's approach to the subject. According to Sarton (Sarton, 1940) no work has ever been criticized as lengthy.

Conclusions

Chevreul was a pioneer not only in organic chemistry but also in many other fields. The results of his experimental work were not sufficient and his curiosity led to his contributions in the areas of dyeing, color theory, and psychology. Many of the questions that he asked himself could not be answered experimentally, but only by patient efforts in the library and long meditations.

Acknowledgment

The help of Mrs. Karine Barker, Librarian, Document Supply Department, Radcliffe Science Library, Oxford, in providing copies of hard-to-get documents is gratefully acknowledged.

[4] *Quintaessence*: In the Antiquity it was thought as the material that composes celestial bodies. In the Middles Ages it became the intimate substance extracted from a body.

References

Bouchard, G., *Chevreul*, Editions de la Madeleine, Paris, 1932.

Chevreul, M.E., Recherches Chimiques sur Plusieurs Corps Gras et Particulièrement sur Leurs Combinaisons Avec les Alkalis, *Ann. Chim.*, **88**, 225-261, 1813.

Chevreul, M.E., Recherches Chimiques sur Plusieurs Corps Gras et Particulièrement sur Leurs Combinaisons Avec les Alkalis, *Ann. Chim.*, **94**, 80-107, 113-144, 1815.

Chevreul, M.E., Recherches Chimiques sur Plusieurs Corps Gras et Particulièrement sur Leurs Combinaisons Avec les Alkalis, *Ann. Chem.*, **2**, 339-372, 1816.

Chevreul, M.E., *Recherches Chimiques sur les Corps Gras d'Origine Animale*, Paris, 1823.

Chevreul, M.E., *Leçons de Chimie Appliquée à la Teinture*, 2 vols., Paris, 1829-1830.

Chevreul, M.E., *De la Loi du Contraste Simultané des Couleurs*; Paris, 1839. (An English edition appeared in 1854 under the title *The Principles of Harmony and the Contrast of Colors.*)

Chevreul, M.E., *De la Baguette Divinatoire, du Pendule dit Explorateur et des Tables Tournantes, au Point de Vue de l'Histoire, de la Critique et de la Méthode Expérimentale*, Paris, 1854.

Chevreul, M.E., Exposé d'un Moyen de Définir et de Nommer les Couleurs d'Apres une Méthode Précise et Expérimentale, avec l'Application de ce Moyen à la Définition et à la Denomination des Couleurs d'un Grand Nombre de Corps Naturels et de Produits Artificiels, *Mém. Acad. Sci.*, **33**, 1-936, 1861.

Chevreul, M.E., *Histoire des Connaissances Chimiques*, Vol. I, Gide, Paris, 1866.

Chevreul, M.E., *De la Méthode a Posteriori Expérimentale et de la Généralite de ses Applications*, Paris, 1870.

Chevreul, M.E., *Résumé d'une Histoire de la Matière depuis les Philosophes Grecs Jusqu'à Lavoisier Inclusivement*, Didot, Paris, 1878.

Chevreul, M.E., Mémoire sur la Vision des Couleurs Matérielles en Mouvement de Rotation, et sur les Vitesses Numériques de Cercles don't une Moitié Diamétrale est Colorée et l'autre Blanche; Vitesses Correspondant à Trois Périodes de leur Mouvement à Partir de l'Extréme Vitesse Jusqu'au Repos, *Mém. Acad. Sci.*, **42**, 1-287, 1883.

Chevreul, M.E., Gay-Lussac, J., French Patent No. 2493, July 12, 1824.

Chevreul, M.E., Gay-Lussac, J., British Patent No. 5185, 1825.

Costa, A.B., *Michel Eugène Chevreul and the Chemistry of Fatty Oils*, Ph.D. Thesis, University of Wisconsin, Wisconsin, 1960.

Faraday, M., *The Chemical History of a Candle*, Dent & Sons, London, 1920.

Jastrow, J., Chevreul as a Psychologist, *Scientific Monthly*, **44**, 487-496, 1937.

Lemay, P.; Oesper, R.E. y Michel Eugène Chevreul (1786-1889), *J. Chem. Educ.*, **25**, 62-70, 1948.

Malloizel, G., *Oeuvres Scientifiques de Michel Eugène Chevreul*, Paris, 1886.

Metzger, H., Eugène Chevreul-Historien de la Chimie, *Archeion*, **14**, 6-11, 1932.

Sarton, G., Hoefer and Chevreul, *Bull. History Medicine*, **8**, 419-445, 1940.

Varron, A., The Gobelins. A Family of Dyers, *Ciba Reviews*, **5**, 170, 1938.