RESEÑA

LOUIS-CLAUDE CADET DE GASSICOURT

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RESUMEN. Louis-Claude Cadet de Gassicourt (1731-1799) descubrió (y murió sin saberlo) en forma accidental, los primeros compuestos organometálicos (cadodilos), durante un trabajo relacionado con tintas invisibles. Estudió el bórax y la fabricación de carbonato de sodio a partir de algas. Desarrolló un proceso más económico para fabricar éter en forma continua y estudió junto con Lavoisier y otros la combustión del diamante, usando un lente cóncavo-convexo.

ABSTRACT. Louis-Claude Cadet de Gassicourt (1731-1799), discovered (and died without knowing it) accidentally, the first organometallic compounds (cacodyls) while carring out a work related to invisible inks. He studied borax and the preparation of sodium carbonate from algae. He developed a more economic process for the continuous manufacturing of ether and studied together with Lavoisier and others, the combustion of diamond using a liquid concave-convex lens.

LIFE AND CAREER[1-4]

Cadet, born in Paris, on July 24, 1731, was the second son of Marie-Madeleine Godefroy and Claude Cadet (1695-1745), a surgeon at the Hôtel-Dieu in Paris who died in 1745 leaving his wife and thirteen children (seven boys and six girls) in dire misery. His father was a second cousin of Antoine Vallot (1594-1671), the Principal physician of Louis XIV (1638-1715). Initially, Joseph de Saint-Laurent (1707-1773), Treasurer of the Colonies, and a friend of the family, took care of the family, and later on had the children adopted by friends in different localities of Mantes-la-Jolie. Each of the brothers added to his name that of the place where they grew up. Thus Louis-Claude, who went to the village of Gassicourt, became Cadet de Gassicourt. After completing his studies at the *Collège des Quatre-Nations*, Louis Claude first worked as apprentice in pharmacy and chemistry at the pharmacy of Claude Humbert Piarron de Chamousset (1717-1773) and then found employment in the prestigious apothecary shop owned by Claude-Joseph Geoffroy (Geoffroy jeune) (1685-1752) and his son, Claude-François (1729-1753), both members of the *Académie Royale des Sciences*. At this place he acquired a solid competence in pharmacy and chemistry and pretty soon was put in charge of the business.

In 1753, at the age of 22, and through the intervention of Saint-Laurent, Cadet got a position as *premier garçon* at the pharmacy of the Hôtel Royal des Invalides in Paris, replacing Pierre Levasseur: Towards the end of the same year he received an appointment as *apothicaire major gagnant-maîtrise*. This position was limited to six years (1753-1759) but had the advantage that at its end the appointee could receive, by royal decision, the *maîtrise* (mastery) in pharmacy. In 1756 Cadet received a short-term appointment to the Army of Maréchal de Richelieu (1696-1788), who was fighting the British in the island of Minorca. After his return to the *Hôtel* he was appointed for examining the young men destined to serve as pharmacists in military hospitals. In 1759, Cadet ended his work at the *Hôtel des Invalides* and became, by royal decision, *Maître en Pharmacie* and hence, member of the *Collège de Pharmacie* in Paris. Provisionally, he continued his military career; in 1761 he was appointed *apothicaire-major et inspecteur des pharmacies des hôpitaux sédentaires de l'Armé du Roi* (replacing Chamousset) first of the French Army stationed in Germany and then of the French Army stationed in Spain, under the orders of Prince Charles Juste de Beaveau-Caron (1720-1793). Together with Chamousset, they devoted a lot of effort to reorganize the stationary military hospitals, which were in a deplorable state.

In 1764, after quitting his military appointment, Cadet returned to Paris and purchased the Chachignon pharmacy on rue Saint-Honoré, (managed by the widow of Michel-Eléonore Chachignon). In order to be able to operate it, Cadet had to pass the exams required by the *Corporation des Apothicaires*. His wide professional knowledge and experience helped him transform his pharmacy into a very prosperous business. In 1765, he published a catalog describing the line of products, which should be available in pharmacies of different sizes, including a private home.[5] This catalog included 119 preparations divided in four groups: internal medicines, external medicines or tonics, particular medicines, and agreed compositions. Since it was destined for the general public, the catalog did not contain the formulation of these medicines; it only described their properties, the ways of using them, and the pertinent doses.

In 1779, Cadet took his cousin François Derosne (1743-1796) as partner in running the pharmacy and sold it to him in 1786.

Cadet was regarded by his contemporaries as a chemist of reputation, the importance of his research led to his election as *adjoint chimiste* [replacing Pierre-Joseph Macquer (1718-1784)] to the *Classe de Chimie* of the *Académie Royale des of Sciences* in 1766, followed by promotions to *associé chimiste* in 1770 [replacing Guillaume François Rouelle (1703-1770)] and *pensionnaire chimiste* (*Classe de Chimie et Métallurgie*) in 1777 [replacing Louis Claude Bourdelin (1621-1699)]. In 1761, he was elected *agrégé* of the *Académie Impériale de Curieux de la Nature*, and assigned the name Avicenne III. Afterwards, he was elected corresponding member of the *Académie des Sciences* of Lyon, Toulouse, of the *Société de Médicine* of Bruxelles, etc. In addition, he served as Royal Commissioner at the Sèvres porcelain works and was a member of the Service de Pharmacie de Paris.

In 1771, Cadet married Marie Thérèse Françoise Boisselet, the daughter of the *Contrôleur de la Bouche du Roi*, who brought to their home a two-year old son, fathered by Louis XV. Cadet adopted the boy as Charles-Louis Cadet (1769-1921), although he never considered him a son; according to Flahaut[4] years later this situation led Cadet to a serious emotional crisis that also affected his scientific work.

On October 8, 1793, the Revolutionary Committee suppressed all the French *Académies*, including the *Académie des Sciences*. At that time Cadet was Doyen de la Classe de Chimie. This event marks the end of Cadet´s scientific activities. In October 1795, the *Institute National des Sciences et des Arts* was created, composed of three classes. Cadet's name was not included among the members. The six chemists members of the first *Classe de Chimie de l'Institut de France* were Pierre Bayen (1725-1798), Claude-Louis Berthollet (1748-1822), Antoine-François Fourcroy (1750-1809), Louis-Bernard Guyton de Morveau (1737-1816), Bertrand Pelletier (1761-1797), and Louis Nicolas Vauquelin (1763-1829).

After suffering painfully from urinary calculus, Cadet was operated by Joseph Souberbielle, a well-known specialist. Apparently, the procedure was conducted under inappropriate precautions because Cadet promptly developed gangrene and passed away five days after the operation (October 18, 1799). He was buried at the Montmartre cemetery. His wife passed away the next year,

During 1755 and 1756 Cadet worked with his teacher, Guillaume François Rouelle (1703-1770), on the analysis of a sulfate (*vitriolique*) mineral water of the fountain of Passy owned by the family Calsabigi and on new experiments to prepare a blue precipitate then known as Prussian blue.[6] In the same year, he read to the *Académie a memoir* about potassium acetate. The following year, while working on the distillation of a mixture of arsenious oxide with potassium acetate, he discovered the red "fuming liquor" that carries his name.[7] Cadet did not realize that he had discovered the first organometallic compound. This finding was presented to the *Académie des Sciences* that same year, reported on favorably by Bourdelin and Joseph Marie François Lassone (1717-1788) in January 1758, and published in the *Académie's Mémoires de Mathématique et de Physique* in 1760.[7] Cadet's fuming liquor remained a curiosity until 1837 when Robert Wilhelm Bunsen (1811-1899) studied the reaction in depth, determined the nature and composition of the compound, and prepared many derivatives of what became known as the cacodyl radical.[8,9]

In 1758, Cadet begun to study borax and came to the (wrong) conclusion that it contained a copper arsenic principle, as well as a vitrifiable earth.[10-12] He did succeed, however, in developing more efficient methods for producing potassium acetate and ether.[13,14] He made significant improvements to the preparation of ether in larger amounts, proving that the spent sulfuric acid could be used to etherify new amounts of alcohol.[14] In 1759, together with Philippe-Nicolas Pia (1721-1799), he analyzed the sugarcoated pills (Keiser's sugarplums) offered by the German charlatan Keiser for the cure of venereal diseases. These pills were found to contain mercury chloride (a poison), Arabic gum, sugar, and starch. In 1761, Cadet communicated to the *Académie* the results of his study of the composition of Vesuvius lava, which indicated that it was composed of sulfate and aluminum pyrites, with a large percentage of sulfur.[15] The violence of fire had removed the sulfur (the phlogiston and sulfuric acid, according to Cadet), the iron, the copper, and the aluminum earths. The vitrifiable earth had melted and formed, with the accompanying quartz, a kind of opaque glass. In 1774 Cadet reported that calcining HgO resulted in the formation of elemental mercury, a fact that was disputed by his fellow academician Antoine Baumé (1728-1804).[16] A committee composed of Antoine-Laurent Lavoisier (1743-1794), Mathurin Jacques Brisson (1723-1806), and Balthazar-Georges Sage (1740-1824) investigated the problem and reported to the Academy of Sciences that Cadet results were correct.

Of particular interest are the investigations he made between 1772 and 1774 with Lavoisier and Macquer on the effect of a burning lens on the melting of platinum and the burning of diamond.[17,18]

To these important memoirs, the autor must add these: (1) examination of the Séverac charcoal, composed of fossil vegetable carbon, mixed with martial vitriol (iron sulfate), partially crystallized in this carbon,[19] (2) analysis of the mineral water from the abbey of Fontenelle in Poitou and from de city of Roye, together with important observations regarding selenite,[20,21] (3) examination of a mineral source found at Vaugirard en Rouerge,[22] (5) observations regarding a solution of mercury nitrate, which distilled with rectified wine spirit generated volatile alkali, as well as an oil of bituminous smell. This result, which would have seemed extraordinary at a time when the principal components of nitric acid, ammonia, and alcohol, were absolutely unknown,[23] (4) examination of the substances contained in the water of the *Grotte du Chien* near Naples in Italy (the site of toxic fumes due to the volcano in the region),[24] (5) memoirs about meteorites,[25,26] and (6) memoirs related to alkaline carbonates.[27,28]

At the request of the *Comité des Monnaies*, Cadet, together with Mathieu Tillet (1714-1791), Fourcroy and Jean Darcet (1725-1801), prepared a report on the different procedures for converting the metal of church bells into small coins.[29]

SCIENTIFIC CONTRIBUTION

Cadet wrote over 50 papers and reports, some of them very significant. Here we describe a few of his contributions.

Invisible (sympathetic) inks

The existence of invisible ink was an essential factor for the activity of ministries of foreign affairs at that time. In the 18th century, research on their composition was an active field that exerted the sagacity of chemists. In the eyes of the State their secret represented a value similar to that of the philosophical stone of the alchemists. Research and purchase of invisible inks was a government activity.

In 1737, Jean Hellot (1685-1766) published two papers reporting his findings on invisible inks.[30] By occupying himself on the subject, Hellot was not only reacting to a need of his time but also to an economical one. The price of recipes for their fabrication and usage, the difficulties of chemical manipulations, or the lack of quality (accidental exposure, too early, or too easy), determined their selection. Involvement of Hellot in the subject was greatly aided by his previous work in the domain of dyeing of wool and cotton and wool cloths. It was also an extension of his previous researches on certain mineral salts and metallic compounds (bismuth, arsenic, cobalt, etc.) In his first paper, Hellot described the properties of the available invisible inks and the ways of making them visible. He was particularly interested in the ink obtained from a pink material extracted from the mine of Schneeberg (Saxony) in Germany. This ink was different from the others known it that moment it become visible (blue) by heating and invisible again by cold, as many times as desired, without any addition and without alteration of the color. After experimenting with the German salt, Hellot tried several classes of French cobalt minerals (cobolt, either smaltite, $CoAs_2$, or cobaltite, $CoAsS_2$), without success until he tested arsenic bismuth and arsenic copper minerals from the *Dauphiné* region. A complex chemical procedure, involving digestion with hot acid (HCl or HNO_3), allowed him to produce a salt that had the same properties as the one shown by the German one. Digestion with HNO_3 allowed a shorter and simpler management of the process. The digestion with HCl was characterized by a very slow reaction, the need of heating to higher temperatures, and the release of red pungent vapors. Hellot's ink, which was basically an aqueous solution of cobalt chloride or nitrate, obtained from the salts present in mixed minerals rich in arsenic and bismuth, was put to a large use. An important advantage of the new ink was that it could be made in different colors, such as such as green, blue, yellow, colombin, rose, and carmine, depending on how it was treated. Hellot found that the final color of the writing solution depended on the other metals present in the mineral, as well as the additional salts he added to stabilize the solution (sodium chloride, borax, sodium sulfate, or sodium nitrate).

Cadet replicated Hellot's process and decided to extend the investigation by studying in detail the action of other acids on the mineral, as well as on other metals such as copper.[7] Initial experiments with sulfuric acid showed that the mineral was hardly attacked, a result, which Cadet believed to be caused by the presence of sulfur derivatives in the mineral. Therefore, he calcined the mineral previous to treatment with the acid and noted the release of a copious amount of white sulfurous fumes. Once the fuming had stopped he treated the residue with concentrated sulfuric acid and observed that the liquid became pale rose. He then added water and kept the contents warm for two hours. The final liquid was red. After decantation and cooling, he diluted the clear liquid with six parts of water and added one part of NaCl. The resulting solution proved to be an invisible ink, similar to that of Hellot, except that on heating it turned bluish.

Cadet attributed the difference to the foreign material present in the mineral and extracted it in different amounts by the acid (HNO_3 or H_2SO_4).

Encouraged by these results, Cadet repeated the procedure using this time HCl. The reaction was very vigorous; the liquid became first strongly red and then green emerald, and did not release a disagreeable smell. A singular result was that the liquid, which was green when hot, became again strongly red when cooled down, and this process could be repeated as many times as desired.

The next step was to try a mixture of HCl and HNO_3 (aqua regia). Heating it on a sand bath with the calcined mineral yielded a strong red solution, which on cooling became light red wine colored. The cold liquid produced a violet writing on paper, which left to dry turned first into a nice violet color and then into carmine red, which did not disappear. Addition of potassium nitrate or sodium chloride turned the liquid into disappearing ink.

From these results Cadet concluded that the combination of HCl and HNO_3 were absolutely necessary to produce an invisible ink from cobalt.

Cadet also studied the possibility of producing an invisible ink using vinegar (diluted acetic acid). Repeated hot digestion of the calcined mineral with vinegar yielded a liquid that left no marks on paper, but after concentration, marked in light red. Humidifying the writing with traces of HCl transformed the color into blue green, which did not disappear totally.

The next set of experiences was the study of the influence of cupric sulfate on the behavior of the invisible ink. Cadet found that addition of different amounts of a solution of this salt allowed producing ink in a variety of yellow tones, which turned green when adding more ink.

Summarizing his results, Cadet wrote that he believed that the coloring material in cobalt was no other that the metallic part of the mineral because no matter how he treated it with acids, it always colored the ink. He also believed that this semimetal was actually arsenic (one of the names given to white arsenious oxide, As_2O_3) combined with a metallic earth, which he could not identify because it volatilized as a garlic-smelling fume, when in contact with burning coal. These results led Cadet to do further experiments with his "arsenic". He put a mixture of equal weights of "arsenic" and potassium acetate into a small reverbatory furnace connected to a glass receiver, and heated it slowly. The first distillate was a slightly colored liquid with an extremely penetrating garlic odor, followed by a red-brown liquid that filled the receiver with a thick vapor. On continued distillation a black powder sublimed into the neck of the retort, which looked like what the Germans called müscken gift (fly poison, *poison des mouches*); he also found some "arsenic" metal and a material that burned like sulfur when exposed to the flame of a candle. In the neck of retort he also observed a small amount of "arsenic" in the form of small crystals. The distillation residue was a carbonaceous material (white arsenic, As_2O_3), which gave off a garlic odor when heated over hot coals. The first liquid to distill was found to react with caustic alkali with strong effervescence generating a garlic odor so strong that it was impossible to breathe. According to Cadet, the odor remaining in the vessels impregnated with this liquid could not be eliminated with vinegar or other compounds with very strong odors. It only disappeared after exposing the vessel to fresh air during several months. The last liquid to distill, which was red-brown, deposited, after some time, a solid of a beautiful yellow color, which Cadet assumed to be a metallic substance that was entrained during the distillation and, due to its weight, precipitated to the bottom of the first liquid. The two liquids had a light amber tone. When exposed to air they fumed like phosphorus, generating a very strong odor of garlic, and did not catch fire when exposed to a burning candle. Cadet was surprised to find that opening the grease-sealed receiver and exposing the two liquids to the air caused the immediate inflammation of the grease.

Cadet concluded his paper as follows: (1) Cobalt was not the only metallic substance capable of yielding an invisible ink because dissolving copper in nitric acid resulted in a solution that presented the same phenomena of appearance and disappearance, (2) the latter phenomena where caused by the humidity of the air, which dissolved the solid particles of salt and extended on the paper the coloring material causing its appearance, (3) dissolution of the cobalt mineral by mineral acids yielded different metallic salts, which became the coloring salts of the corresponding invisible inks, (4) the coloring matter of copper minerals, intimately united to a glass named *émail des quatre feux*, may be set on fire with the help of alum, and (5) with the help of potassium acetate it was possible to extract from "arsenic" a very particular fuming liquid (*liqueur fumante*), which demonstrated the high volatility of this mineral substance provided by cobalt.[7]

Although Cadet was not aware of the real nature of his fuming liquid (tetramethyldiarsine, cacodyls), his work represents, historically, the first reported synthesis of an organometallic compound.

Guyton de Morveau, Hughes Maret (1726-1786), and Jean-François Durande (1777-1857) corroborated Cadet's results on the preparation and properties of fuming liquid.[31] They repeated Cadet's procedure and then modified it by digesting As_2O_3 with vinegar instead or potassium acetate. The resulting liquid was filtered and then evaporated; during this process the surface of the liquid became covered by a white saline layer that seemed to be the same as the one remaining at the bottom of the flask. The first distillate of a mixture of As_2O_3 and potassium acetate, subjected to the same procedure, was a clear liquid having a penetrating smell of garlic. The second fraction was a reddish brown liquid that filled the receiving flask with a dull cloud and emitted an intolerable odor. After cooling, this liquid continued to fume every time the flask was opened, and spread the same atrocious odor, impossible to neutralize. In addition, when poured on another vessel it inflamed the sealing grease immediately. The same features characterized the semi-solid deposited by the red liquid in the bottom of the flask.

Guyton de Morveau, Maret, and Durande (1732-1794) reported that although they were exposed to the penetrating odor for some time, they did not notice any lasting bad effects except for a very disagreeable irritation of the throat.

The next one to investigate the fuming liquor was Louis Jacques Thenard (1777-1857),[32] who claimed that the gases given off during the distillation of a mixture of As_2O_3 and potassium acetate contained "*l'hydrogène arsènique*" (arsine, AsH_3), carbon dioxide, and hydrocarbons; potassium carbonate remained in the retort and crystals of As_2O_3 were obtained by sublimation. Two liquids distilled, the upper one was a solution of the lower one in aqueous acetic acid. The denser oily liquid had the horrible stench and the spontaneous inflammability in air reported by Cadet. The denser liquid was oxidized with chlorine. From these results Thenard concluded that it was a compound of oil, acetic acid, and arsenic that resembled the one in the metallic state and should be regarded as "*une espèce de savon à base d'acide et d'arsenic ou comme une sorte d'acetite oleo-arsènical*" (a type of soap of acid and arsenic, or as a type of oleo-arsenical acetate).

The next chemist to investigate the nature of the fuming liquor was Robert Wilhelm Bunsen (1811-1899). Bunsen prepared large quantities of the material and separated from it the main component. His results showed that the main component was a substance consisting of arsenic, carbon, hydrogen and oxygen and having the formula $As(CH_3)_2$, which he named *alkarsin*. Further work by Bunsen corrected the formula to $C_4H_{12}As_2O$.[8,9] Berzelius recognized in this component an analogue of the alkali oxides in which the elementary alkali radical is replaced by a compound organic radical, $C_4H_{12}As_2$. Berzelius named the radical *kakodyl* (from the Greek, κακοσ, pernicious, evil, and δζη, odor) on account of the disagreeable stench of its compounds.

Borax

It is presumed that the Babylonians brought borax from the Far East more than four thousand years ago to be used by the goldsmiths. Archeological evidence shows that tinkar (tincal) was first used in the eight century around Mecca and Medina, having been brought there (and to China) by Arab traders. The use of borax flux by European goldsmiths dates back to around the twelfth century.[33] Jean-Antoine Chaptal (1756-1832), in his book about chemistry applied to industry,[34] had already generalized without further analysis the names of materials available in different civilizations which he felt was borax: "*Le nitron baurake des Grecs, le borith des Hébreux, le baurach des Arabes, le boreck des Persans, le burach des Turcs, le borax des Latins, paroissent exprimer une seule et unique substance, le borate de soude des chimistes*" (The nitron baurak of the Greeks, the borith of the Hebrews, the baurack of the Arabians, the boreck of the Persians, the burack of the Turks, the borax of the Latins, all appear to express one and the same substance, the borate of soda). The word *borith* appears in early translations of the Bible, along with other substances like nether, but it is clear that it refers to a cleaning material derived from plants.

For nearly a thousand years prior to the nineteenth century, borax trade was very small, its main use being as a flux in metalworking. It was expensive and this confined it largely to gold and silver smiths, and to jewelers.

In 1702, Wilhelm Homberg (1652-1715) noticed that when borax was heated with green vitriol (ferrous sulfate) a new substance was obtained, which he named sedative salt (later to be known as boric acid).[35] As described by Homberg, he heated borax with a solution of iron vitriol and sublimed off with the water vapor a substance which he called *de sel volatile narcotique du vitriol*. By redistilling the aqueous distillate eight or ten times, Homberg obtained a good yield of sedative salt.[36]

Homberg's discovery started many attempts to resolve the chemical composition of borax. According to Macquer,[37] George Ernst Stahl (1660-1734) showed in 1723 that sedative salt could be prepared by treating borax not only with sulfuric acid but also with other acids. Louis Lemery (1677-1743) made the same discovery five years later but thought that the acid merely combined with the borax to form the sedative salt. In 1732 Claude-Joseph Geoffroy showed that borax had the same basis as Glauber's salt and soda and described the resulting green flame when a solution of sedative salt in alcohol was ignited. Bourdelin believed that the green color was caused by the presence of copper in the sedative salt, but in spite of many trials, he was unable to detect the metal.[36]

Many attempts were made to analyze and classify borax. Hyacinthe Théodore Baron (1707-1787) showed that borax was formed by the combination of marine alkali (soda) with sedative salt.[38] The green flame test for borax caused some further confusion. Chemists associated the green flame with copper, thus originating the old confusion between borax and the copper compound chrysocholla. Cadet also devoted much effort trying to decipher this enigma.[10,11] In his first experiment, he struggled to separate the sedative salt from Dutch borax using sulfuric acid. He concentrated the solution by evaporation and then let it crystallize. To his surprise, he got a few ounces of the salt instead of the several pounds he expected to obtain. He noticed that his salt looked like Epsom salt (magnesium sulfate) because of the form of its crystals and the presence of properties of the sedative salt, which dissolved completely in alcohol and its dissolution produced a green flame. The remaining liquid had converted into Glauber's salt (sodium sulfate). Based on these results, he thought that perhaps the Dutch borax he had used was adulterated with sodium carbonate. Cadet knew that the Dutch borax was more pure than the one coming from China and because of the much dissolution and filtration it had gone during in its purification, it had lost most of the earth that was probably essential for the formation of sedative salt. To remedy this situation he added to the solution a borax flux and enough sulfuric acid to make it very acid; then brought it to boiling several times followed by the crystallizing process. To his satisfaction, he got the expected amount of sedative salt, both from the Dutch and the China borax. To Cadet, these results indicated that the role of sulfuric acid was not only liberation of the sedative salt but also to become part of the salt itself.

After many other experiences to corroborate these findings, Cadet performed some more to prove his belief that the sedative salt contained sulfuric acid and hydrogen chloride combined with the alkaline base of marine salt (sodium) and the vitrifiable earth of borax. To do so, he used the known fact that the best procedure to prepare mercuric chloride (*sublimé corrosive*) was to react pure mercury with a mixture of sulfuric acid and sodium chloride; the acid displaced the chlorine from the salt and the liberated chlorine reacted with mercury. It was also known that mercury combined with sulfuric acid formed a yellow substance known as *turbith mineral* (basic sulfate of mercury, $HgSO_4 . 2HgO$); hence, if both acids were present in sedative salt, their reaction with mercury should produce both products. The results confirmed his predictions. The addition of mercury to the sedative salt produced only the turbid mineral; to prove the presence of hydrogen chloride it was then necessary to add sulfuric acid. This Cadet did by adding alum to the solution and distilling the mixture. To his satisfaction he obtained a sublimate of mercuric chloride.

Cadet summarized his findings stating his belief that copper was one of the essential components of borax, that the acid in borax was actually hydrogen chloride and not sulfuric acid, that the only way to prove the presence of hydrogen chloride in borax was by treating the sedative salt with sulfuric acid and with mercury, that sedative salt as such was not a component of borax, that sulfuric acid not only helped separating the sedative salt from the alkaline base of borax, its main role was to help its formation, that the presence of sulfuric acid in sedative salt was clearly demonstrated by the turbid substance it formed with mercury, that borax contained a white earth, friable and vitrifiable that separated upon solution and was indispensable for its conservation; and finally, that fixed alkalis, combined with sedative salt, constituted a kind of regenerated borax, different from natural borax.[10,11]

The confusing ideas of Cadet and other famous chemists of his time about borax may be partly justified by the fact that the element boron was still to be discovered (1808) by Humphry Davy.[39]

A well-known phenomenon was the property of ammonia of turning blue solutions of any copper salt, independently of the anion. One of Cadet's results was the finding of a copper regulus that was an exception to the rule, and Cadet wanted to decipher how the copper it contained was able to avoid the action of ammonia.[40] The regulus he had extracted seemed to have an arsenical character. Cadet believed that perhaps it was arsenic the factor that guarded the copper from the reaction with ammonia. In order to test this possibility, he prepared mixtures of crystalline copper and arsenic (arsenious oxide), and distilled them in a retort. The distillate was prickly vinegar with a strong smell of garlic. The arsenic sublimed and deposited on the neck of the retort while the arsenical regulus remaining in the retort was quite sour. A solution of the regulus yielded silky crystals, not much different than those given off by a solution of tin in HCl: this solution did not colored in blue under the action of ammonia. Handling these materials made Cadet very sick, and for this reason he turned to use tin substances, which where known to contain a lot of arsenic.

Cadet prepared an alloy of tin and copper (the copper made the tin harder) and turned it into filings, which he dissolved in HCl, obtaining a yellow solution. The solution deposited a black powder, which Cadet recognized as copper liberated from the alloy during its dissolution in HCl. He dissolved this powder in nitric acid, added ammonia and obtained a blue solution. He then added ammonia to the yellow solution and resulted in the precipitation of a yellow precipitate, but no blue coloration. On evaporation it yielded silky crystals.[40]

The high fusibility of the glass obtained from borax, and the property it had of eroding the crucible, similar to that of lead glass, suggested Cadet to mask the copper with the aid of lead glass. To do so, he used sodium carbonate to precipitate the copper contained in a solution of copper sulfate. He first melted a mixture of sand and yellow lead oxide in a crucible and then added the precipitate well washed. The product was a milky glass, which absorbed humidity from the air, yielding green liquor, prickly like a solution of NaOH. Drying it somewhat, it yielded a kind of green-yellow gluten, which on further drying produce a substance looking like borax, which swelled on heating and then vitrified. These properties suggested Cadet to use this flux to facilitate the welding of metals. The results proved that his conjecture was correct. Cadet thought that the swelling of the flux might be due to the HCl that had entered into its formation. To clarify this point, he tried to employ the copper glassy material before being acted by HCl. He now observed that this glass melted without swelling and that he could not obtain a flux from it.

After many additional experiences in this direction, Cadet concluded as follows: (1) HCl combined with different saline substances, vitrifiable or metallic, yields a type of glass that bubbled under the action of fire and bounded like borax, (2) this property was due to the HCl forming part of this glass, which was also found in borax, and (3) the black precipitate obtained during the dissolution of certain tins was not the sulfur or arsenic of tin but the copper that was mixed during the first fusion. The amount of copper found could be used as a measure of the purity of the tin.[40]

In a later work, Cadet studied the properties of sedative salt (boric acid), sodium nitrate, sodium chloride, and sodium acetate in order to determine their differences.[12] Up to then, these four salts had been considered to have the same nature.

According to Baron, sedative salt existed as such in borax and the only role played by vegetable and mineral acids was to release the sedative salt from the alkaline base of sodium chloride. His arguments were based on the fact that purified borax, under the action of sulfuric acid yielded potassium sulfate and sedative salt. Cadet did not agree with this opinion and the experiences he did on the subject tended to dispel the supposition. His results indicated that the sedative salts removed from borax by vinegar (acetic acid), nitric acid, or HCl, had completely different characteristics. For this reason in Cadet's opinion borax should be considered as formed by a copper earth, which existed in crude borax as a separate entity, and by sodium chloride. Hence, the sedative salt was a combination of the earth with the acid employed to decompose borax. Therefore, it was important to improve the technique of borax analysis in order to determine more clearly the true nature of the earth.[12]

Bile

In 1766, the physician Touissaint Bordenave (1728-1782) read to the *Académie* a memoir on the human bile. This secretion, accumulated and kept in the vesicle, flowed under the action of the organ, helped by the breathing movements. It accumulated in larger amounts when the stomach was empty. The vesicular bile was different from that of the liver. Both types of bile evacuated into the duodenum to perform the task for which they were produced. Touissaint did not want to determine the physical facts on the way these fluids acted before having some idea about their composition; for this reason, he requested the help of Cadet and Pia and provided them with five ounces of the material.

The sample did not have a bad smell but had a flat and disagreeable taste. Slow distillation in a retort produced a large amount of phlegm, a little of volatile alkali (ammonia), and a large amount of animal oil.[41] The addition of hydrogen chloride produced abundant effervescence; water was then added and the solution filtered and slowly evaporated. During the latter process a saline layer formed on the surface, which proved to be ammonium chloride.

Since it was very difficult to obtain a large amount of fresh human bile, Cadet and Pia decided to continue their experiences using animal bile, selecting beef bile for this purpose. In their first experiment, Cadet and Pia added fuming hydrogen chloride to the bile and noted the generation of a strong smell of liver of sulfur (a substance mainly consisting of alkali sulfides) and the immediate coagulation of the bile. After a few hours, the coagule became fluid and could be filtered leaving on the paper a small amount of a gelatinous green, almost white, substance. The concentration of the clear green liquid by evaporation precipitated a powder looking like black pepper and which Cadet and Pia identified as the coloring matter of the bile.

In the next experiment, the bile was treated with nitric acid and heated in a sand bath. The green solution was filtered, leaving on the paper a white gelatinous material similar to the one obtained with hydrogen chloride. The liquid was concentrated by evaporation and this time, instead of separating a precipitate, it deposited a yellow resinous substance, which looked like the material that forms on the surface of fresh blood. Further evaporation of the filtered liquid resulted in the precipitation of white quadrangular crystals, shaped like needles. Filtration of the new liquid, followed by evaporation, yielded now a precipitate of white trapezoidal crystals, similar to the ones obtained when using hydrogen chloride.

Cadet summarized his findings as follows: (1) at the beginning of putrefaction, the bile releases a volatile alkali, which is probably not present in the animal body. With the hydrogen chloride contained in the bile this volatile alkali forms a kind of ammonia salt, (2) mineral acids coagulate bile by reacting with the alkali it contains; afterwards, they make it fluid enough to pass through gray paper, (3) bile contains the alkaline salt that is the base of marine salt and is the same as in sodium carbonate; this salt is combined with an animal oil forming a kind of liquid soap, (4) the salts in form of needles that separates with the aid of acids are due to the combination of these acids with a calcareous earth found in the bile; it seems that these calcareous salts are the ones producing bile stones, (5) the trapezoidal crystals that separate from bile serum are very similar to those of sugar milk (lactose), both hardly soluble in water. These crystals do not have the same sweet flavor as lactose. It is probable that they also contribute to the formation of stony concretions, and finally, (6) bile is truly a soap formed by a fat or animal oil and the alkaline base of marine salt. In addition, it contains a salt of the nature of milk and a calcareous earth slightly ferruginous, which is probably the origin of the green and yellow color of bile and its bitter flavor.[41]

Sodium carbonate from algae

Up to the middle of the eighteenth century potassium carbonate (vegetable soda) and sodium carbonate (mineral carbonate) were obtained from natural deposits or from the ashes of certain plants and seaweed. Ashes were produced from wood (*potash or pearl ash*) imported from Eastern Europe and the Colonies; from seaweeds (*kelp*) growing in Scotland, Ireland, Norway, and Northern France, and from Salsola soda (*barilla*), a salty plant growing in the Mediterranean coast of Spain. The two carbonates were an essential raw material for three growing industries: it was used in the textile processing as an alkaline scour in the bleaching of linen and cotton cloth; in glassmaking as a fluxing ingredient to lower the melting point of soda lime glass compositions; and in soap-making.[33,39]

Plants growing in land absorb potassium from the ground and their ashes contain the element in the form of potassium carbonate. Plants growing near or in the sea contain large amounts of magnesium and sodium soluble salts; the latter appears in their ashes as sodium carbonate. High soil salinity is deleterious to normal plants; the ones that survive have done it by developing several physiological features. For example, their leaves have foliar glands that excrete the salts in an active manner; they have also developed a system for accumulating water to avoid the decrease in osmotic potential caused by the increased salt concentration.

Plants resistant to high salinity belong mainly to the genus *Salsola*, *Salicornia*, *Atriplex*, *Statice*, *Chenopodium*, and *Fucus*. The predominant species in Spain is *Salsola soda*, and are usually called *barillas*. In France the corresponding variety belong to the genus Salicornia and the product is called *soda of salicor* or *Blanquette*.

Varek soda was prepared in Normandy and Brittany from different seaweed species, particularly from *Fucus vesiculus* (*goémon*). *Kelp* had the same value as varek and was manufactured in the west coast of England (Scotland, Ireland, and the Orkneys) from different species of Salsolaceas and algae (*Fucus serraturs*, *Fucus nodosus*, *and Laminaria digitata*), and in Jersey Island from *Zostera marina*.

The name *varech* is generally given to all the plants that live in the sea at a low depth and are left on the shore by the low tide. The term varec was also used to design the soda that was prepared from it. The plants used for producing varech were brown algae, particularly of the focus variety; the *goémons* (seaweed) included various species of Fucus and Laminaria, depending on the sea depth from which they were collected. All the algae species contained, after calcination and treatment, the carbonates, chlorides, sulfates, bromides and iodides of sodium, potassium, magnesium, and calcium. Kelp is a mixture of sodium carbonate, sodium chloride, sodium sulfate, magnesium sulfate, magnesium chloride, and other minor constituents. In those days, some of these components were as valuable as sodium carbonate, hence more intrinsic value per unit weight. For example, some samples of kelp contained up to 25% of sodium chloride, an essential ingredient for manufacturing soap that could be obtained without paying for the salt excise. Similarly, glassmakers were not taxed by the presence of salt unless a very high percentage was present. Even the insoluble residue of kelp was valued as manure.

In the seventeenth century, French peasants began manufacturing soda, first from brown rockweeds and then from oarweeds, to use it in the glazing of pottery and in glass manufacture. The resulting ashes were called *kelp* in Scotland and *varec*, *soude de varech*, or *varech* in France. Several brown seaweeds were employed in the manufacture of kelp, the most common being the species of *Laminaria* and *Saccorhiza polyschides*, particularly in those places where storms deposit them in large amounts on the coast.

The kelp soda was a substitute for the expensive substance called *barilla soda* or *salichord*, which was prepared, especially in Alicante, Spain, from certain coastal salt-rich plants. The kelp manufacturing process was very simple. The seaweed was gathered from the sea and then dried in the sun during the summer months. For this reason, the process was limited to a few months during the year. After drying, the seaweed was burned in sand pits, taking care that the burning process be as lively as possible to so that the ashes would agglomerate. The burning process caused iodine losses and the burning process in the sand pits also caused an increase of impurities. All these resulted in a variable composition of the finished product. The ash consisted of a mixture of charcoal, iodides and other salts (sulfates, carbonates, chlorides, etc.) of sodium, potassium, and magnesium.

The sodium carbonate prepared from algae was very different from the one prepared from natural sources, it had a very salty taste and a strong smell of sulfur hepar. Kali did not smell and had a burning acrid taste. End consumers used the smell property to detect if the natural soda was adulterated with varech soda, of lower value and quality. This was the motive which led Cadet to study in detail the properties of varech soda.

Cadet dissolved varech ashes with water, boiled the mixture for some time, and then filtered the liquor.[27] During evaporation he observed that the iron spatula he was using to agitate the liquid became covered with a green precipitate, which on drying became red. Cadet believed that this solid was composed of a blue substance, which was present even in the best soda, combined with a yellow ferruginous earth. To test his hypothesis he mixed a part of the solution with nitric acid, to absorb the earth. To his surprise he noted the appearance of yellow flakes, which he recognized as pure sulfur. Cadet commented that it was not hard to understand how a liquid containing sulfur and alkali carbonate had acquired the smell of *hepar sulphuris* (liver of sulfur, a mixture of various compounds of potassium and sulfur made by fusing potassium carbonate and sulfur). He added that other chemists had already reported the extraction of a blue material from the barilla soda.

The evaporation of the liquor also produced a precipitate of cubic crystals, which Cadet identified as sodium chloride. The result of the addition of cream of tartar (potassium hydrogen tartrate) to the liquor prepared with barilla soda or with varech soda, showed an important difference between the two carbonates: the later was able to dissolve a much smaller amount of tartar, meaning that varech soda was not appropriate for preparing Seignette's salt (Rochelle's salt, a double tartrate of sodium and potassium, used in medicine as a laxative and in the process of silvering mirrors).

From all his experiments, Cadet concluded that varech soda was substantially different from barilla soda in (1) having a penetrating smell of hepar sulfuris and precipitating sulfur when mixed with acids, (2) containing potassium sulfate, a substance absent in barilla soda, and (3) containing much more sodium chloride and less sodium carbonate. The last property suggested that varech soda should not be appropriate to use in the manufacture of soap and in bleaching operations.[27]

Henri Louis Duhamel du Monceau (1700-1781) had reported that certain plants degenerated when planted in soils different from their natural habitat.[42] He was particularly interested in studying what happened to barilla (growing in the seashore of Alicante) when planted inland, and for this purpose he requested Cadet's help in analyzing the ashes of several generations of growth inland. Cadet reported that as the generations went on the content of sodium carbonate decreased successively until it disappeared completely.[28]

Separation

Many well-known chemists, such as Georg Brandt (1694-1768), Henrik Theophilus Scheffer (1710-1759), and Torbern Olof Bergman (1735-1784), had suggested that highly pure nitric acid was capable of dissolving a certain amount of gold, and this effect seemed to influence the security of the important operation of silver purification. The Mint administration submitted to the *Académie* several questions on the subject, requesting an answer. Consequently, the *Académie* charged the *Class de Chimie* to get busy with the subject and perform the necessary experiments to answer the query in the most precise manner. A committee was appointed for this purpose, composed by Macquer, Cadet, Lavoisier, Baumé, Claude-Melchior Cornette (1744-1794), and Berthollet.

The silver purification process consisted on separating with the maximum efficiency alloys of silver and gold. The procedure was based on the property that nitric acid dissolved silver completely and did *not* dissolve gold. The operation was performed using large amounts of alloy, or on a very small scale, on a small sample taken from a bullion of alloy, in order to determine the proportion of both metals in the ingot, and hence, the gold titre of the same. The question posed to the committee was then to determine if the claims mentioned above, could influence the acid test that expert jewellers normally used to check the purity of gold. In the acid test, the gem is rubbed on a black, hard and slightly abrasive touchstone, so as to leave a slight trace of metal, which is then subject to the acid test. An alloy containing less than 9 to 10 carat becomes rapidly green when reacting with nitric acid. Gold, up to 18 carats is tested with aqua regia that quickly dissolves other metals, slowly leaving a golden trail and then more gold.

The committee performed many tests, using alloys of different composition, and treating them with highly concentrated nitric acid, under different conditions. The results were negative; in no case they detected a decrease in the amount of gold.[43]

Ether

Ether was one of the most important substances that interested the chemists of the first half of the 18th century. It had attracted the attention of Daniel Newton, who around 1730 had published a procedure for its preparation. According to Jean Hellot (1685-1766), ether, the most volatile and most inflammable of all known liquids, was known through the efforts of Duhamel and Johann Grosse, who in 1734 published its composition and the procedure for manufacturing it.[44] The ethereal liquor was obtained by heating gently a mixture of one part of white concentrated sulfuric acid and two parts of rectified wine sprit. After a few hours the mixture became red, even when using the best wine sprit. The retort was then heated in a sand bath and the different distillate fractions collected. Hellot used the procedure of Duhamel and Grosse and examined all the fractions besides that of ether, which had been the sole objective of Duhamel and Grosse's memoir. The first fraction was a flammable acid liquid, which Johann Heinrich Pott (1692-1777) had named *acide vitriolique vineux*, and proved to be only slightly related to ether. Other German scientists had named it *spiritus naphthœ*, because it caught fire immediately when coming near a lit candle. Hellot proposed naming it *sprit acide vineux* to distinguish it from the ether or other Frobenius' liquor fraction, which was even more volatile and more flammable. Hellot showed that employing an alkaline earth intermediate it was possible to prepare ether very easily, without appearance of the oil, black froth, or the sulfurous fraction.

By the middle of the 18th century, ether had become an important chemical product, used in large quantities in chemistry and medicine. Unfortunately the available manufacturing methods were rather costly because the sulfuric acid was used only once, and not recycled. For this reason, Cadet begun his experiments looking for a cheaper procedure for synthesizing the chemical.[14] The improvement he proposed was based not on modifications of the standard procedure, but on the equipment used and the mode of operating it. He mixed equal weights of white sulfuric acid and spirit of wine well rectified and let the mixture stand for some time to allow the settling of *arcanum duplicatum* (potassium sulfate, an impurity that came from the procedure used for preparing sulfuric acid, or from bleaching it). The mixture was then filtered and the clear liquid put in a glass retort heated in a sand bath. The novelty was that Cadet installed in the upper part of the retort a glass cap, which was carefully sealed during the operation and was taken out to pour fresh spirit of wine. The time to add the new portion of alcohol was when the retort begun to fill with white vapors. This procedure implicated a substantial economy in sulfuric acid, which resulted in the ether being prized at one-sixth compared to that obtained by the traditional methods.

Burning lenses

According to Smeaton,[45] during the seventeenth century concave mirrors or convex lenses were occasionally used by chemists to produce a high temperature by bringing the sun's rays to a focus. They had the advantage over charcoal furnaces that there was no risk of contaminating the reaction vessel with fumes or ash and a substance could be heated in glass, which would melt in a furnace.

An important use of this technique was made by Macquer and Baumé.[46] After many fruitless attempts to melt platinum using a variety of techniques; they decided to try heating a small portion of it in the focus of a burning mirror (concave spherical mirror, *miroir ardent*), a method that no one had tried before. They used a silver glass mirror belonging to the Abbé Bouriot, 22 in diameter and with a focal length of 28 in. With it they were able to melt the metal in a few places; the liquid globules produced remained attached to the mass and solidified as soon as they were moved out of the focus of the mirror.

In 1702, Phillipe, Duke of Orleans, bought a large burning glass manufactured by Ehrenfried Walter von Tschirnhaus (1651-1708), which initially was used by Guillaume Homberg (1652-1715) and afterwards stored as a curiosity in the basement of the *Académie*. In July 1772 Cadet, with the support of Mathurin Jacques Brisson (1723-1806), requested permission from the *Académie* for the use of the great lens. The *Académie* agreed and asked Macquer and Lavoisier to join a committee to take part in the proposed experiments. The apparatus was set up in the *Jardin de l'Infante* together with another Tschirnhausen lens owned by the *Comte de la Tour d'Auvergne*, and the investigation began in mid-August. A small piece of native platinum was exposed to the heat of the *Tour d'Auvergne lens*, and Lavoisier described the result in these words: "The sky being but little favorable because of many light clouds, the platinum exposed for 24 min, did not melt but softened and agglomerated more than it had done in earlier experiments and was still attracted by a magnet". On the 29th of the same month a further trial again resulted only in agglomeration, while on September 5th, as Lavoisier describes it: "a small mass of platinum, strongly agglutinated, that had already been exposed twice in the fire, exposed for 22 min in strong sunlight, hardly changed".

In 1773, Macquer, Cadet, Lavosisier, and Brisson reported to the *Académie* the results of the experiments they had done on the action of burning lens on different substances. The contents of this report were also included in a memoir read in 1774, by Jean Charles Philibert Trudaine de Montigny (1733-1777).[47] The Tschirnhausen lenses did not give satisfactory results; they contained bubbles, striations and other defects, and allowed testing only small amounts of the specimens. The group felt that a better effect would be obtained with an apparatus consisting of two large pieces of glass with a curvature forming part of a sphere, joined at their circumferences and then filled with alcohol (see below). Trudaine de Montigny took up this suggestion and provided the necessary funds for building such a lens. The actual construction was carried on by Nicolas de Bernières, the Contrôleur des Ponts et Chaussées, using the glass made in a newly built furnace in the Paris works of Saint Gobain. De Berniéres had already been able to bend large pieces of glass and polish them uniformly. The great lens was four feet in diameter, against the three feet of the Tschirnhausen lenses, and was mounted in such away as to allow following the movement of the sun and be operated by only one person. The focal length was ten feet, at which point the light was so strong as to harm the eyes of the observer, and a smaller lens was arranged to concentrate the sun's rays still further. The cavity was filled with wine spirit because it had a larger refractive power than water; it did not leave a deposit, and would not freeze.

After making many experiments to determine the best arrangement of the different parts, the best manner to operate the apparatus, as well as its optical characteristics, the group put it into formal operation at around midday on October 5 and proceeded to test it with different materials (charcoal, metal coins, cast iron, steel, silver, and platinum grains). All the metals melted readily, but once again no success was obtained with platinum: "Having exposed to the fire some grains of platinum in a carbon cavity it appeared to congregate and to be reduced in volume and to be about to melt. A little later it bubbled and fumed and all the grains united into a single mass, but without forming a spherical button as with the other metals. After this kind of semi-fusion the platinum was no longer attracted by a magnet as it had been before exposed to the action of the sun".[47]

Another use of the technique was as part of the discussion regarding the possibility of burning diamond. In 1771 Jean Darcet (1725-1801) had heated a diamond in a crucible in Macquer's furnace and noticed that after 20 min the diamond appeared to be enveloped in a small pale flame. When the experiment was repeated for a longer time, it was found that the diamond had been completely destroyed. This was a surprising result because jewelers were accustomed to remove or diminish flaws from diamonds by exposing them to a strong heat for some time. In a following experiment, done in 1771 by Hilaire-Marin Rouelle (1718-1779), a diamond covered with a paste of chalk and charcoal, was heated in the furnace and seen to *vanish* completely. This fact suggested that its destruction was due to volatilization rather than to combustion, or decrepitation into fragments to small too be observed.

Lavoisier invited Cadet and Macquer to assist him in performing additional experiments to clarify the doubt. The method adopted was to heat the diamond in such an apparatus that whatever was given off could be collected either by distillation or by sublimation in the cooler parts of the apparatus. They were, however, unable to detect any product.[17,48] When a diamond was subjected to the heat from the Académie's large burning glass,[17] it decrepitated and split up into many fragments, some so tiny that could not be seen with the naked eye. Heating the diamond slowly, it disappeared without giving off any smell or visible fumes. When it was burned in a closed vessel by means of the glass in an apparatus designed by Lavoisier, it was found that a part of the air in the vessel disappeared, as it was the case with other combustible bodies. Limewater was subsequently added and seen to turned milky and deposited a precipitate.[18]

In 1797, Guyton de Morveau heated diamond in oxygen under a bell jar, using first a 40.59 cm lens with an auxiliary lens. The diamond burnt when the sun rays were focused on it, but the thick glass of the bell jar cracked and the experiment was abandoned. In 1798, the experiment was repeated with a diamond immersed in an atmosphere of pure oxygen contained in a thin glass globe over mercury, using the Tschirnhausen lens. This time the diamond was completely consumed and transformed into CO_2. Guyton found that the diamond yielded more CO_2 than an equal weight of charcoal and thus concluded that diamond was pure carbon and charcoal a lower oxide of the element.[49] Further experiments by Guyton, Jean Nicolas Pierre Hachette (1769-1834), and others still indicated that charcoal was an oxide of diamond.[50]

In a following work, Cadet and Brisson decided to study in detail the constructional features of the liquid burning lenses to find if they could improve their performance and perhaps reduce their dimensions.[51] In order to make this instrument as powerful as possible, it is necessary to fill it with a liquid having the largest refractive power. The main purpose of Cadet and Brisson work was to use the same lens to compare the refractive power of different liquids. Although some of the liquids could not be used for burning purposes because of their color, their corrosiveness, etc., they might, one day, help provide an explanation for the refraction of light, a phenomenon about which so little was known.

Cadet and Brisson employed a liquid lens formed of two spherical glass caps, leaving between them a lenticular cavity having a diameter of five pouces and eight lines (1 pouce = 2.707 cm = 12 lignes; 1 ligne = 0.216 77 cm) and nine pouces radius of curvature. The operational technique consisted in filling the lens with a given liquid, observes the same object, located it at a given distance from the lens, and to judge its capability by the focal distance required to observe its image distinctly.

In the first series of experiments they used aqueous solutions of salts such as potassium nitrate, sodium chloride, sodium sulfate, magnesium sulfate, potassium sodium tartrate, and zinc sulfate. Of the thirteen salts investigated, only sodium chloride and ammonium chloride had an effect larger than that of wine spirit. The second series of experiments involved liquids such as filtered milk serum, ammonia, vegetable and mineral acids, olive oil, essential oils (lavender, turpentine, thyme, etc.), and ethyl ether. In both series, the solutes affected the refraction of light because of their different solubility (the more soluble, the larger the density of the solution), and the nature of their composition. The results indicated that the refractive power of vegetable acids, ammonia, and ether was lower than that of wine spirit, those of mineral acids was even larger but their corrosiveness prevented their use; the largest effect was caused by oily materials. The latter, although substantially less dense than the other liquids tested, had a considerable refractive power, although their transparency was low.

Based on these results, Cadet and Brisson concentrated their efforts on the essential oils, in spite of their being quite expensive and very colored. Among those that could be used in practice, turpentine oil seemed to provide much transparency with a very strong refringency; it reduced by more than 27 pouces the focal distance obtained with wine alcohol. It had the additional advantage of low cost and availability in large quantities, although it had the serious disadvantage of producing a large dispersion of the rays. For this reason, Cadet and Brisson thought that turpentine could be used only with flint glass, a product hard to obtain with a uniform density and without defects, particularly in large pieces.

Cadet and Brisson noting the strong dispersion of turpentine, suggested to fill with it the glasses and to substitute the lenses thus formed by objectives of flint glass.[51]

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