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Jean Henri Hassenfratz

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Life and career

Jean-Henri Hassenfratz was born in Montmartre (Paris) on December 27th, 1755, the eldest son of Jean Hassenfratz and Marie-Marguerite Dagommer. Both parents were originally wine merchants, and afterwards owners of the well-known large tavern *Grand Salon*. There were three other children, Marie-Catherine, Jean-Charles, and Jean-Louis.[1,2]

From an early age Jean-Henri showed the adventurous nature, which would characterize his life. Little is known about his early education and probably he did not have a formal one, except that he was an ambitious autodidact. When he was 14-16, he took a boat to Martinique Island, where he stayed for 6 years. After his return to France, he first dedicated himself to the practical application of arts, then worked as colorist apprentice in an industry for printing calico in St. Denis, and afterwards, as a carpenter studying under Nicolas Fourneau (1726-1792).[1] As a young man, he always tried to cultivate the friendship of important and educated people. Thus, in 1778, he became a geography student at the atelier of the chevalier Jean-Baptiste Beaurain (1730-?), the King's geographer. Soon aware of the abilities of his new pupil, Beaurain commissioned him to publish a map of all the battles that took place during the taking of Dominique. This 12-page long work was published under the name *Détail de la Prise de la Dominique*.[3] Afterwards, Hassenfratz continued his cartography studies under Jean chevalier de Champigny (1712-1787), who introduced him to the two young sons of the marquis de Serent (1736-1823). Thanks to Serent, he was able to participate in the 1779 military maneuvers of Saint Omer. There, he met the mathematician Gaspard Monge (1746-1818) and promptly followed his courses in 1780-1781. The marquis de Serent gave Hassenfratz a certificate validating his military services in the camp of St. Omer and specifying that Hassenfratz had been attached to the chief of staff under the orders of the chevalier de Coigny, field marshal of logistics, and employed by the latter as engineer-geographer to follow all the maneuvers and draw up the plans. Beaurain helped Hassenfratz obtain the appointment of geographer engineer of the regiment Dragons de la Reine in 1781 and that of as professor of physics in the same.[1,2]

Pretty soon Hassenfratz changed directions again. He became a friend of Balthazar Sage (1740-1824) who allowed him to become a member of the first student promotion of the École des Mines. In 1782 he was named a mining student, first grade, at the Service des Mines and sent by the French government on a mission to Styria and Carinthia in Austria to study the art of iron and steel fabrication (1783-1784). He used this trip to travel through Germany for the same purpose and to carry out large number of mineralogical observations, which he communicated to Antoine-Laurent Lavoisier (1743-1794). He returned to Paris late in 1784 and in January 1785 he was appointed *sous-inspector* (sub-inspector) of Mines. In 1786, Hassenfratz read to the Académie a memoir regarding the decomposition of pyrites in their minerals[4], resulting from his visit to a mine located in Schemnitz, Hungary, an area noted as mining center since Roman times.[1,2]

In the 1780's, Monge introduced Hassenfratz to Lavoisier who appointed him director of his laboratory. Between 1786-1787, Hassenfratz worked with Lavoisier on Prussian blue, took part in the controversy about phlogiston, collaborated in the writing of *Descriptions des Arts et Métiers*, an encyclopedia dedicated to collect and spread artisanal knowledge and up to 1792 he published profusely in *Annales de chimie*, a journal he had helped to found.[2] In 1786, Lavoisier presented Jean-Henri as candidate for membership in the *Académie des Sciences*, a proposal that failed (several posterior trials also failed). During 1790 Hassenfratz studied the distillation of wood[5], had numerous experiences related to the growing of trees, visited the forges, particularly those directed by the master forger Rambourg, and published, with Pierre August Adet (1763-1832) a memoir proposing a new chemical notation following the nomenclature of Louis-Bernard Guyton de Morveau (1737-1816), Lavoisier, Antoine-François Fourcroy (1750-1809), and Claude-Louis Berthollet (1748-1822).[2,6-8] In addition, Hassenfratz taught physics at the *École des Mines* from 1786 to 1788. At about the same time he was admitted to the Freemasons. Thanks to the support of Fourcroy and Pierre Jean Claude Mauduyt de la Varenne (1732-1792) he was appointed corresponding member of the *Société Royale de Médecine* (1783).

Sometime after the fall of the Bastille, a group of intellectuals and scientists (among them, Lavoisier, Monge, Vandermonde, Condorcet, and the Duke of Rochefoucauld) decided to found a fleeting institution (the Club of 1789), with the purpose of publishing instruction material for the political institutions. In 1790, Hassenfratz became a member of the Club and published, under the its journal column "Variétés" of, popular articles about new industrial processes and their economic aspects, e.g., mining economics, recuperation of metals from bells, manufacture of soda from marine salt, etc. Between 1791 and 1793, Lavoisier and Hassenfratz were among the 30 members of the *Bureau de Consultation des Arts et Métiers* entrusted by the government to evaluate, certify, and eventually reward technical inventions presented in the different arts.[1,2,9]

Hassenfratz was one of the many striving and intelligent young men who felt discouraged by the impasse situation of the old *régime* and, with the break of the French Revolution, became passionate with the new ideas and engaged deeply in the political arena. In 1790, he published a *Manuel militaire de l'infanterie, cavalerie et artillerie nationale*[10] and in 1792 he became a member of the *Société Patriotique du Luxembourg*, founded by Jean-Nicolas Pache (1746-1823) and Monge. In August 1792 he became a member of the Commune de Paris (1792) and afterwards (1793), Pache, the Minister of War, appointed him director of the administration of war material at the Ministry. As a very active Jacobin, he was deeply involved in the revolutionary events of 1792-1793, especially during the famous day of May 31, 1793 which led to the fall of the Girondins (His actions during May 31, 1793 would become the source of heavy criticism that would haunt him the rest of his career). He also contributed to the debate on public education by advancing technical training.[2,9,11,12]

In 1794, the Committee of Public Safety appointed Monge and Hassenfratz to organize the new Manufacture d'Armes of Paris (charged with manufacturing weapons for the defense of France), the mining corps, and its *École des Mines*. He was also appointed professor of general physics at the *École Polytechnique*, which was founded at the end of the year. He became head of the faubourg *Saint-Marceau* during the insurrection of the 1er prairial year III (20 May 1795). In spite of the support of *Prieur de la Côte-d'Or* (1763-1832) and Monge, he would exile himself to Sudan until after he was granted freedom thanks to a law voted by the Convention before its dissolution.[1,9] He later took refuge in Sedan to escape prosecution by the Thermidorians (The Revolution of Thermidor, was the name given to the coup of 9 Thermidor, July 27, 1794, in which Maximilien Robespierre was guillotined and the Reign of Terror ended).[1] After his return to Paris, in October 1795, Hassenfratz became then a full time teacher of physics and chemistry; professor of metallurgy at the *École des Mines* (until 1822) and instituteur of general physics at the *École Centrale des Travaux Publics*.[9] Towards the same period, he was promoted to *inspecteur des mines*.

The consequences of Hassenfratz's activities in all the bloody events that occurred during the turbulent stages of the French Revolution have been judged by many in extremely opposite manner. For example, Michaud[13] wrote "*during the first stage of the Revolution Hassenfratz assumed the most violent principles, nevertheless in 1794 he affiliated with the monarchist club headed by de Clermont-Tonnerre…from where he was soon expelled…After the terrible events of August 10th, 1779, Hassenfratz was one of the members of the commune of Saint-Marceau, that took audaciously cover under the power and use it to carry out terrible acts…*" On the other hand, Arnault *et al*.[1] wrote that "*during the night of the 29 to the 30 of May, when the large coups were to take place, Hassenfratz tried to postpone them for a few hours…The conspirators presented a petition in which they requested the arrest of 32 deputies…Hassenfratz was able to erase from the list Baudin des Ardennes and many of his friends…*"

Hassenfratz designed the first course of Technology given in France and played a role in every first curriculum put into action by the *École* of Monge, the future *École Polytechnique*, and the Conservatoire des Arts et Métiers. In 1791 Hassenfratz was admitted to the *Société d'Histoire Naturelle*.

During the reorganization of the corps of mine engineers decreed by Napoleon, he was nominated ingénieur divisionnaire in 1810, a position he kept until his retirement in 1822. He taught General Physics at the *École Polytechnique* until the return of the Bourbons.[14,15] He also taught Celestial Physics,[16] Elements of Machines, Mine Operations,[17] Fortifications, etc. None of these courses was a success with his students. Judging from his publications and books, Hassenfratz, did not seem to have been bitten by the bug of mathematics, as viciously described by François Arago (1785-1853) during his course of 1805: "*As I have been led to speak of the school (École Polytechnique) as it was in 1804, I will say that its faults were less those of organization than those of personal management; for many of the professors were much below their office, a fact which gave rise to somewhat ridiculous scenes. The pupils, for example, having observed the insufficiency of M. Hassenfratz in making a demonstration of the dimensions of the rainbow, full of errors of calculation, but in which the one compensated the other so that the final result was true. The professor (Hassenfratz) who had only this result whereby to judge the goodness of the answer, when he saw it appear on the board, did not hesitate to call out, Good, good, perfectly good! which excited only shouts of laughter on all the benches of the amphitheatre. When he professor has lost consideration, without which it is impossible for him to do well, they (the students) allow themselves to insult him to an incredible extent*".[18] This situation was a reflection of the basic teaching philosophy at the *École Polytechnique* during its early years: highbrow science, with little consideration for technology and the professions. Basic sciences were a purpose, not a tool; every application had to been sustained by a theoretical explanation.

Hassenfratz was invited to submit his resignation in 1814, while being appointed emeritus professor with rights to pension. In 1815, these benefits were withdrawn in 1815, after the 100 d of Napoleon.

The French government, during the occupation of Savoy, transferred the *École des Mines,* from Paris to *Moûtiers,* in order to instruct young men in the arts of mineralogy and metallurgy (The *École* was returned to Paris after the *Restoration*). Three professors were appointed to the teaching staff: Arsène Nicolas Baillet du Belloy (1765-1845), for teaching mining technologies, André Jean Marie Brochant de Villiers (1772-1840), mineralogy and geology, and Hassenfratz, chemistry. There Hassenfratz organized the practical work in chemistry and published his masterpiece: *La Sidérotechnie, ou l'Art de Traiter les Minerais de Fer*.[19]

At the beginning of the decline of his political status, Hassenfratz was living, unmarried, with Josephine Terreux (1765-1839); they had a three-year old daughter, Virginie-Josephine, and Antoinette was expecting her second child (Henri). In order to limit the possible damages to his family caused by his political downfall, he married Antoinette in 1795. Through this marriage Hassenfratz became the brother-in-law of Pierre Baudin (1748-1799), afterwards known as Baudin des Ardennes, deputy of the *Législative*, the well-known thermidorien who was the last president of the Convention.[2]

Hassenfratz passed away in Paris, on February 24, 1827, and was buried in the *Père Lachaise cemetery* (51$^{\text{ème}}$ division). His wife and two children survived him.

Contributions

Hassenfratz published over 100 papers, reports on papers of other scientists, and several books on a variety of subjects reflecting the many interests he had developed during his career. [6,8,11,16,19-23]

Economic geography

Between the many social, economical, educational, and legal changes that took place in France as a result of the Revolution of 1789, was the property tax decreed by the Constituent Assembly to be imposed on all the assets, and distributed proportionally to substitute all the levies that had been imposed by the old regime. This territorial tax fell on all owners and put an end to all fiscal privileges, particularly to the nobility and the Church. In order to apply it was first necessary to establish a tax basis and carry out an inventory of all the land property. On September 1791 the Constituent Assembly ordered the establishment of a special bureau to carry out a national cadastre and an evaluation of the potential income from all real estate, particularly the agricultural one. Gaspard Riche de Prony (1755-1839) a member of the *Académie,* a geometer, a surveyor, and expert in public works, was appointed director of the Bureau, and Hassenfratz sub-director in charge of classifying the terrains and designing the procedures for evaluating the potential income of the properties. In this enormous task, and in the absence of reliable information, Hassenfratz's goal was, on one hand, to establish the criteria for classifying the cultivated lands according to their agricultural quality, and on the other hand, to define the economical parameters that differentiated between exploitations of the same nature. As described by Grison,[2] Hassenfratz thought in the beginning to request from every canton samples of all the cultivated lands, the varieties of cultivars (wheat, rye, alfalfa, vineyard, etc.) being exploited, and all the necessary information about the structure of the pertinent soils. With all these data, he planned to build a Geoponic Atlas of France. Hassenfratz understood that the absolute value of a piece of landed depended not only on the nature of its soil, but also on other factors such as availability of water resources, dryness, irrigation, and permanent inundation. Here Hassenfratz introduced a new nomenclature, the degree of *marécagite,* which measured the number of days per year during which the land was flooded. If the owner had invested money to eliminate the causes of *marécagation,* he would then be credited accordingly in order not to penalize his enterprise. The next step was to consider the true agricultural exploitation and the cultivars liable for tax, a burden that had to be equitable and applicable only to the effective benefit. Unfortunately, the typical French farmer hardly knew how to read and write and, hence, was unable to present an accounting report. It seemed then necessary to be satisfied with an approximation, an approach that Hassenfratz felt was far from reflecting the economic reality he was looking for. Hence, his proposal that the communes themselves carried out this work.[2]

Hassenfratz concluded his memoir "*Sur l'Évaluation du Produit Net*" with a set of tables, which would be sent to each municipality for the above purposes. [2]

On March 9th, 1792, Hassenfratz presented to the *Assemblée Nationale* with copy of the book *Géographie Élémentaire*[20] he had just finished editing. In his letter to the president of the Assemblée he wrote: "*Public instruction lacks an elementary geography adapted to the new French Constitution and to the spirit of equality and freedom now prevalent among us. Pressed more by my patriotism than by the efforts and enlightenment that this work requires, I have tried to delineate to the French geographers a new road, more akin to our principles. The elimination of the privileges has entrained with them a prejudice that moves away from commerce all the affluent people, and the fortune class of the citizens is now addressed to their speculations towards the means of increasing their wealth and France's prosperity. I have felt the need to make known the agricultural and commercial products of other countries, in order to familiarize the youth young with the ideas of industrial relations that the French may have with the different countries that cover the surface of the earth. The purpose of my publication is, on one hand, to present the new geographic cadre of the country, the departments, and on the other, to inaugurate an economic geography, to complete the physical one*". [2]

Chemistry

The search for the composition of blue of Prussia was a hot chemistry subject in 1786. What was the dyeing substance of this beautiful dye which had been accidentally discovered by Heinrich Diesbach about 60 years before. Its composition was unknown and its mode of preparation was highly empirical: "*Mix in a crucible, equal parts of bull blood and KOH and then heat to red. Add the residue to boiling water, followed by the addition of a solution of iron and alum sulfate. Wash the resulting blue precipitate*".[2] Its unknown principle was called prussite or prussiate, without knowing what was prussic acid. Johann Friedrich Westrumb (1751-1819) had found that the coloring matter contained phosphates and hence concluded that the coloring mater was phosphoric acid. It was known that phosphoric acid and iron were present in blood and that alkali released the phosphoric acid from blood and dissolved a little of the iron. Nevertheless, Hassenfratz in a letter addressed to Jean-Claude La Métherie (1743-1817), expressed his doubts that phosphoric acid was the coloring dye. If this was so, the synthesis of blue of Prussia should be very easy, contrary to his experience.[24] He had prepared the dye by fusing a mixture of wood charcoal and vegetable alkali, dissolving the resulting mixture in water and adding nitric or hydrogen chloride to the solution.[2]

Hassenfratz continued working on the subject and reported his results in two memoirs.[25,26] In the opening statement of his first memoir,[25] the stated that its purpose was to answer the question why all marshy iron mines, which were always found in terrains that he had named modern primitive or modern secondary, were shown to contain phosphoric acid, while all the other mines exploited in the so-called ancient or volcanic terrains, showed no presence of this acid. It was known that all iron minerals dissolved in an acid and then precipitated by alkali, combined with the dyeing substance of Prussian blue to produce iron phosphate (*sydérite*). Some chemists believed that the phosphoric acid contained in this new combination had been released by the mineral and that the presence of the prussiate was absolutely necessary to make the acid sensitive. For these reasons, Hassenfratz's first objective was related to the dyeing matter of Prussian blue, not the determination of its nature and components, but to find if phosphoric acid was one of its constituents. He divided this stage into two parts: (a) to determine if all Prussian blues contained or not phosphoric acid, (b) to determine if phosphoric acid was a constituent of Prussian blue or simply an accidental component.

Hassenfratz prepared the prussiates by melting potassium hydroxide with different vegetable substances, such as potatoes, mushrooms, soot, wood carbon, and bitumen. All the Prussian blues thus prepared from animal, vegetable, or mineral substances yielded iron phosphate. He observed that spraying ammonium chloride over a semi melted mixture of wood carbon and potassium caused its instant decomposition and a strong smell of muriatic acid gas (HCl) as well as the inflammation of the hydrogen generated. These two phenomena were critical for determining if the fusion of wood carbon with KOH yielded prussiate: if the inflammation did not take place after spraying, a strong odor of ammonia was felt and the alkaline dissolution was unable to precipitate the iron in Prussian blue. The stronger the inflammation, the larger the amount of precipitate formed.[5]

Hassenfratz believed that it was natural to assume that the iron phosphate obtained from commercial Prussian blue originated from the phosphoric acid present in the animal substances used in its preparation (urine, bones, horns, blood, beef meat, etc. etc.). So, he followed Scheele's procedure to eliminate all traces of phosphorus present in the commercial dye. The dye was first dissolved in water and then boiled together with mercuric oxide (red mercury oxide). The resulting mixture was filtered, treated with sulfuric acid and after some days distilled over calcium carbonate. Addition of iron precipitated Prussian blue without indication of phosphoric acid. In other words, the presence of phosphoric acid was accidental; it was not a constituent of the dye. Hassenfratz concluded that all non-purified commercial Prussian blues produced iron phosphate; that it was possible to produce it by employing coal instead of bull blood; that all the known materials which were fused with alkali to produce the dye, particularly wood, wood charcoal, and coal, contained combined phosphoric acid, and that it was possible to prepare Prussian blue free of phosphoric acid.[25]

In his second memoir,[26] Hassenfratz examined the combinations of phosphoric acid with different iron minerals and the different varieties of the metal. The minerals came from different terrains (according to his classification): ancient, modern primitive, modern secondary, and volcanic. His results indicated that phosphorus was not present in minerals originating from ancient terrains but did so in minerals originating from more recent formations (modern secondary and volcanic terrains). All the latter were characterized by the presence of a modern deposition caused by water. From this particularity he inferred that the phosphorus originated from the decomposition of the vegetables and marine species growing in water. To verify this hypothesis, Hassenfratz proceeded to analyze twelve species of plants growing in swampy terrains and found that all of them contained oxalic and phosphoric acids.

He then analyzed the different varieties of iron metal: cast iron, wrought iron, and steel. It was known that cast iron contained iron, oxygen and carbon, steel contained iron and carbon, and wrought iron only iron. Each of these existed in different varieties, depending on the proportion of their components. All of them were found to contain phosphorus in different amounts, although, some were prepared from minerals that did not contain the element. Hence, it was easy to understand that the phosphorus present in the latter had originated from the charcoal employed in their elaboration, and that the quality of the charcoal (or coal), influenced the properties of the resulting metal.[26]

This work would lead Hassenfratz into the field of iron and steel industry, where he would make his most important contributions (see below).

Jean Claude de la Métherie (1743-1817) contested Hassenfratz's results about Prussian blue arguing that his conclusions assumed the decomposition of water, a fact that had not been proven (water was then believed the be an element, particularly by many supporters of the phlogiston theory). In 1786, Hassenfratz published a short letter describing the additional experiments he had done to prove his thesis.[27,28] These related to the oxidation of blades of different metals, suspended in pure oxygen "*in vases closed hermetically, and left in a corner of the laboratory*". The blades had become more or less tarnished, and this allowed him to tabulate the affinity of the metal for oxygen, in an order somewhat different from the one suggested by Torbern Olof Bergman (1735-1784). Hassenfratz's were very rudimentary, particularly at a time when corrosion phenomena were hardly understood. Once again, de la Métherie contested Hassenfratz's results in a long answer where he tried to prove that the hydrogen generated did not originate from water but from the iron "*this air (hydrogen) is the flammable principle of iron, or its phlogiston…Water is here only the means to facilitate its disengagement*".[29] In his annual report of the most important scientific findings of 1786, he commented about the new doctrine (Lavoisier's) proposed by "*savants that are trying by all means to explain everything without the phlogiston*". He refused to "*consider sulfur, phosphorus, metals, and carbon, as elementary substances*" and argued that according to his experiences "*pure air (oxygen) vitiated and changed into phlogisticated air (nitrogen)*", in the same way that flammable air (hydrogen), regarding phlogisticated air, it improved and changed into pure air, a result proving that "*these airs are only a modification of others*".[30]

In a paper about hydrogen gas,[31] Hassenfratz indicated that he had repeated the experiences developed by Richard Kirwan (1733-1812) and other advocates of the phlogiston theory, who claimed that hydrogen maintained under water for three or four months, transformed into breathable air. He prepared very pure hydrogen by reacting zinc with dilute sulfuric acid and kept it in a glass bell under water for three years. He observed that the only alterations in the volume of the gas were those anticipated from the changes in pressure and temperature. He reacted the gas with oxygen in a Volta eudiometer and found the product to be only water, proving that it continued to be hydrogen. Hassenfratz's results were a new argument against the phlogiston theory.

Metallurgy

Hassenfratz's first publication[4] was connected to a problem related to the metallurgy of lead, from the mines of Poullaouen, in Bretagne, exploiting a silver lead ore since the 15th century. The mineral was a galena (lead sulfide) treated by the classical method of roasting-reduction in a furnace heated by wood or coal. In the first roasting stage, the mineral was partially converted into sulfate, which was then mixed with lead sulfide not oxidized, resulting in the release of sulfur dioxide. Heating was continued and a layer of melted lead formed at the bottom of the furnace. The slag floating on top on the liquid was removed before the lead had cooled down. Kirwan had found that this slag was actually another mineral, which he named saturnite. In 1785, Hassenfratz and Alexandre Giroud, a super numéraire student of Mines, were charged with making a detailed analysis of saturnite. These careful experiments and results were confirmed by the synthesis of saturnite from its elements. The material was found to be a sulfurous slag containing, atom-wise 48 % sulfur, 13 % lead, 33 % copper, 4 % iron, and traces of silver.[2]

The knowledge of the real nature of steel was fairly recent. The researches of Rene-Antoine Ferchault de Réaumur (1683-1757) and Bergman had shown that steel is intermediate between wrought iron and cast iron and that carbon plays an important part in it.[32] In 1786, Vandermonde, Monge, and Berthollet presented a memoir to the *Académie*, where they concluded: "*cast iron and chilled steel contain combined carbon, but there is also present a large amount which, being freed by the chilling, is disseminated throughout the mass and is not in combination. This is not pure carbon, it is graphite, which is prevented from collecting at the surface because of the quick cooling and the pasty condition of the metal*." They had previously shown that the graphite of steel was actually a compound of iron and carbon: "*Accordingly, gray cast iron and steel, especially that which has undergone too much cementation, cannot be regarded as homogeneous materials. They are both the result of solutions that are troubled by a preliminary cooling, and then hardened by a more intense chilling*".[33,34] Shortly thereafter, Hassenfratz published an extract of this long paper.[35]

In a following publication,[36] Hassenfratz discussed the phenomenon of iron oxidation. Initially, he participated in Joseph-Louis Proust (1754-1826) opinion that iron existed only in two oxidation states, a green and a red form containing 28 parts of oxygen and four parts of oxygen per 100 of iron, respectively.[37] Nevertheless, the experiences of Lavoisier, of Vandermonde, Monge, and Berthollet, and other chemists, had shown that iron in its lowest oxidation state contained 30 parts of oxygen per 100 of iron, and in its highest oxidation state a ratio (undecided) between 5/100 to 45/100. It seemed that iron was actually able to exist in more than two states of oxidation. In order to clear this disagreement, Hassenfratz and his students at the *École Polytechnique* conducted a series of experiments on the oxidation of iron filings, containing very small amounts of iron carbide, silica, alumina, and chalk. The results of a series of calcinations experiments indicated that at its maximum oxidation state iron contained 45 parts of oxygen/100 parts of iron, confirming Proust's results.

In another publication, Hassenfratz analyzed in detail the different procedures used to oxidize iron (by air and fire; by reduction of the oxide by heat and by heat in the presence of hydrogen or carbon; by other metallic oxides; by water, and by acids,) as well as the amount of oxygen combined with iron (by measuring the amount of gas released during dissolution; by analysis of the oxides contained in the dissolution; and by decomposition of nitre). His results indicated the presence of three iron oxides, a red, a black, and a white one, composed of 31/69, 34/76, and 225/557, parts of oxygen/parts of iron, respectively.[38]

In another work about iron oxide, Hassenfratz studied its reduction by means of hydrogen and by a mixture of oil and coal.[39] To his surprise, the results indicated that the diminution in weight of the oxide caused by hydrogen was always larger than when using oil and coal. The possible explanations for this result were three: the coal combined with the metal when the two were fused together, oxygen remained combined with the metal, and hydrogen dissolved and carried off some of the metal (!).

Hassenfratz was inclined to accept the latter option because when hydrogen obtained by decomposition of water, or by dissolving the metal in acids, was preserved in jars over water, the interior of the jars sometimes became coated with a slight stratum of iron oxide. In addition, it had been noted in the experiments "*a great deal of ferruginous hydrogen gas was evolved as found by its smell, so that probably some iron was lost during the passage of the hydrogen through it*". Hassenfratz finished his memoir suggesting that these experiments should be repeated in several ways, before deciding on a fact of such importance (solution of iron in hydrogen).[39]

Hassenfratz summarized his extensive work on the metallurgy of iron, which began in 1782 as a mining student sent by the French government on a mission to Styria and Carinthia, to study the Austrian iron industry, in his masterpiece, *La Sidérotechnie, ou l'Art de Traiter les Minerais de Fer*, a four-volume, 1200 pages treatise.[19] The first volume was a description of the methods of iron production in a blast furnace, the second cast iron and its fabrication, the third, wrought iron and its fabrication, and the fourth, the manufacture of steel.

Chemical nomenclature

During the eighteenth century, there had been numerous attempts to construct a systematic chemical nomenclature. Louis-Bernard Guyton de Morveau (1737-1816) was in the forefront of nomenclatural reform in France, suggesting numerous ways by which the names of substances could be made simpler and more precise. His most significant ideas were embodied in a memoir of 1782 in which he proposed that the names of compound substances should reflect their composition.[40] For example, the name of a salt should indicate the acid and the base, which formed it. In 1786, Guyton the Morveau met with Lavoisier, Claude Berthollet (1748-1822), and Antoine-François Fourcroy (1750-1809) and the four agreed to collaborate in recasting the terminology of chemistry. The results of their labors was a new method of nomenclature, which took into consideration Lavoisier's theories concerning oxygen and Guyton's concern for nomenclature based on composition.[41,42] Their suggestions, augmented by a scheme of chemical symbols proposed by Hassenfratz and Pierre August Adet (1763-1832), were published in 1787 as an attachment to "*Méthode de Nomenclature Chimique*".[6,34,42]

In their opening statement, Hassenfratz and Adet wrote:[7] "*when offering characters in chemistry we should not propose the same ones used by the ancients. These used all the means to steal their understanding from the ordinary people. On the contrary, we should do all the efforts to spread them. They must be chemical characters, which will become uniform among all chemists, like the writing of people in China, Tonking, and Japan…chemical characters must express the number, the nature, the amount of simple substances that form a mixture by their union…*" Then they went into a detailed description of the different symbolic systems that were then prevalent, proving that knowledge of new compounds required introducing additional symbols, leading to a tremendous confusion and incoherence.

According to Hassenfratz and Adet, 56 simple substances were presently known. These could be classified into six genres: (1) those which seemed to enter in the composition of a very large number of bodies, (2) alkaline and terreous substances, (3) inflammable substances, (4) metallic substances, (5) acidifiable substances, for example the bases of vegetable acids, and (6) composed substances, for which we did not know their components.

Each of these types required a proper sign, which with proper modifications could be used to represent the different species of each genre. For example, Hassenfratz and Adet selected to identify the first genre by a straight line. This line could be vertical, horizontal, inclined left to right or right to left, or wavy. The second genre was identified by a semi circle, the third by a triangle, the forth by a circle, the fifth by a square, and the sixth by a square standing on one a corner.[7]

The proposed symbolism considered the chemical composition of a body as well as its physical state (solid, liquid, gas), which was "*a result of the amount of caloric they contained*". Their table of symbols followed the following order: "*(a) simple substances that existed as a gas at room temperature and were part of a very large number of bodies, required a maximum of simplicity in their representation, and hence were represented by a simple trait. These were caloric, oxygen, nitrogen, and light (represented by a wave)*"; (b) then came "*the four simple combustible substances, commonly called inflammable*", symbolized by four different positions of half a circle (hydrogen, carbon, phosphorus, and sulfur); (c) Metals were represented by a circle inscribed with the first letter of the Latin name of the metal, A for silver, F for iron, etc. Gold continued to be represented by the alchemist symbol, a circle with a point in its center; (d) The symbol for binary compounds collated the symbols of their components; a solid metal was represented by a circle, etc. etc.[7]

The book *Nomenclature* closed with the report of the committee appointed by the *Académie* (Lavoisier, Berthollet, and Fourcroy) to judge the new system of chemical nomenclature proposed by Hassenfratz and Adet. The pertinent part said: "*We cannot disagree with MM. Hassenfratz and Adet for having adopted the new signs to the new nomenclature; we will not examine here up to what point the use of characters and signs may be useful for chemistry, but we believe that those that Hassenfratz and Adet propose to be adopted are far preferable to the ancients…they have the advantage of painting to the sight, not the words but facts and give just ideas of the combinations, which they represent. We believe that their method seems to possess also another advantage: it determines before hand the characters of substances to be discovered in the future in a way that there is no arbitrary in the formation of the sign, and a complete table of these characters represents at the same time all that has been done in chemistry and what remains to be done…Hence, we believe that the work of Hassenfratz and Adet deserves the approval of the Académie and should be published under its privilege (seal)*".[6]

The new system of chemical symbols proposed by Hassenfratz and Adet was a significant contribution to the state of the art, but not practical enough to be adopted. It required a large number of symbols, a complicated set of rules for their use and extension, and solution of the technical problems associated with their use in printed matter.

Sometime after the appearance of *Nomenclature,* James Watt (1736-1819) developed his own ideas in an unpublished manuscript, entitled *Essay on a New System of Characters for Chemical Subjects*.[43] In this essay Watt paid tribute to the efforts of Hassenfratz and Adet to find a simple way to represent chemical elements, compounds, and reactions, but claimed that he had developed a better procedure, which made the characters "*more easily written and applicable to both the old and the new systems of chemistry*".[43] In addition, Watt's procedure provided symbols for laboratory procedures such as boiling, distillation, and sublimation, and the physical state of the compound (gas, liquid, solid). As stated by Larder,[43] these symbols were intended as a "*laboratory shorthand notation and speeding communication in writing to other scientists*", rather than for publication and accordingly were not meant to be exhaustive but only deal with the most frequently used and well established compounds.

Watt's intention was to present as many different symbols as necessary, clearly dissimilar so that they could be easily identified and remembered. For example, a single symbol was used to identify substances which remained undecomposed and those which were as simple substances. "*Thus a genus could readily be developed to include such classes as acids, alkalis and so on, with a specific initial letter to distinguish the individual members; his chemical symbols could be used both within the older chemical framework, as well as within the new*".[43]

Plant nutrition

According to Hassenfratz, the large number of experiences carried out by Johannes Baptiste van Helmont (1579-1644), Henri Louis Duhamel du Monceau (1700-1781), Mathieu Tillet (1714-1791), and others, had suggested that vegetables grow and develop with the only help of water and air and that these two substances sufficed for providing nutrition to plants. In the 1600s, van Helmont carried out his famous experiment in which he grew a willow tree in a pot for five years. At the end of this period, the tree had increased in mass by 74 kg but the mass of the soil had changed little. Van Helmont believed that water was the source of the extra mass and the plant's source of life. Duhamel and others had also succeeded in growing and bringing to bear fruit trees in moss watered only in distilled water, although the moss was unable to provide soluble materials since it had been previously boiled with distilled water.[44]

Hassenfratz was somewhat skeptic about these ideas because they seemed to reduce the role of manure to retain the humidity necessary for vegetation, producing a little of heat to help the development of the plants, and separating the ground to allow an easier growth of the roots. In general, plants were composed of carbon, oil, water, acid, and cinder. The latter constituted a very small fraction of the total; for this reason it was enough to consider the other components as the main substances contributing to growth. Hence, the principal substances were those composed of water, hydrogen, carbon, and oxygen [there was no knowledge about the fundamental role of the metals in the cinder; the presence and importance of nitrogen would have to wait until the work of Jean-Baptiste André Dumas (1800-1884), Claude-Louis Berthollet (1748-1822) and others]. Since the content of each of these materials varied from plant to plant, it was perfectly possible that growth was the result of the combination of one, two, three, or four of these substances, that is, it was the result of the carbon contained in the plant and transported everywhere by the water sucked in by the roots. This carbon combined with a part of the water and with the hydrogen and oxygen coming from the decomposition of another portion of water. Thus, the growth of the plant was simply an accumulation of water, hydrogen, and oxygen.[44]

Tillet had filled several pots with different soil materials, some with old plaster, others with pure river sand, broken stones, etc., and kept them well closed to maintain their humidity and with their bottom immersed in regular soil. After sowing these pots with wheat, the seeds developed into beautiful ears whose grains grew up again into well-developed ears. Further experiments showed that plants developed in a media providing only water did not contain the same amount of carbon originally present in the seeds.

Hassenfratz repeated Tillet's experiences to find out if the carbon increase in plants was due to air or water alone. First, he thoroughly washed three kinds of soil, then soaked in water, and finally planted them with seeds of wheat, beans, and watercress. The resulting seedlings grew very little and most of them rotted. He repeated the experiments, this time immersing only the bottom part of the pots in water. Then, the seeds germinated, the plants grew up but never lived to the point where they developed flowers, a result opposite to that reported by Tillet. A detailed comparison indicated that the difference was due to the fact that Tillet had immersed the bottom of his pots in regular soil. Water traveled through the stratum, combined with the soil and acquired the necessary materials to nourish the plants and increase their carbon content. Therefore, the results of both sets of experiences were insufficient to find out if water and air alone were responsible of plant growth.[44]

Hassenfratz decided then to attack the problem directly by using plants capable of growing in water alone, e.g. hyacinth, kidney beans, and watercress, and determining their content in carbon, hydrogen, and water, before sowing. After weighing the seeds, he allowed them to grow in pure water, some indoors, and others in the open air. The seeds germinated, grew up, and flowered; but produced no seed. Hassenfratz collected all the plant material and subjected it to a chemical analysis. The results indicated that the amount of carbon present in each one was somewhat less than the quantity originally present in the bulb or seed from which the plant had developed.[44]

From these results, Hassenfratz concluded that the development of plants growing only in contact with air and water was due to the water that combined with the constituent parts of the element being developed, and that the carbon present in all the development organs (roots, leaves, branches, etc.) was contributed by the organ and transported by water to all its parts during the act of vegetation. In addition, the results indicated that the increase in the amount of carbon in plants growing in a vegetable soil *was not contributed only* by water and air; during the act of vegetation there was still a portion of the carbon, which had been lodged in the plants. Hassenfratz remarked that his results illustrated the significant analogy that existed between plant seeds and animal eggs. The materials contained in the egg served to develop the animal and to provide a certain degree of growth, beyond which it could continue its development only with the help of new nutrients that provided them with the required carbon and other substances.[44]

In his second memoir on the subject,[45] Hassenfratz examined the possible causes that contributed to the increase in the amount of carbon present in plants. He repeated his previous arguments that the increase in water content was easily explained by its absorption from the soil, and the increase in hydrogen content by the decomposition of a part of the water deposited in the interior of the plant and by the oxygen released during the act of vegetation. The increase in carbon depended on a completely different cause. The prevailing hypothesis was that plants decomposed the CO_2 (carbonic acid), assimilated the carbon thus produced and released the resulting oxygen to the atmosphere. Hassenfratz tried to develop plants in water slightly acidulated with CO_2 and found that the resulting seedling did not contain more carbon than the one present in the original seed or bulb. It was known that the decomposition of water and carbon dioxide into its elements required a substantial amount of caloric, hence the prevailing theories required that in order to close the thermal balance, the act of vegetation is accompanied by production of cold, or by some reactions that generated the amount of heat required, for example the formation of oils in the plant.[45]

The hypothesis that the act of vegetation was a natural process that decomposed CO_2 and released oxygen to the atmosphere could be easily tested by covering the plant with a large jug that contained a little of atmospheric air: after a sufficiently long period of time the air inside the jug should have increased its volume substantially and contain more oxygen that the original gas. Hassenfratz experiments proved both hypotheses to be wrong. The only changes in volume observed were those due to the changes in atmospheric pressure and temperature. Once again, Hassenfratz concluded that the increase in carbon of plants growing in the soil was not produced by the decomposition of carbon dioxide, and that the act of vegetation was not the means employed by nature to decompose CO_2 and return to the atmosphere the oxygen that had been employed in the processes of combustion and respiration.[45]

In his third memoir,[46] Hassenfratz tried to explain the mechanism employed by nature to increase the carbon content of plants. It was known that the water that soaked manure acquired a brown color; evaporation of the liquid left carbon as the principal residue. This result proved that carbon could be dissolved or suspended in water and provided an explanation of the fact that fertilized soils led to a more vigorous growth of plants.

In a new set of experiments, Hassenfratz treated one plot of land with straw that had just begun to rotten, and another with straw well rotten and finely divided. The plots were cultivated with the same seeds during three consecutive seasons. In each season the first plot produced plants which were clearly stronger and more vigorous than those produced by the second plot. This difference was explained on the basis of the amount of carbon dissolved in water. Oxygen was produced by the decomposition of water; the increase in hydrogen in the plant was produced by the decomposition of water, and carbon dioxide by atmospheric oxygen combined with part of the carbon contributed by the water and drawn in by the roots.[46]

According to Hassenfratz, during growth, there were two operations that tended to decrease the "heat" of the plant, and two that tended to increase it. The *decrease* in heat was caused by the decomposition of water and formation of oxygen gas, which was released, and by vaporization of part of the water sucked in by the roots. The *increase* in heat was due to the formation of carbon dioxide from atmospheric oxygen and the carbon from the plant, and the intimate combination of hydrogen with carbon and other plant constituents. The experiences of Jean Ingen-Housz (1730-1799) had proven that during the release of oxygen there was no formation of carbon dioxide and that at that moment, when the plants were illuminated by solar light, caloric was absorbed by the decomposition and vaporization of water, and released by the combination of carbon, hydrogen, and other plant constituents.[46]

Hassenfratz ended his paper with the statement that all the available information supported the hypothesis that the increase in carbon during the growth of a plant was due to the solution of carbon in water, followed by its suction by the roots and deposition in the interior of the plant.[46]

In the same session (February 20, 1792), Armand Seguin (1767-1835) read a memory contradicting Hassenfratz's results. His opinion was the same as that of Ingen-housz: in the same manner that a vegetable substance plus oxygen formed CO_2 and water, withdrawing the oxygen from the water and the CO_2 regenerated the vegetable combination. To support this opinion, Seguin quoted the results of his experiences where bulbs of onions, crocus and hyacinth immersed in an aqueous solution of odorous substances (i.e. lemon, rosmarin, orange flowers, anis, and rose) or of colored solutions (saffron, indigo, copper sulfate, madder, etc.) did not suck in the active material. He observed that the roots seemed to be able to separate the principle from the water and absorb only the latter.[47]

Sometime later, Nicolas Théodore Saussure (1767-1845)[48] conducted additional experiments on the subject, by growing mint (*Mentha piperita*) and beans in bottles filled with distilled water; exposed to the sun on the outside of a window, and protected from the rain. He weighed the plants, then dried them up and determined the amount of carbon present in the residue. His results left no doubt that the carbon content had increased, in contradiction with Hassenfratz's results.

In another paper, Hassenfratz discussed the influence of snow and rain on plant growth.[49] Most people believed that snow was one of the means employed by nature for increasing the vigor of plants and promoting the evolution of their organs. They also believed that a winter season, in which little or no snow fell, resulted in a poor harvest and weak vegetation. These results were attributed to the salts (or nitre) held to be dissolved in frozen water because snow corroded leather and other substances covered by it. According to Hassenfratz, this was a fanciful explanation because the distillation of melted snow took place without leaving any residue. Hence, a more plausible explanation was needed. All plants were able of supporting different degrees of cold, some perished when exposed to the freezing temperature of water while others were not affected by the most intense colds. It was known that covering the susceptible plants with an insulating material prevented their decay and death. Since snow was a poor conductor of heat it had, therefore, the property of preserving the plants it covered; it defended them against the influence of intense degrees of cold, affording them a continuous supply of water and their preservation in a state of greater strength and vigor that they would have attained had they not been covered with snow.[49]

Hassenfratz performed a series of experiments in which he put into different flasks snow and distilled water, and added to them a solution of litmus or of iron sulfate. The snow flasks caused a deep reddening of the litmus and precipitation of iron oxide, which led Hassenfratz to conclude that snow was *oxygenated water*, and thus had a different influence upon vegetation than ordinary water. Hence, there was a third reason why snow helped producing a better harvest: it covered the seeds with a cold protective layer that provided them with the oxygen necessary for their proper germination and increased the number of viable plants available after the cold season.[49]

Rainwater was found to have no action on litmus paper or on iron sulfate solutions, whence it would appear as if it did not have the same properties as snow. Nevertheless, rainwater contained oxygen but in a state of solution and not of combination as in snow. Rainwater exposed to vacuum was found to contain a much larger proportion of oxygen than river or spring water (!).[49]

Respiration

Lavoisier had assumed that the oxygen of the air drawn into the lungs during inspiration, came into contact with the hydrogen and carbon present in the blood and reacted with both, either in the lungs or during the circulation. The resulting CO_2 and water were expelled. Nitrogen played a neutral role; it was just a carrier of the reagents and of the products. Adair Crawford (1748-1795) believed that the blood received what he called a hydrocarbon in the capillaries, and that the presence of this substance in venous blood made it different from arterial blood.[50] The oxygen of the air inspired combined with the hydrocarbon in the lungs and formed carbon dioxide and water vapor. Elimination of the hydrocarbon reconverted venous blood into arterial. Lagrange believed that the blood when passing through the lungs, dissolved oxygen abstracted from the air inspired; the blood loaded with oxygen was transmitted through the arteries and thence to the veins. During its passage, the oxygen, little by little, abandoned its state of dissolution and partially combined with the carbon and the hydrogen in the blood, forming water and carbon dioxide. The latter was disengaged as soon as the blood left the heart to enter the lungs.[50]

Hassenfratz provided some details of this theory and supported them by experiment. According to Joseph Priestley (1733-1804) and others, venous blood exposed to oxygen became bright red, but after some time of exposure it lost its florid hue. Blood exposed to any gas not containing oxygen, turned black. Priestley believed to have proven that when "vivid arterial blood is exposed to inflammable air, or any other species of aerial fluid, known to contain that principle at its basis, it speedily acquires the deep and livid hue of venous blood…The proper function of the blood is not receive phlogiston from air, not meeting with any phlogisticated air in the course of its circulation, but to communicate phlogiston to air, and therefore there is by no means the same reason to expect that the air will be mended by red blood, as that it will be injured by black blood".[51]

Hassenfratz explained these facts by assuming that the bright color of arterial blood was caused by the oxygen it held in solution; when the oxygen abandoned the blood, in order to combine with the carbon and hydrogen present, the blood lost its bright red color, turned dark, and became venous blood. Parallel with this explanation, he ascertained that when chlorine (which indirectly supplied oxygen), mixed with venous blood, it rendered it immediately very dark colored. Hassenfratz attributed this phenomenon to the facility with which chlorine supplied oxygen in a state ready for immediate combination with carbon and hydrogen, while the oxygen of the atmosphere, being gaseous, combined with difficulty. Chlorine did in an instant what common air could do only by a long continuous contact.

According to Hassenfratz,[52] Hamilton, Priestley, and others, had observed that arterial blood in contact with hydrogen gas, lost its vermillion color and that venous blood exposed to the action of oxygen gas lost the color of arterial blood and the oxygen became vitiated. From these results Crawford and Lavoisier had concluded that the change in color of blood that took place during circulation came from its combination with hydrogen, and that while flowing through the lungs blood released part of its hydrogen to the oxygen it contained and recovered its vermillion color.

In addition, during respiration a large part of the oxygen disappeared and was replaced by water and carbonic acid (CO_2). Water was composed by hydrogen and oxygen and carbon dioxide by carbon and oxygen, and each time that oxygen combined with carbon or hydrogen, there was a release of heat. Hence, Crawford, Lavoisier, and other scientists concluded that animal heat was the product of the combination of oxygen of the air inspired with the carbon and hydrogen present in blood. Since blood and oxygen inhaled came into contact in the lungs, then blood, during its passage through the organ, decomposed, abandoning its carbon and hydrogen to the oxygen present, and acquiring, by this combination a large amount of heat, which became distributed through all the body. Christoph Gertanner (1760-1800) performed numerous experiences comparing arterial blood with venous blood. According to his results, during the act of respiration, oxygen divided into four portions while the caloric released had three different effects. Part of the oxygen combined with venous blood and changed its color from dark to vermillion; a second part combined with the carbon contained in the hydrocarbon of venous blood forming CO_2; a third part combined with the large amount mucus contained in the lungs, which decomposed continuously, and formed CO_2; and the fourth part of the oxygen combined with the hydrogen of blood to form water, which was exhaled during respiration. The caloric contained in vital air remained united in part to the oxygen and the blood, another part combined with CO_2, and a third part produced the temperature necessary to form water by combination of hydrogen and oxygen.[52]

Edmée Bouillon Lagrange (1764-1844) argued that if all the heat distributed in the animal economy were released in the lungs, then the temperature of the lungs would increase continuously and lead to their destruction. If this were true, people studying the phenomenon would have observed the difference in temperature. Consequently, he believed that the heat of the animal economy was not released only in the lungs, but everywhere where blood circulated. Blood passing through the lungs dissolved the oxygen of the inspired air; this dissolved oxygen was carried by the blood into the arteries and the veins, and along its way, oxygen was released and combined with the carbon and hydrogen of the blood, forming water an carbon dioxide, as soon as blood left the heart to enter the lungs. This explained the small difference in temperature that existed between the lungs and other internal parts of the animals, and how caloric was able to reach the points the farthest away from the lungs.[52]

Pierre-Simon Laplace (1749-1827) had tried to solve the question raised by Adrien-Marie Legendre (1752-1833) by assuming that the oxygen combined with the blood released only part of its heat, and that the rest remained combined as latent heat and not as sensible heat, that is to say, it did not disengage during the circulation of blood.[52]

According to Hassenfratz, Laplace's ingenious explanation was not supported by experimental evidence and seemed to have only a remote analogy with the absorption of caloric that took place during fusion and during boiling. For this reason, he decided to conduct some experiments to clear the situation, based on the accepted facts that venous blood mixed with oxygen acquired a beautiful vermillion color and that this color changed little by little until it acquired a color close to purple wine while the blood was in continuous contact with oxygen, and that arterial blood in contact with any gas that did not contain oxygen took a purple wine color. He believed that the red color of blood was a result of the dissolution of oxygen in it, and the purple wine color resulted from oxygen abandoning blood to combine with hydrogen and oxygen. To verify the latter assumption he added oxygenated muriatic acid to venous blood and observed that the blood decomposed, acquiring a dark almost black color. Further addition of ordinary muriatic acid (HCl) did not change the color of the blood. Addition of HCl to fresh ordinary blood led to its decomposition and precipitation of light brown flakes. The black color of blood was the result of the intimate combination of oxygen with the carbon and hydrogen of the blood, while the red color was the result of the dissolution of oxygen in the blood.[52]

Since (a) the vermillion color of blood was the result of the dissolution in it of oxygen gas, (b) the purple wine color and the brown black color were due to the combination of oxygen gas with the carbon and hydrogen of the blood, (c) venous blood was purple wine, and (d) arterial blood was vermillion, it turned out that arterial blood contained oxygen gas dissolved, that this oxygen combined little by little with hydrogen and carbon during circulation. When blood returned through the veins to the lungs, all the combination had taken place, and there the redissolution of new oxygen gas took place and returned the vermillion color in the arteries.[52]

The brown black color of blood was the result of the combination of oxygen with the carbon and the hydrogen in the blood, and blood passing from the veins into the lungs and then into the arteries, became vermillion. It followed that in the lungs there was little combination of the hydrogen and carbon in the blood with the inspired air.[52]

Since caloric was released during the combination of oxygen gas with hydrogen and carbon and this caloric maintained the animal heat, and that the combination of the oxygen, the carbon, and the hydrogen took place substantially on the blood passing from the lungs to the arteries, it followed that during this stage the largest amount of caloric was released.

Hassenfratz concluded his paper stating that the red color of blood was the result of the dissolution of oxygen; the brown and black colors were the result of the combination of the dissolved oxygen with the carbon and hydrogen present in the blood; the lungs were not the not the place where all the caloric needed to maintain the animal heat was released; the caloric necessary for maintaining the animal temperature disengaged during the circulation of blood by the combination of hydrogen and carbon with the dissolved oxygen.[52]

Physics of sound

Hassenfratz wrote two papers related to the physics of sound, one about the causes that increased the intensity of the sound in speaking trumpets,[53] and the other on the propagation of sound.[54] In his first paper, after describing the historical development of the speaking trumpet and the ideas regarding the theories concerning its way of operating, he expressed his astonishment to the fact that this kind of trumpet, other trumpets, as well as hunting horns, were assumed to operate under different principles. In the speaking trumpet the cause was attributed to the reflection of sound while in the others, to the vibration of the air contained in the tube. After making many experiments with speaking trumpets of different geometry, Hassenfratz concluded that in every case the augmentation of sound was not due to the reflection of the sound wave (he called it sonic rays), hence there was no reason for providing a different explanation than that for trumpets and hunting horns. In every case, the different sounds produced were due to the vibration of the air in the tubes, and their strength or intensity, to the augmentation of the amplitude of their vibration, which arose from the greater impulse (velocity) that the air received when it was enclosed in a tube.[53]

In his second memoir,[54] Hassenfratz wrote that it was commonly believed that sound was produced by the vibration of molecules. This vibration could be modified in two ways, the speed and the magnitude; the first one determined the nature of the tones while the second their strength and intensity. The velocity of sound had been extensively measured in air. The experimental results indicated that the speed of sound in a given medium was uniform, independent of its distance from the source and the intensity, and that the density of the medium at constant pressure was an important variable in determining the speed of sound. Some believed that the speed of sound was independent of temperature, while others claimed that this was not so. Laplace suggested Hassenfratz to measure the speed of sound in different media, particularly solid bodies. Initial experiments done in the quarries underneath Paris and in the open fields, showed him that the propagation of sound through stone, wood, and metals occurred much faster than through air and that both grave and acute sounds travelled at the same speed.

Core boulders

While traveling in the southern Massif Central near Aumont, between St. Flour and Montpellier, Hassenfratz observed rounded masses of fresh granite protruding from a bank of weathered rock. Some were only just visible, others partly exposed, and yet others detached. He deduced that the free-standing blocks and boulders had been once covered, and suggested that the assemblage were members of a sequential series: "*All stages can be observed between a block of granite totally contained within the mass of altered rock and one wholly detached*".[55] This initiated the two-stage or etch interpretation of landforms and its implications.

Color optics

According to Hassenfratz it was customary to define as black the shadow produced by an opaque body when intercepting the light that illuminates a white piece of cardboard, although, in practice it was very difficult to obtain black shadows, because that absolutely required that the luminous body be a point and that the surface illuminated did not receive any kind of reflected light.[56] Illumination with a larger source resulted in the shadow being accompanied by a colored penumbra. When the distance between the lighting body and the lightened body was larger than one meter and the one intercepting the light was at about 50 cm from both of them, then the penumbra acquired characteristic colors, which depended largely on the nature of the combustible body producing the light. Nothing was more variable than the shades of penumbras, among them, all the prism's colors. In a first memoir on the subject, Hassenfratz described the large variety of penumbras that was possible to distinguish and the circumstances under which they were produced. To do so he studied the color of the penumbra produced by the meeting of atmospheric light with sunlight, and of atmospheric light with artificial light. In the first case he found that the penumbras varied from almost green to violet black, passing through blue, indigo, and violet; and that this variation depended on the intensity of the light, compared to that of the atmosphere. The penumbra formed in flats by atmospheric light and reflected lights corresponded to all the colors of the prism, and their shades were always complementary one of the other. The penumbra obtained over a cardboard illuminated with artificial light were always intense red or intense blue, depending on the carbon and hydrogen content of the combustible bodies.[56]

Education

One of the largest projects initiated by the Constituent was the reform of public instruction. In 1791, Charles Maurice de Talleyrand (1754-1838) submitted his *Rapport sur l'Instruction Publique*, where he proposed, "*a public education common to all citizens, free for all those parts of education indispensable to every person*", and organized it into a hierarchic pyramid culminating in a National Institute, responsible for controlling education and encouraging research. While preparing a second edition of his report, Talleyrand consulted with Lavoisier, who suggested a more aggressive requisite: "*Public education, as it exists in France and almost all Europe, was established not with the purpose of forming citizens, but to form priests, monks and theologians. The spirit of the Church has always abhorred any kind of innovation. It is indispensable to put an end to Latin and turn our back to sixteen centuries almost completely lost to reason and philosophy, during which the progress of human spirit has been almost completely stopped*". [2,57]

The various reports on the subject agreed that the pyramid of the architecture of education should start at the vertex with a *Société Nationale des Sciences et Arts* (a reminder of the *Académie des Sciences*), followed in descending steps, by a *Lycée* for each region, an *Institute* at the capital of each department, a *École secondaire* in the principal towns, and finally, an *École primaire* in each commune.[2,9,12]

From his part, Hassenfratz was worried about the role of practical education, which had to be provided to the artisans, the hands-on men who would not advance to the highest scientific level. This was the subject of his *Mémoire sur l'Éducation*. Hassenfratz's purpose was obviously based on the political, economic, and philosophical ideas of his period. His memoir started by recalling the importance of education and its economic role: "*It is the improvement of the natural abilities, which will increase the amount of work of each individual, and lead, finally, to the enrichment and prosperity of the Nation. Education must optimize this improvement, taking into account that for different individuals the extension of their faculties is not the same…there are some who are unable to grasp abstract ideas, who are refractory to the teaching of mathematics. These can only improve the faculty of reasoning, which is the most important of the spiritual faculties…Public instruction has neglected the most essential part, which is the development of national industry and the education of arts and professions, and has replaced it by education for holidays. It is not by means of celebrations that the British have acquired a great preponderance in the European balance of politics. It is not through holidays that United States has become a flourishing Nation…The best festivity we can give to the French Republic is to organize the instruction of arts and* *professions, the activity at our factories, our commerce, and destroy forever the tyranny, the intrigues, and all the germs of division present among us*".[2,9,12]

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