



PARA QUITARLE EL POLVO

William Prout

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Abstract William Prout (1785-1850) a multifaceted English physician, conducted important research in the areas of physiology, meteorology, and chemistry; he studied the processes of digestion, respiration, and blood formation, the urinary system, urine and urinary calculi, identified the presence of HCl in the gastric fluid, and proposed the theory that the atomic weight of an element is an integer multiple of the atomic weight of hydrogen (Prout's hypothesis).

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PALABRAS CLAVE

Digestión;
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Orina;
Cálculos;
Fluido gástrico;
Hipótesis de Prout

William Prout

Resumen William Prout (1785-1850), un médico inglés multifacético, realizó importantes investigaciones en las áreas de medicina, fisiología, meteorología y química; estudió los procesos de digestión, respiración y formación de la sangre, el sistema urinario, la orina y los cálculos urinarios, identificó la presencia de HCl en el jugo gástrico y propuso la teoría que los pesos atómicos de los elementos eran un múltiplo entero del peso del hidrógeno (hipótesis de Prout).

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Life and career

William Prout was born on 15 January 1785 at Horton, Gloucestershire, the eldest of the three sons of John Prout (1745-1820) and Hannah Limbrick (1756-?), who earned their living as tenant farmers. He learned reading at a dame's

school at Wickwar, a neighboring market town, writing and arithmetic at a charity school in Badminton, and also helped his parents in farming. Since an early age Prout suffered from strong pain in the ear and when he went to bed he used to cry for a long time until he fell asleep (Anonymous, 1851). When he was seventeen he entered the Sherston Academy, a

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private institution managed by the Reverend John Turner, where he learned Latin and Greek. In 1805, aware of the shortcomings of his education, Prout put an ad in one of the local newspapers requesting information about a possible place to complete his education. As a result of this query, at the age of twenty-one, he joined a private academy managed by the Reverend Thomas Jones (1758-1812), and located at Redland, Bristol. He stayed at the academy for about two years, studying the classics and earning his living as a private tutor. In 1808, at Jones's recommendation, Prout enrolled in the Faculty of medicine of the University of Edinburgh. While there he boarded with Jones's friend, Dr. Alexander Adam, rector of high school of Edinburgh, and eventually married his daughter. Prout remained in Edinburgh during his studies and graduated MD on 24 June 1811 with a 27-page dissertation on intermittent fevers (Prout, 1811; Brock, 1965). After graduation Prout moved to London where he completed his practical training at the United Hospitals of St. Thomas's and Guy's in London. On December 1812 he gained the licentiate of the Royal College of Physicians and in May of the following year he was elected member of the Medical Society. In the latter he became a member of Council from 1817 to 1819 and served twice as its Vice-President (in 1823 and from 1833 to 1835) (Brock, 1965).

Simultaneous with his medical practice, Prout gave a successful course of public lectures on animal chemistry in his London home. The course was intended to "give a connected view of all the principal facts belonging to this department of chemistry, and to apply them, as far as the present state of our knowledge will permit, to the explanation of the phenomena of organic actions"; quite a challenge at a time when the subject was in its infancy. The clear success of these lectures ensured Prout's election to the Medical and Chirurgical Society on May 1814 (Anonymous, 1851; Brock, 1965; Rosenfeld, 2003).

On 22 September 1814, Prout married Agnes Adam (1793-1863); a daughter was born in 1815, which only survived a few months. There were six further children: John William (1817-1881), Alexander Adam (1818-1854), Walter Robert (1820-1857), Thomas Jones (1823-1909), and two daughters, Elizabeth (1825-1918) and Agnes (1826-1878).

Prout's later life was marred by deafness that affected him since childhood. This flaw led to his social and professional isolation. His health aggravated in the spring of 1850, apparently from lung problems. Before his death he requested no inspection of his body he made, so the cause was entered as "gangrene of the lungs." He was buried in Kensal Green cemetery and by his request a plain slab was erected to his memory in Horton Church. His wife, four sons, and two daughters survived him (Anonymous, 1851; Brock, 1965).

Prout was elected fellow of the Royal Society (1819) and of the Royal College of Physicians (1829). He was awarded the 1827 Copley medal of the Royal Society and elected Gulstonian lecturer at the Royal College of Physicians (1831). Among his many professional duties were member of the Council of the Royal Society and of several of its committees and on those of the British Association for the Advancement of Science. He was also active in the Medico Chirurgical Society of London.

Prout developed his medical career as an expert in stomachal and urologic diseases, becoming a well-known and popular physician in these areas. He summarized his findings

in his book *An inquiry into the nature and treatment of gravel, calculus and other affections of the urinary organs* (Prout, 1821), republished later as *On the Nature and Treatment of Stomach and Urinary Diseases* (Prout, 1840; Prout, 1848).

His first paper beyond the doctoral dissertation was published in 1812 and dealt on the sensations of taste and smell (Prout, 1812). In 1813 a published a long memoir on the quantity of CO₂ emitted from the lungs during respiration, at different times and under different conditions. The pertinent experiments were made on himself over a 3-week period, under very controlled conditions, and using an instrument of his design (Prout, 1813b; Prout, 1814).

In 1815 and 1816, Prout published two anonymous articles on the "relation between the specific gravities of bodies in their gaseous state and the weights of their atoms", where he suggested the atomic weights of all the elements were whole number multiples of the atomic weight of hydrogen so so this element could be considered the $\rho\omega\tau\eta\ \upsilon\lambda\eta$ of the ancients (Prout's hypothesis) (Prout, 1815f; Prout, 1816a). Eventually Jöns Jacob Berzelius (1779-1848) and Jean Servais Stas (1813-1891) proved this theory to be wrong.

In 1815 he analyzed a sample of pulverized excrement of the boa constrictor and found that the portion insoluble in HCl was a bluish material containing 90.16 wt % uric acid, mixed with minute amounts of potassium, ammonia, magnesium, and calcium salts, and animal matter (Prout, 1815b). This was the first time uric acid had been shown to be synthesized by this type of animals. Prout was surprised that nearly the whole food taken by the animal was converted into uric acid, and speculated that the possible reason was a disease arising from the artificial conditions in which the reptile was kept. He mentioned that William Hyde Wollaston (1766-1828) had previously demonstrated that the excrement from birds fed on animal matter also contained uric acid, although in a lesser proportion (Wollaston, 1810).

In 1818 Prout prepared urea in its pure state and described its properties, composition, and the preparation of many derivatives, as well as the analysis of several urinary stones (Prout, 1818a-c; Prout, 1819a). Three years later he published a study of the changes that take place with time in fresh and incubated eggs (Prout, 1822a).

In 1823 he announced to the Royal Society he had found that the walls of the human stomach secrete free HCl and that this acid was the main digestive agent of the organ, and the salts usually met with in it were alkaline chlorides (Prout, 1824). Initially this discovery was hotly contested but was later confirmed by many important scientists, among them Friedrich Tiedemann (1781-1861), Leopold Gmelin (1788-1853), John G. Children (1777-1852), and William Beaumont (1785-1853) (Copeman, 1970).

A completely different research was the measurement of the specific gravity of air and the laws of its expansion. Here he showed his abilities as instrument maker by building a barometer, which probably served as prototype to the one built for the Royal Society in 1835 (Prout, 1832; Copeman, 1970).

In 1834, the paleontologist William Buckland (1784-1856) requested from Prout to analyze the bezoar stones found at the geological sites in Lyme Regis and Westbury on Severn. Prout found all of them to have a very similar composition, basically, calcium phosphate and calcium carbonate, with

small amounts of iron, sulfur, and carbonaceous material. He believed the basis of these stones was digested bones, confirming Buckland's opinion the bezoar stones were fossil faeces (Prout, 1834a).

Francis Henry Egerton, eighth and final Earl of Bridgewater, who died in 1829, bequeathed £8,000 to the Royal Society as a payment to the person or persons chosen by its President who would "write, print and publish 1,000 copies of a work on the Power, Wisdom and Goodness of God as manifested in the Creation; illustrating such work by all reasonable arguments, as for instance the variety and formation of God's Creatures in the animal, vegetable and mineral kingdoms; the effect of digestion, and thereby of conversion, the construction of the hand of man, and an infinite variety of other arguments." The Earl also dictated the profits arising from the sale of these books should be paid to their authors. Prout was invited by the President of the Royal Society, Davies Gilbert (1767-1839), and his advisers (among them, William Howley, archbishop of Canterbury, and Charles James Blomfield, the bishop of London) to write one of the eight Bridgewater treatises. Prout's volume, *Chemistry, Meteorology and the Function of Digestion with Reference to Natural Theology* (Prout, 1834b), appeared in February 1834; the first 1,000 copies were rapidly sold and led to the publishing of a second edition in June 7, 1834. A third edition, slightly modified, appeared in 1845. A fourth edition appeared posthumously in 1855 (Anonymous, 1851; Brock, 1965).

Scientific contribution

Prout published about forty papers and five books (Prout, 1821; Prout, 1834b; Prout, 1848), mostly in the areas of physiology. Many of his books went through several editions, and for quite some time were considered standard textbooks.

Taste and flavor

As mentioned before, Prout's first paper was devoted to a qualitative and descriptive discussion of the concepts of taste, flavor, and smell (Prout, 1812; Brock, 1967). He mentioned flavor was commonly defined "to be that quality or principle in a substance, which is capable of exciting the sense of taste... In common language the term flavor is used... synonymous with taste." According to Prout, this was a mistake, the two sensations represented different qualities of substances (Prout, 1812). Taste was the sensation produced by substances when brought into contact with the tongue under certain circumstances, while holding the nostrils closed. To generate the pertinent sensation required the tongue to be moist and in motion and the substances be more or less soluble in water. Motion was required because when the substance was on the tongue at rest, the sense of taste was hardly, if at all, produced. Once it was moved around on the tongue, and more especially, if the tongue was applied with it to any part of the mouth, taste was perceived very clearly. It was common experience that the tongue involuntarily moved when we wanted to

feel the taste of a substance. The seat of taste was mainly confined to the upper surface of the end of the tongue (Prout, 1812).

Prout believed smell was the sensation produced by substances when they were brought into contact, under particular circumstances, with the internal membrane of the nose. Its activation required the nose be moist, the substance be soluble in air, and thirdly, motion. Again, it was common experience that it was possible to suppress the sense of smell by simply holding the breath, without closing the nose. Sinuses, not being in the path of the air, did not participate in the production of this sense, as some had supposed (Prout, 1812).

Regarding the notion of flavor, Prout made use of the popular saying "a nutmeg has no taste." No feeling of taste was generated when a portion of nutmeg or any other substance was introduced in the mouth, with the nostrils closed. This result suggested the sensation produced in the mouth by the nutmeg or any other substance, which ceased when the nostrils were closed, was really very different from taste, and hence should be given another name, which Prout believed should be flavor. Consequently, flavor should be defined as the sensation produced when substances under certain circumstances are introduced into the mouth with the nostrils opened. Flavor seemed to be a sense intermediate between taste and smell and hence it involved activation of all the factors required for the manifestation of these two senses. In the human species flavor sensing seemed to be located everywhere in the mouth (Prout, 1812).

Almost all substances containing a principle soluble both in water and air, especially the latter, produced less of flavor but the strongest sensation. Thus substances containing a volatile oil, e.g., spices, aromatics, etc., produced a strong flavor, although they hardly had taste. Ammonia was an exception to this rule, it excited slightly more flavor than a common salt because of its high solubility in water (Prout, 1812).

Accepting the above arguments provided a simple explanation for the fact a person born without a tongue was able, nevertheless, to smell. Also, it explained why someone who had lost the sense of smell necessarily lost that of taste, etc. The sense of taste could, however, exist independently of smell, as Prout was acquainted with a person who had lost his smell, and consequently his flavor, but fully enjoyed the power of taste (Prout, 1812).

Staining of animal vessels

According to Prout, the art of injecting colored substances in tissues had progressed very little since the pioneering work of Frederik Ruysch^a (1638-1731) (Prout, 1813a). The Ruysch technique was difficult to carry on and there were many parts of the animal, which did not admit coloring the particles of blood, a serious obstacle for physiological studies. Prout did much experimentation on the subject,

^a Frederik Ruysch (1638-1731), Dutch anatomist, pioneer in techniques of preserving organs and tissue by injecting colored solutions in the arteries of cadavers. He kept secret the composition of the fluid he used for this purpose.

looking for a better technique. His results indicated that all types of solids (opaque substances), even when finely crushed, were unable to penetrate the vessels of transparent parts; even a solution of isinglass was unable to do so. Hence, the probable answer was to find a substance(s) fluid as water and able to hold the coloring agent in solution. His search led him to saturated solutions of potassium ferrocyanide and dilute ferric sulfate, which when mixed inside the vessels precipitated Prussian blue on the pertinent tissues and made them clearly visible. His procedure consisted in inserting a syringe pipe in the organ to be colored followed by heating the combination in water to about 900-100° F. The staining solutions were also heated to the same temperature level and then injected through the syringe. Prout demonstrated how his procedure allowed bringing to light the vascularity of most of the transparent parts of an ox eye. In his words in the stained eye “the vessels of all parts of this organ appear to communicate freely with one another; the part least connected with the rest [was] the retina, and this [was] supplied by its own proper artery. A successful injection... by one of the ciliary arteries, will... extend to every part, except the retina, and this is at all injected, will be only partially so at its interior part.” He successfully stained the cornea, the hyaloid membrane, the capsule of the lens and its external coat, and described in detail their appearance (Prout, 1813a).

Respiration

At Prout's time it was already known that the quantity of oxygen consumed and, consequently, the CO₂ formed varied considerably in the same individual, under different situations. The chemical effects of respiration were the temperature of the air inhaled, the degree of muscular exertion, the state of the digestive system, and the conditions of the system as affected by the presence or absence of fever. Prout decided to investigate the process in a more detailed manner in an effort to discover the laws that controlled it (Prout, 1813b; Prout, 1814). For this purpose he built a simple apparatus to analyze the air, and subjected himself, during a period of three weeks, to a controlled regime in which he kept himself as nearly as possible in the same state. He carried on the measurements every hour during the day and sporadically during the night. The results of hundreds of experiments led him to the following generalizations: (1) the quantity of oxygen consumed, and consequently of CO₂ formed, was not the same during the 24 hours; it was maximum between 10 AM and 2 PM, and its minimum begun at about 8.30 PM and continued nearly uniform until about 8.30 AM. He was particularly surprised by the sudden increase in the quantity of CO₂ given out by the lungs about the beginning of twilight; and (2) whenever the quantity of oxygen consumed, and consequently of CO₂ formed, was by any cause augmented or raised above the natural standard of the period, it was subsequently as much decreased or depressed below the standard, and vice versa (Prout, 1813b).

He then considered the quantity of CO₂ given off by the same individual on different days, and its variations of its

quantity as given off by different individuals. His results indicated no two days were exactly alike; the conditions, which immediately increased the amount of CO₂ formed, appeared to be comparatively few, while those which decreased it were abundant. Among these factors, Prout discussed exercise (moderate and violent led to a decrease or increase), depressing passions, such as anxiety and grief (diminution), food (slight increase), alcohol (diminution), sleep (diminution), presence or absence of the sun, etc. (Prout, 1813b).

In a following publication Prout (1814) reported the results of additional experiments done with the purpose of establishing whether the quantity of CO₂ emitted from the lungs began to increase at the same hour in the morning at all periods of the year. In order to find if the discharge was related or not with the movements of the sun, he carried on a series of measurements from about the winter solstice until the summer solstice. These were conducted by staying up all night and repeating the measurements at different hours, in the same manner and with the same instrument. His results confirmed his previous finding that the increase in CO₂ always took place soon after the beginning of twilight and before sunrise, and was the greatest when the days were longer. The decrease of the evening CO₂ emission appeared to begin at about the end of twilight. He also confirmed the experimental results reported by another physician that the quantity of CO₂ emitted from the lungs was affected by factors such as a vegetable diet, ingestion of wine, diluted nitric acid, or mercury. The experiments with mercury were made upon a man suffering from syphilis, who had been ingesting the metal for several weeks (Prout, 1814).

Urine and its components

In a paper about the nature of the components of urea (Prout, 1817, 1818a), Prout remarked he wanted to study only urea, the saccharine matter (carbohydrates), and lithic (uric) acid, because the other constituents of urine had an uncertain nature. Urea had been obtained in an impure state by Hilaire-Marin M. Rouelle (1718-1779) in 1773 under the name *matière savonneuse* (saponaceous extract of urine) and further studied by William Cruickshanks (1745-1800) and by Antoine François Fourcroy (1755-1809) and Nicholas Vauquelin (1763-1829), who named it *urée* (Fourcroy and Vauquelin, 1799a,b). A few years later, Berzelius succeeded in preparing urea in a pure state, although he did not report the procedure he used (Prout, 1817; Prout, 1818a).

Prout gave a detailed description of the method he had developed for obtaining urea in a highly pure state, pointing out he had described it three years before during his lectures about animal chemistry. It consisted in evaporating urine to a syrupy state followed by addition of portions of nitric acid until it became a dark colored crystalline mass. This was washed with cold water and the excess acid neutralized with a concentrated solution of potassium or sodium bicarbonate. The resulting solution was gently evaporated until the bicarbonate crystallized and the remaining impure liquid was then treated with a large amount of animal charcoal and converted into a paste. Treatment with water separated the urea in a colorless

state, and evaporation to dryness and washing with boiling alcohol dissolved the urea leaving out the saline and extraneous matter. The alcoholic solution was evaporated to dryness, and the process repeated several times. The urea thus prepared appeared as transparent colorless crystals, shaped as four-sided prisms having a density of about 1.35, which did not affect litmus or turmeric papers and did not decompose in contact with the atmosphere although they were slightly deliquescent. They dissolved easily in boiling water and partially in alcohol. Urea was decomposed by fixed and earth alkalis yielding ammonia carbonate; it combined with most of metallic oxides; the combination with silver oxide was grayish and detonated on heating. It formed crystalline compounds with nitric acid oxalic acids yielding crystalline compounds, sparingly soluble in water (Prout, 1817; Prout, 1888a).

Prout determined the composition of urea by oxidizing it with copper oxide and conversion into water, carbon dioxide and nitrogen (the paper gives a description of the apparatus and the mode of operating it). To assure the accuracy of the measurement of the volume of the gases Prout used a very delicate balance, with platinum weights made by him. In addition, he dried all the substances in vacuum with sulfuric acid at a temperature above 200°C. Analysis of the gases indicated urea contained 6.66% hydrogen, 19.99% carbon, 26.66% oxygen, and 46.66% (weight) of nitrogen; values very similar to the ones obtained from its formula (19.99, 6.71, 26.64, and 46.66%). Prout also analyzed urea nitrate because he believed this compound might be useful to estimate the quantity of urea present in any given specimen of urine. Sugar, diabetic sugar, and milk sugar were submitted to the same analytical method and all found to contain 6.66% hydrogen, 39.9% carbon, and 53.33 wt % oxygen. Analysis of the lithic acid indicated its composition was 2.857% hydrogen, 34.286% carbon, 22.857% carbon, and 40.000 wt % nitrogen (Prout, 1817; Prout, 1818a).

Prout concluded as follows: (1) the atomic theory or theory of definite proportions (Proust and Dalton) was followed in every case and it would probably be satisfied by all animal or vegetable substances capable of forming crystalline compounds; (2) the above compounds appeared to be formed by the union of more simple compounds; as urea of carbureted hydrogen (methane) and nitrous oxide, lithic acid of cyanogen and water, etc., that is, their artificial formation fell within the limits of common chemistry; (3) the remarkable relation existing between urea and sugar seemed to explain in a satisfactory manner the problem of diabetes, which could be considered as a "depraved secretion of sugar"; and (4) lithic acid had a composition very different from urea, justifying the finding that phosphoric diabetes was accompanied by an excess of urea but not by an excess of lithic acid (Prout, 1817; Prout, 1818a).

In following works on the subject (Prout, 1818b; Prout, 1819e), Prout studied in more detail lithic acid, oxalic acid, and cystic oxide (cystine, today) and how, together with urea and sugar, they associated with the albumen of the blood of a person laboring under a slight inflammatory affection, but otherwise in good health. The albumen present in the serum was separated and oxidized with copper oxide. Analysis of the gases produced indicated it contained 7.77% hydrogen, 50.00% carbon, 26.66% oxygen,

and 15.55 wt % nitrogen, a composition very similar to the one reported by Gay-Lussac and Thenard (Gay-Lussac and Thenard, 1811).

The next step was to repeat the procedure using blood from a person suffering from diabetes. Measurement of the specific gravity of the serum of a healthy person and of one suffering of diabetes gave the values 1.0448 and 1.0295, respectively. The amounts of albumen were identical for both situations. The diabetic and healthy urine extracts were found to contain 6.5 and 35 to 40 parts of nitrogen respectively. Prout also reported that his previous analysis of lithic acid was wrong and that the correct figures were 2.22% hydrogen, 40.00% carbon, 26.66% carbon, and 31.11 wt % nitrogen (Prout, 1818b). Prout built his own portable apparatus for determining the specific gravity of the urine in diabetes and other diseases. The scale of the same carried one mark for healthy urine and another for diabetes (Prout, 1825).

Prout performed the analysis of samples of mulberry calculus (so called because its resemblance to the fruit) and cystic oxide, and found them to contain 4.4% hydrogen, 20.00% carbon, and 75.5 % oxygen, 5.00% hydrogen, 30.00% carbon, 53.33% carbon, and 11.68 wt % nitrogen, respectively (Prout, 1818b).

In another publication, Prout reported the results of the examination of the purple substance produced by the action of nitric acid and heat on lithic acid, a reaction considered to be typical of this acid (Prout, 1818c). His results indicated the substance was a compound of ammonia and a particular principle having the properties of an acid. Prout named the principle purpuric acid, as suggested by Wollaston because of its ability to form red or purple colored substances with bases (Wollaston, 1810). Purpuric acid was found to be slightly soluble in water and insoluble in alcohol and ether; it dissolved readily in concentrated acids and in alkalis; it did not affect litmus paper. In contact with air it did not deliquesce although it acquired a purple tint probably caused by absorption of ammonia from the atmosphere or release of this gas by its spontaneous decomposition. It combined with alkalis, alkaline earths and metallic oxides, indicating it was an acid and not an oxide. Analysis by oxidation with copper oxide indicated it contained 4.54% hydrogen, 27.27% carbon, 36.36% oxygen, and 31.81 wt % nitrogen.

Prout prepared a series of purpurates (ammonia, potassium, sodium, calcium, strontium, magnesium, aluminum, gold, etc.) and described their properties. All these salts had beautiful colors, a fact that led Prout to speculate purpuric acid and its compounds probably constituted the basis of many animal and vegetable colors. He remarked that the pink sediment, which appeared in the urine of people with fever, appeared to owe its color to ammonia purpurate (and perhaps occasionally to sodium purpurate). He believed some of these purpurates could find use in paints and in dyeing wool and other animal products (Prout, 1818c; Prout, 1820a).

In 1822, Alexander Marcet (1770-1822) reported having examined a sample of the unusual urine discharged during several months by a healthy seventeen-month old boy. This urine was black and opaque though without any sediment or turbulence. After two days the sample retained its black color but had developed an ammoniacal smell and was quite

alkaline. Marcet kept the sample for several years and noticed that the color remained, without depositing any sediment, and having the same ammoniacal smell. Its specific gravity was 1.0222; treated with any acid it produced an effervescence and slight turbidness without changing its color. Treated with dilute nitric acid and then evaporated to dryness did not leave a pink stain showing it did not contain a sensible quantity of lithic acid. Provoked by these results Marcet asked Prout to make a more detailed analysis of this urine (Marcet, 1822). Prout reported that the residue of the urine did not contain lithic acid or urea, and although addition of diluted acids did not produce an immediate change in color, a black precipitate was formed after standing for same time (Prout, 1822b). The remaining liquid was transparent and slightly colored. Treatment of the black residue with ammonia, followed by evaporation, left a black or deep brown residue, which appeared to be ammonia compound, which Prout named melanic acid.

Prout summarized all his findings about urine in a book, which “established his reputation as a chemist and practical physician” (Prout, 1821; Brock, 1965).

Blood

In 1816, Prout published a long paper on the origin and properties of blood (Prout, 1816b). After a historical analysis of the available information he stated his belief “that the blood begins to be developed, in all of its parts, from the first moment of digestion, and it gradually becomes more and more perfect as it passes through the different processes to which it is subjected, until its formation is completed, when it represents a solution in much water, of all the parts of the animal body, to which it belongs.” The process of formation took place in three stages, chymification, chylification, and sanguification, and the products of these operations were chyme, chyle, and blood, respectively. The properties of each varied gradually and almost imperceptibly ran into each other; thus chyle as it existed in the lacteals differed but little from the chyme in the intestines, and the blood differed but little from the chyle, when perfectly formed, and about to enter the sanguineous system from the thoracic duct. Chyme was incipient blood, as it existed in the intestines; chyle as blood as it existed between the intestines and the thoracic duct inclusive, and blood as it existed in the sanguineous system (Prout, 1816b).

Prout then described the properties of the chyme and chyle of several animals (dog, ox, rabbit, turkey, pigeon, carp, and mackerel), and discussed the phenomena and nature of the processes by which substances foreign to animal bodies were assimilated. Previous investigators had assumed the digestive process was the result of a variety of factors, among them: concoctive fermentation, heat, Archæus (a spirit that presided over and governed bodily processes), trituration, fermentation, and the gastric juices. The latter were assumed to originate from at least four different sources, each providing a clearly different fluid: the salivary glands, the mucous coat and exhalents of the stomach itself, and the gastric glands. These different fluids, with often a portion of bile, were always found mixed together in the stomachs of animals, at different times in

very different proportions. Lazzaro Spallazani (1729-1799) maintained the natural fluids of the stomach were naturally neutral. The digested alimentary matters, as fast as the digestion process reduced them, passed into the duodenum where they experienced a remarkable change in their appearance and properties. These changes were induced by the action of the bile and the pancreatic juice and resulted in the evolution of a gaseous product, a distinct precipitation of an excrementitious nature, the mixture becoming neutral, and formation of an albuminous principle. The amount of the latter decreased as the material progressed in the alimentary channel, and at the end all that was left was excrementitious matter, consisting of the undissolved parts of the food, combined with the mucus of the intestines, and the biliary principle (Prout, 1816b).

The phenomenon of chylification was little understood. The proportion of albuminous matter, particularly fibrin, appeared to be much less. According to Prout, part of these albuminous principles were either formed altogether or its formation was at least completed during the passage of the chyle through the lacteal vessels; for this reason he named it incipient albumen. Incipient albumen was assumed to be similar to the caseous principle of milk, making the chyle analogous to milk in its properties. The chief objective of the digestive process appeared to be the creation of an aqueous solution of the alimentary matters, and the principal agents, who carried on this solution, appeared to be the fluids of the stomach. The chyle from the thoracic duct flowed into the sanguineous system where it mixed with the general mass of circulating fluids and almost immediately passed through the lungs, where it was exposed to air, and appeared to undergo the last final process and to be converted into blood (Prout, 1816b).

Prout went on to discuss the following details of the phenomenon of respiration: (1) whether is of the same nature in all animals, (2) whether any gas can be substituted for oxygen in respiration, (3) whether its degree is the same in different classes of animals compared with one another, or in different animals of the same class, (4) whether they be liable to any differences in degree in the same animal at different times, (5) whether the blood as a whole, or in part, participates in the production of these phenomena, and (6) what is the intimate nature and use of respiration.

With respect to all animals having organs of respiration similar to man, the same manifestations took place, but in the inferior animals some modifications occurred; for example, fishes had no lungs but could not live in water deprived of air; the conversion of oxygen into CO₂ was carried on with the help of the gills. Insects died very soon if the holes of the stigmata through which the air entered into their bodies, were blocked with oil or honey. Experiments had clearly shown that that no other compound except atmospheric air, containing 20% oxygen, was capable of supporting life. Pure oxygen and gaseous mixtures containing a larger proportion of this gas than atmospheric air, destroyed life in a short time by over excitation. Gases of a gentle and inactive character, such as hydrogen and nitrogen, when pure or in too large proportion destroyed life by opposite means or suffocation, while other such as methane, CO₂, etc., were fatal simply because of their deleterious properties. None of the higher animals were able to exist, even for a few minutes, without oxygen, while

many inferior animals could exist for a considerable time upon very little. Prout experiments had shown that the amount of CO_2 was liable to be very materially affected by the quantity of the gas in the same individual, by various circumstances (see above). It also appeared from the experiments of Berzelius, that the coloring matter of blood was the principle from which the carbon was chiefly derived in respiration (Prout, 1816b).

It had been supposed that one use of respiration was to convert the chyle into blood, a process assumed to be carried on by the removal of superfluous carbon, since more CO_2 was released when the chyle was believed to be entering the blood. Prout stated his conviction that the galvanic agency was extensively employed in the animal economy by the vital principle, and that respiration was the function by which it was generated or triggered on. Within this picture, the coloring principle represented the most oxidizable metal in the galvanic battery, and CO_2 represented the metallic oxide formed during its action. The action of the ordinary galvanic battery continued as long as any of the acid employed to stimulate it remained in the free state. Clearly, this required the exertion of some attractive power between the particles of the oxygen and the metal, by which they were jointly and equally, directed one towards the other. Hence a similar type of attraction had to take place between the carbon and oxygen in the lungs, with the following galvanic excitation. The only difference between the two cases was the mode in which the particles of the metal and carbon existed, those of the metal being amassed and thus unable to move towards the oxygen, while those of the carbon were isolated, and free to move to the oxygen or meet it half way (Prout, 1816b).

The last part of this paper described the properties of blood and its components (albumen, serosity, fibrin, and red particles). Serosity was the fluid holding mechanically suspended in the red particles.

Three years later Prout published a corrected version of this paper, in which he gave "a summary and connected view of what is known respecting the phenomenon and intimate nature of sanguification" (Prout, 1819b). Once again he stated that the blood began to be formed or developed from the food, in all its parts from the first moment of its entrance into the duodenum, or even, perhaps, from the first moment of digestion, and it gradually became more and more perfect as it passed through the different stages to which it was subjected, until its formation was completed in the sanguineous tubes, when it had become an aqueous solution of the principal textures and other parts of the animal body to which it belonged. The main components of blood were albumen, fibrin, and the coloring body, assumed to represent the common cellular, muscular and nervous texture, respectively. The principal conspicuous stages in the formation of blood in all the more perfect animals were digestion, chymification, chylification, and sanguification. The first process was restricted to the stomach, the second to the duodenum, the third to the lacteals, and the fourth to the blood vessels.

Prout went on to describe the phenomenon of digestion in a rabbit, a pigeon, a carp and macquerel.

Prout's master piece on digestion was his paper *On the Ultimate Analysis of Simple Alimentary Substances, with some Preliminary Remarks on Organic Analysis* (Prout,

1827), which earned him the Copley medal, the highest distinction of the Royal Society of Physicians. In the opening statements Prout indicated that he had "proposed himself to investigate the modes in which the three or four elementary substances entering into the composition of organized bodies are associated so as to constitute the infinite variety occurring in nature." From his studies about the process of digestion he had come to the conclusion that the principal alimentary matters employed by man and the more perfect animals could be classified in three classes, namely, the saccharine (carbohydrates), the oily (fats), and the albuminous (proteins). His main purpose was to determine their exact composition and the modes in which they associated to generate the infinite variety occurring in nature. The present paper discussed the proper ways of analyzing organized bodies, and the composition of the saccharines (Prout, 1827).

After a historical review of the state of the art of analysis, Prout discussed the problems in oxidizing organic matter with copper oxide. The latter was hygrometric, but also "condensed air". After being used in the combustion tube and then triturated and burned again, it would show invariably a gain in weight, instead of the expected loss. According to Prout the gain in weight was due to a combination of the reduced oxide with the oxygen present in the tube. When a substance composed of hydrogen, carbon, and oxygen was burned in a given quantity of oxygen gas, the volume of the gas remained the same when hydrogen and carbon were present in the substance in the proportion in which they form water, or it increased when oxygen exceeded that proportion, or it diminished, when there was an excess of hydrogen. Prout then described the apparatus he had developed to determine the adequate situation, while eliminating the effect of moisture. In this paper he reported the analysis of several saccharines (sugar candy, honey sugar, milk sugar, starches, vinegar, lignin, etc.), a category that included all those substances in which hydrogen and oxygen were combined in the proportion they form water (Prout, 1827).

Prout remarked that he believed that the minute quantities of foreign bodies normally present in all organic products, instead of being mechanically mixed with them, as generally held, they performed the most important functions; organization could not exist without them. When a crystallized substance passed into the organized state its chemical composition frequently remained essentially the same, and the only difference, which could be traced in it, was the presence of small amounts of water, and invariably of minute portions of some of the foreign bodies mentioned before. All these appeared not only to destroy its power of crystallization, but also usually to change entirely its sensible properties. Prout suggested to name merorganized those substances formed essentially on the principles of crystallized bodies, but not capable of assuming that form, probably on account of the presence of the foreign bodies mentioned before. "By these incidental matters... the ordinary essential properties of the essential elements of the organized living structure are variously modified; in particular, that the essential elements are hindered from assuming a regular crystallized form. Moreover, these incidental matters entering into the composition of a living body apparently furnish the organic agent new powers

utterly beyond our comprehension... Thus starch consider as merorganized sugar; the two substances having... the same composition essential composition, but the starch containing minute portions of other matters... (which) prevent its constituent particles from arranging themselves in the crystalline state, and thus cause it to assume totally different sensible properties" (Proust, 1827).

In 1831 Prout was selected to give the Gulstonian lectureship^b, which he named *The Application of Chemistry to Physiology, Pathology and Practice* (Prout, 1831). Prout chose as subject of the lectures an expanded view of his ideas about digestion, supplemented with religious arguments, as well as speculations about the future relation between chemistry and physiology. Being a very religious man, he uncovered his beliefs "upon which the organic agent operates and the nature of the influence it exerts on the formation of organic products... this view of the subject leads us to the conclusion that in different instances it is (the organic agent) endowed with different degrees of power, but that in all cases it must be considered as an ultimate principle, endowed by the Creator with a faculty short of intelligence by means of which it is enabled to construct such a mechanism from natural elements... and natural agencies..."

Gastric fluid

According to Prout, most scientists believed that a free or at least an unsaturated (not neutralized) acid was usually present in the stomachs of animals, and was in some manner connected with the process of digestion. Lazzaro Spallanzani (1729-1757) had hypothesized that gastric fluids when in a perfect natural state were neither acid nor alkaline, although the contents of the stomach were normally acid. With respect to the nature and origin of this acid there were many conflicting opinions, some considered it as an acid, *sui generis*, others believed it was phosphoric, acetic, lactic, etc.; that it was derived from the stomach itself, from the food, it was a result of fermentation, etc. etc. In this paper, Prout was intent in proving that the acid in question was hydrogen chloride, its relation with the pathology and physiology of the digestive process, and other important animal functions (Prout, 1824).

In his experiments Prout removed the contents of a rabbit immediately after its death and repeatedly washed them with cold distilled water until it gave no reaction. The resulting total liquid, of a clear acid nature, was divided into four portions; the first one was evaporated to dryness and the residue burned in a platinum vessel. The saline residue was dissolved in distilled water and its chloride content determined by means of silver nitrate; the second portion was first treated with an excess of potassium hydroxide and then dried and burned. The chloride content was determined as before. The third portion was neutralized with a solution of potassium hydroxide of a known concentration. The result indicated the amount of free acid present. Adding the results obtained from the first and third

portions, and subtracting this sum from the total quantity of HCl present, determined the total quantity of hydrochloric acid combined with ammonia. The remaining fourth portion of the original fluid was reserved for miscellaneous experiments and for determining the possible presence of other acids (Prout, 1824).

The results of these experiments proved that free or at least unsaturated HCl is present in substantive amounts during the digestive process. Similar results were obtained with the fluids present in the stomachs taken from a horse, a calf, and a dog. Prout also found free HCl in the acid fluid ejected from human stomach in severe cases of dyspepsia (Prout, 1824).

François Leuret (1747-1851) and Jean-Louis Lassaigne (1800-1859) contested Prout's results, claiming that they found free lactic acid in the stomach; similarly, Friedrich Tiedemann (1781-1861) and Leopold Gmelin (1788-1853), asserted they had found free acetic, butyric and hydrochloric acids. The latter two, nevertheless, confirmed that Prout had been the first to clearly identify HCl in the gastric juice (Tiedemann and Gmelin, 1826; Prout, 1826; Prout, 1828). Eventually, Prout's results were confirmed by additional tests made, particularly by John G. Children (1777-1852), and William Beaumont (1785-1853). The results of the latter were particularly decisive because they were carried on Alexis St. Martin; a 19-year-old French-Canadian fur trapper who had been wounded from an accidental gunshot. As a consequence of this incident, the young man developed a gastric fistula that remained after his wounds had healed.

Proust hypothesis

In 1815 an anonymous paper was published in *Thomson's Annals of Philosophy*, discussing the relationship between the specific gravities of bodies in the gaseous state and the weights of their atoms (Prout, 1815f). In the following number, the editor of the journal, Thomas Thomson (1773-1852), wrote: "A very important paper was published in a late number... though the paper is anonymous, several circumstances enable me to fix with considerable certainty the author... I do not consider myself as at liberty to mention his name" (Thomson, 1816a). Nevertheless, in a paper published in the same volume, Thomson goes ahead and identifies Prout by his name (Thomson, 1816b).

In his opening statement, Prout wrote: "The author of the following essay submits it to the public with the great diffidence, for though he has taken the utmost pains to arrive at the truth, yet he has not that confidence in his abilities as an experimentalist as to induce him to dictate to others far superior to himself in chemical acquirements and fame. He trusts, however, that its importance will be seen and someone will... verify or refute its conclusions... if they should be verified, a new and interesting light will be thrown upon the whole science of chemistry." Prout added that all the observations presented were founded on Gay-Lussac's doctrine of volumes. He then proceeded to calculate the specific gravities of the four elementary gases oxygen, nitrogen, hydrogen, and chlorine, of a large number of elementary substances which were not in the gaseous

^b Annual lecture series given on behalf of the London Royal College of Physicians. They were established in 1639 by a bequest from Theodore Gulston (1572-1632).

state at ordinary temperatures (for example, iodine, carbon, sulfur, calcium, iron, sodium and barium), and of another group by analogy, for which the specific gravities were still uncertain. Some examples were as follows:

1. Oxygen and nitrogen. It was known that air was constituted of four volumes of nitrogen and one of oxygen. Considering the atomic weight of oxygen to be 10 and that of nitrogen to be 17.5, it would be found by weight that air consisted of one atom of oxygen and two of nitrogen, that is percentage wise, $(10/45)(100) = 22.22$ and $(35/45)(100) = 77.77$. The respective specific gravities, x and y , were now easily calculated assuming that of air to be 1, and noting that $(x/y) = (22.22/77.77)$ and $(x + 4y)/5 = 1$. Solving the equations yielded $x = 1.1111$ and $y = 0.9722$.
2. Hydrogen. The specific gravity of this gas was not known with enough accuracy because of its extreme lightness and the difficulty of drying it completely. To get around the problem Prout decided to calculate the specific gravity from that of a heavier compound, into which it entered in a known proportion. He selected ammonia because its specific gravity (0.5902) had been reported by several well-known scientists, and contained three volumes of hydrogen per volume of nitrogen. Repeating the above procedure gave $(3x + 0.9722)/2 = 0.5902$ and $x = 0.0694$. Comparison with the results of item 1 indicated that the specific gravity of oxygen and nitrogen were 16 times and 14 times, respectively, that of hydrogen.
3. Carbon. Since the atomic weight atom of carbon was 7.5 then its specific gravity in the gaseous state would be 0.4166, that is, exactly 12 times that of hydrogen.
4. Calcium. Marcet had found that calcium carbonate contained 43.9% CO_2 and 56.1 wt % CaO . Hence $(43.9/56.1) = (27.5/35)$, giving $35 - 10 = 25$ as the atomic weight of calcium. Consequently, the specific gravity of a volume of gaseous calcium was 1.3888, or exactly 20 times that of hydrogen.

The results of all the calculations were presented in four tables giving, among other pieces of information, the specific gravity of the substance and its ratio against hydrogen considered as 1. Table 1 referred to 14 elements, Table 2 to combinations with oxygen, Table 3 to compounds with hydrogen, and Table 4, the estimated figures for 24 more elements.

The final conclusions were as follows: (a) all the elemental numbers, assuming hydrogen as 1, were divisible by 4, except carbon, nitrogen and barium that were divisible by 2, indicating that they were modified by a higher number than that of unity of hydrogen; (b) oxygen did not seem to enter into a compound in the ratio of two volumes of four atoms; and (c) all gases, even after being dried as much as possible, still contained some water. The amount of moisture could be ascertained with the greatest accuracy.

The apparent discrepancies were largely removed in a second publication (Prout, 1816a), which now added two important conclusions: (a) "There is an advantage in considering the volume of hydrogen equal to the atom, as in this case the specific gravities of most, or perhaps all elementary substances (hydrogen being 1) will either exactly coincide with, or be some multiple of, the weights of their atoms; whereas if we make the volume of oxygen

unity, the weights of the atoms of most elementary substances, except oxygen, will be double that of their specific gravities with respect to hydrogen, and (b) "If the views we have ventured to advance be correct, we may almost consider the $\pi\rho\omega\tau\eta$ $\nu\lambda\eta$ of the Ancients to be realized in hydrogen; all opinion, by the by, not altogether new. If we actually consider this to be the case, and further consider the specific gravities of bodies in their gaseous state to represent the number of volumes condensed into one; or, in other words, the number of the absolute weight of a single volume of the first matter ($\pi\rho\omega\tau\eta$ $\nu\lambda\eta$), which they contain, which is extremely probable, multiples in weight must always indicate multiples in volume, and vice versa; and the specific gravities, or absolute weights, of all bodies in a gaseous state, must be multiples of the specific gravity or absolute weight of the first matter ($\pi\rho\omega\tau\eta$ $\nu\lambda\eta$) because all bodies in their gaseous state which unite with one another unite with reference to their volume."

Prout's papers were commented by Thomson as follows: (1) Prout had endeavored to show that the specific gravity of any body could be obtained by multiplying the weight of its atom by half the specific gravity of oxygen gas, that is, the weight of an atom of every body was always double its specific gravity in the gas state (Avogadro's hypothesis), (3) the set of atomic weights of gases could be divided into three groups, in the first group (oxygen, ethylene) the weight of atom and its specific gravity were represented by the same number, in the second (chlorine, phosgene, CO_2 , nitrogen, steam, etc.) the weight of the atom was double that of the specific gravity, and in the third (HCl, ammonia, HI, etc.), the weight of the atom was four times the specific gravity (volume).

Meteorology

In 1832 Prout read a paper at the British Association meeting at Oxford, summarizing his observations on "the absolute weight of atmospheric air and the law of its expansion by heat" (Prout, 1831-1832; Brock, 1967).

According to Prout, in determining the absolute weight of a gaseous body, there are three things to be especially considered: the barometer, the thermometer, and the weights and measures to be employed. The barometer employed in all his experiments was manufactured expressly for the purpose and with the greatest care (a detailed description is given). The distances on the scale were marked using those from a standard formerly belonging to Henry Cavendish (1731-1810), and which was presumed to be identical with the old national standard. Prout remarked that, nevertheless, there could exist a slight constant error of about +0.003 inch, affecting all his results. The balance was also made on purpose and in such as way as to obviate all errors from buoyancy, etc. The weights employed were made of platina and verified with the National standard and the measures were determined from the weights in grains of water at 62 °F. Prout described his experiments as follows: "The air to be weighed was first passed through limewater into a large bell glass receiver where it was permitted to remain for six or eight hours, with the view of separating the carbonic acid present. One portion of it was then introduced into a similar smaller apparatus filled with the

strongest sulfuric acid, while another portion was conveyed into a similar apparatus filled with distilled water. With these two fluids the different portions of air were permitted to remain in contact for at least twelve hours, with the view in the one instance of separating the whole of the water present, and in the other of saturating it with that fluid. A known quantity of air in each state, as determined by a very simple gasometer, was then introduced into the weighing balloon and its weight carefully determined with all the necessary precautions. In weighing air at 32°, an apparatus on the same principle was employed, but so constructed, that the whole gasometer would be with ice for some hours before the air was changed” (Prout, 1831-1832).

A table reported the results of 87 experiments conducted between December 16, 1831 and March 24, 1832, at about noon, and as nearly as possible under similar circumstances. The mean of all the experiments, with the one exception noted below, showed that the weight of 100 in³ of dry atmospheric air, free of CO₂, at 32°F and 30 inches of mercury, in the latitude of London, was 32.7958 grains. Prout remarked that a strange thing happened on February 9, “on which day the weight of the air was 32.8218 grains; and it is remarkable that after this period, during the whole time that the experiments were continued, the air almost uniformly possessed a weight above the usual standard so that... the mean of the 42 observations after this crisis, exceeds the mean of the 44 preceding it by no less than 0.0118 g. The apparatus employed, and the care taken, were the same throughout... there can be no doubt that the difference... really existed, and did not arise from error of experiment. Prout gave a surprising explanation to this anomaly: “... almost precisely at the period above mentioned, the wind veered round to the north and east... and... under these circumstances the epidemic cholera first made its appearance in London. It would seem, therefore, as if some heavy foreign body had been diffused through the lower regions of the atmosphere about this period, and which was, somehow or other, connected with the disease in question. The action of this body is quite unknown; but it could have scarcely possessed acid or alkaline properties, as in the former instance it would have been separated by the limewater and in the latter by the sulfuric acid.”

Prout also commented: “the weight of the air is observed to be very unsteady, and usually heavier about the new and the full moon. Whether this arises from aerial tides has not been satisfactorily determined. It may, however, be proper to observe that many of the minute differences in the weights of the air at different times are more apparent than real, and depend upon the sluggishness of the mercurial barometer, which prevents it from being an exact measure of the movements of the lighter and more mobile fluids.”

Another table reported the results of nearly a thousand experiments made upon dry and moist air, at different temperatures between 32°F and 72°F. The results proved beyond a doubt that the readings of mercurial and air thermometers did not change at an equal pace between 32 and 72°F as was generally supposed, but that there was a gradually increasing difference from 32° upwards, and amounting at 72°, to upwards of 5/8ths of a degree. This result was very significant because it proved what very little reliance could be placed on experiments hitherto made with gases, using the air thermometer.

An interesting feature of this paper is that Prout used the word convection to describe heat transfer by a rising stream of air. Benjamin Thompson (Count Rumford, 1753-1814) had been the only one to use this term before.

Miscellaneous

Egg incubation

In 1816 Prout began to study the nature of the changes that took place in an egg during its incubation, particularly on the possible role that the earthy and saline matters played in the formation of the skeleton of the chick. For this purpose, he conducted experiments on recent and unaltered eggs of fowl, and at the end of the first, second, and third week of incubation. The first part of this work, published in 1822 (Prout, 1822a), reported the changes that took place in fresh and unaltered eggs. The specific gravity of new laid eggs varied from 1.08 to 1.09; when kept for some time, they rapidly lost weight and eventually became lighter than water. The diminution of specific gravity was produced by the substitution of air for a portion of the water, which escaped. A table was given showing the gradual loss of weight during a period of two years. The egg lost about 0.75 grains in 24 hours, and this uniformly during a very long period. The loss appeared to be somewhat greater in summer than in winter. The relative proportions of the shell, albumen, and yolk of a larger number of eggs was found to be 10.69:60.42:28.89. An egg boiled in water lost weight, particularly if it was removed from the water when boiling and allowed to cool in the air. The water was found to contain about 2-3% of the saline contents of the egg. The saline residue in the water was found to be highly alkaline traces of animal matter, sulfuric and phosphoric acids, chlorine, an alkali, lime and magnesia, and carbonate of lime and magnesia. The paper reported the relative proportions of composition of these components in the albumen and the yolk of a recent laid egg.

Prout then analyzed the eggs at increasing periods of incubation and reported that during the first, second, and third weeks of incubation the egg lost 5, 13, and 16% of its original weight, respectively. After the first week the yolk became more fluid than usual and as the liquid amnii increased, the albumen began to assume a peculiar appearance. At the end of two weeks the animal had acquired a considerable size; the albumen had diminished in a corresponding degree and had acquired a very firm consistency, while ossification had already begun. At the end of three weeks all the important changes of incubation had been completed, the albumen had disappeared or had been reduced to a few dried membranes and an earthy residuum. The yolk had considerably reduced in size and taken into the abdomen of the chick, while the animal had attained a weight nearly corresponding to the original weight of the albumen.

Prout summarized his findings as follows: (a) The relative weights of the constituent principles of different eggs varied considerably and during incubation the loss in weight exceeded by about eight times that which the egg sustained by ordinary keeping; (b) in the early stages of incubation an

interchange of principles took place between the yolk and a portion of the albumen, which passed into a substance analogous in its appearance and properties to curd of milk; and (3) as incubation proceeded the phosphorus of the yolk became phosphoric acid, which combined with lime and formed the bones of the chicken. Prout could not ascertain the origin of the lime, which did not pre-exist in any known state in a fresh egg, except in the shell (Prout, 1822a).

Analysis of organic substances

According to Prout, Berzelius had shown that the doctrine of definite proportions applied equally well to organic compounds, with only some slight modifications. Prout was intended in showing that this type of analysis could be highly assisted by using the synoptic scale of equivalents developed by Wollaston (Wollaston, 1814). Use of this scale allowed establishing with almost absolute certainty the number of atoms of each element present in the composition of a ternary or quaternary compound. To do so it was enough to know the proportions of at least two of the elements entering into an organic compound and the weight of its atom (molecule) or some multiple of it. The procedure recommended by Prout consisted in modifying Wollaston's scale by pasting two slips of drawing paper on its edges, wide enough to just overlap over and cover the margins containing the names of the chemical substances and to coincide with the graduated edges of the slide. On these slips of papers were then marked the multiples of an atom of oxygen, hydrogen, and carbon, from one to 10, and of nitrogen from one to four, five, or more (Prout 1815e).

Prout gave several examples to illustrate his procedure, each one illustrating different information available. In one of them he assumed a compound of weight 46.5 (assuming oxygen to be 10), and that 46.5 parts of the compound contained 15.15 of carbon, 1.34 of hydrogen, and 30.01 of oxygen. The procedure now consisted in placing 10 opposite oxygen, and then opposite each of the numbers respectively was found the number of atoms of each element required. Thus, opposite 15.15 would be 2 carbon; opposite 1.34 hydrogen, 1 hydrogen; and opposite 30.01 oxygen, 3 oxygen. Hence, the compound consisted of three atoms of oxygen, two of carbon, and one of hydrogen (Prout 1815e).

Prout then described the procedure and equipment he recommended to carry on the accurate analysis of an organic compound. One basic requirement was to dry the substance completely by heating it at 100°C, in a vacuum in the presence of sulfuric acid. To determine the quantities of the elements entering into an organic compound, he recommended using Berzelius method, based on oxidizing the compound with potassium chlorate, a technique introduced by Louis Gay-Lussac (1778-1850) and Louis-Jacques Thenard (1777-1857). Although the method was very accurate, it was also complicated to use. For this reason Prout thought that it was better to determine the quantity of one element, and carry on separate experiences for each element it was desired to ascertain. This paper also described a spirit lamp he developed in order to improve the combustion process (Prout, 1815e; Prout, 1820b; Prout, 1822a).

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