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John William Draper

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ABSTRACT
John William Draper (1811-1882), a physician, did extensive work on the nature of radiant heat, in proving that the rays of all wavelengths are capable of producing chemical changes, in the determination on the nature of the rays absorbed in the growth of plants in sunlight, and on the interpretation of capillary phenomena in physiology and in plant growth. He used intensively and smartly the science and art of photography, then in its infancy, to give visual proofs of his results. He was one of the first to photograph a human face, the moon, and the solar spectrum.

KEYWORDS: optics, photochemistry, photography, phosphorescence, tithonic rays, spectrum, capillary phenomenon, osmosis, endosmosis

Resumen
John William Draper (1811-1882), un médico, realizó investigaciones extensas sobre la naturaleza del calor radiante, para probar que los rayos de toda longitud de onda son capaces de producir cambios químicos; también sobre la naturaleza de los rayos absorbidos en el proceso de desarrollo de plantas bajo la luz solar, y en la interpretación de fenómenos capilares en fisiología y en el crecimiento de plantas. Usó en forma extensa e inteligente la ciencia y el arte de la fotografía, entonces en su infancia, para dar prueba visual de sus resultados. Fue uno de los primeros en fotografiar la cara de una persona, la luna, y el espectro solar.

Palabras clave: óptica, fotoquímica, fotografía, fosforescencia, rayos titónicos, espectro, capilaridad, ósmosis, endoósmosis

Life and career (Barker, 1886; Hentschel, 2002)

John William Draper was born in May 5, 1811 in St. Helens, Merseyside, England, the third child and only son of Sarah Ripley and John Christopher Draper, a clergyman of the Wesleyan denomination, having moderate economic means.

John William received his earlier education in his own home from private tutors and, at the age of eleven, entered a public school at Woodhouse Grove, then supported by the Wesleyans. Here he showed an early promise in science, and as reward, he was selected in 1824 to deliver the customary address from the school to the Wesleyan conference, which met that year at Leeds. Afterwards he returned home to continue his education under private tutors. In 1929, after finishing his basic studies, he matriculated at the new University of London (afterwards, University College), which had been just been inaugurated to provide higher education to scientists, workingmen, and Dissenters. There he studied chemistry under Edward Turner (1798-1837), the author of one of the earliest English textbooks in organic chemistry. Turner interested Draper in the chemical effects of light and thereby gave his career a decisive turn. In 1831, the unexpected death of Draper's father ended his academic studies without getting a degree. At that time Parliament had not yet broken the monopoly of Oxford and Cambridge for granting degrees and Draper had to be contented with a "certificate of honors" in chemistry.

In 1832, Draper married Antonia Coetana de Paiva Pereira Gardner (c.1814-1870), the daughter of Dr. Gardner, the late physician of the Emperor of Brazil; Dom Pedro I. Three boys and three girls were born to them, John Christopher Draper (1835-1885), Henry Draper (1837-1882), Virginia Draper Maury (1839-1885), Daniel Draper (1841-1931), William Draper (1845-1853), and Antonia Draper Dixon (1849-1923). John Christopher succeeded his father as professor of chemistry in the medical department of the University of New York, Henry became professor of physiology in the university and subsequently professor of analytical chemistry, and Daniel was director of the Meteorological Observatory in Central Park, New York.

Before the American Revolutionary War, several maternal relatives had immigrated to America and settled in Virginia, founding a small Wesleyan colony. In 1832, on their urging, Draper immigrated with his mother, his three sisters, and his new wife to Christianville (now Chase City), Mecklenburg County, in the state of Virginia.

Before moving to America, Draper published three scientific papers, together with William Mullingar Higgins (c.1809-1882), a Fellow of the Geological Society (Higgins and Draper, 1832ab, 1833). His first independent contribution to science was on capillarity (Draper, 1834a) and came from the private laboratory he had established in Christianville. During this period he also was busy improving the galvanic batteries (Draper, 1834b), investigating the alleged magnetic action of light (Draper, 1835a), and the analysis of a native

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chloride of carbon (Draper, 1834c) and certain ancient coins and medals (Draper, 1835b).

In 1833 Draper enrolled as a medical student at the University of Pennsylvania; the earnings of his sister Dorothy Catharine as a schoolteacher financed his studies. At the University he came directly under the motivating influence of Robert Hare's classes in chemistry and physics, and John Kearsley Mitchell (1798-1858) at that time the professor of chemistry in the Jefferson Medical College. Draper helped Mitchell when he used for the first time in the USA Jean Charles Thilorier's (1797-1852) (Thilorier, 1834) apparatus for the liquefaction of carbonic acid gas. Draper graduated in 1836; his thesis, *Glandular Action*, which was related to his current research on capillaries, also reflected Mitchell's in the researches of Henri Dutrochet (1776-1847) on osmosis (Dutrochet, 1827). It discussed the passage of gases through various barriers not having visible pores, such as soap bubbles. Draper showed that these transfusions take place instantaneously as if there was no obstacle in the way and are attended by many interesting phenomena. The special application of these experiments was in the area of physiology, to determine the processes taking place in the air cells of the lungs; how oxygen is absorbed in the blood and CO_2 released from it during inspiration. He published two papers on the subject (Draper, 1836ab).

In that same year, 1836, Draper was appointed professor of chemistry, physiology and natural philosophy at the local Hampden-Sydney College, Prince Edward County, Virginia. This was followed by appointment at the University of the City of New York in 1839, as professor of chemistry and natural philosophy at the undergraduate department. In 1840, together with Valentine Mott (1785-1865), Granville Sharp Pattison (1791-1851), Gunning S. Bedford (1806-1870), and John Revere (1787-1847), he took an active part in organizing the medical department, in which he became the professor of chemistry. At that time there were but few medical students there, probably not more than forty or fifty. But in the session of 1841-1842 the University Medical School alone enrolled 239 students, and the number in attendance at the College of Physicians and Surgeons was also significantly increased. The new Department was strongly supported by James Gordon Bennett (1841-1918), the founder, editor and publisher of the *New York Herald* newspaper, a close friend of Draper.

The first president of the new medical college was Mott, who was also professor of surgery. Draper was elected secretary, and in 1850, upon the resignation of Mott, he succeeded to the presidency (a post he held until 1873) (Barker, 1886; Hentschel, 2002).

Early studies of photosynthesis led to other photochemical investigations, and from 1837 he began experimenting with photography. After learning of Louis-Jacques-Mandé Daguerre's (1787-1851) work in 1839 he attempted to produce a picture of a human subject and succeeded in December 1839. During the winter of 1839–1840, Draper took the first known photographs of the moon, and remained involved with astronomical photography thereafter. He strove to identify the photochemically active rays, and in 1841 demonstrated that light reflected from one daguerreotype plate had no effect on a second. Draper was interested in every type of radiant energy, and in 1847 published results indicating that all solid bodies became incandescent at the same temperature, while the region of maximum radiant energy in their spectra moved towards the shorter wavelengths with increasing temperature. By 1857 he had shown that the maxima of solar luminosity and heat occurred at the same point in the visible spectrum.

To isolate these active rays, Draper constructed powerful spectroscopes. By 1843 he had photographed spectral lines and developed a sensitive instrument, the *tithonometer*, for measuring the intensity of chemically active rays. It involved monitoring a photocatalyzed reaction between hydrogen and chlorine, but experiments convinced him that light affected the chlorine alone, converting it from a passive to an active state. He compared this transformation with the allotropy recently noted by J. J. Berzelius in elementary phosphorus, and in 1849 proposed that the enhanced activity of certain elements (particularly nitrogen) in organic combinations might derive from similar allotropic changes, catalyzed by solar radiation in plants, and by other forms of energy in animal tissue (Sutton, 2004).

Draper's health was disturbed during his later years by severe attacks of urinary stones, which incapacitated him for journeying. He died at Hastings, on January 4, 1882, and was buried at Greenwood Cemetery, Brooklyn, New York. His five children survived him.

Honors and awards

Draper was elected a member of many of he learned societies of Europe, among them the Accademia de Lincei at Rome, the Physical Society of London; the American Philosophical Society at Philadelphia (1843), the American Gastro-Enterological Society, American College of Surgeons, American Medical Association, National Academy of Sciences (1877) etc. He received the degree of LL.D. from the college of New Jersey at Princeton (1860) and the American Academy of Arts and Sciences of Boston awarded him the Rumford medals for his researches on radiant energy (1875). Draper was founding president of the American Union Academy of Literature, Science and Art (1869) and founding president of the American Chemical Society, ACS (1876) (Barker, 1886; Hentschel, 2002).

In 1975, Draper's house in Hastings was designated a National Historic Landmark, in 1976, New York University founded the John W. Draper Interdisciplinary Master's Program in Humanities and Social Thought (Draper Program) in honor of his life-long commitment to interdisciplinary study and in 2001, he was designated an ACS National Historical Chemical Landmark in recognition of his role as the first president of American Chemical Society.

Scientific achievements

Draper published over fifty scientific papers and about a dozen books on scientific, historical, and sociological subjects. Among them we can mention *A Treatise on the Force which Produce the Organization of Plants* (Draper, 1844c); *A Textbook on Chemistry for the Use of Schools and Colleges* (Draper 1846a); *A Textbook on Natural Philosophy* (Draper, 1847a); *Human Physiology, Statical and Dynamical* (Draper, 1856), based on his lectures at the chair of physiology; *History of the Intellectual Development of Europe* (Draper, 1863), probably his most brilliant work on a subject not related to his academic work; *Thoughts on the Future Civil Policy of America* (Draper, 1865), *History of the American Civil War* (Draper, 1867-1870); *History of the Conflict between Religion and Science* (Draper, 1874), his most controversial publication, in which he charged most Christian denominations for persecution and censorship, and outraged many believers, including his sister Dorothy; and *Scientific Memoirs: being Experimental Contributions to a Knowledge of Radiant Energy* (Draper, 1878), a collection of his papers on radiant energy,

1. *Capillarity and osmosis*

Draper investigated the phenomenon of capillarity from many points of view (Draper, 1834a, 1836ab, 1846b). Alexis Claude Clairaut (1713-1765) had already postulated that the phenomenon was due to the mutual attraction of a solid and a liquid; when this attraction amounted to less than half the cohesion of the latter, the liquid would be depressed in a capillary tube made of the solid, when it was equal to half, the liquid the level would not change, and when it was more than one half, the liquid would rise in the tube (Clairaut, 1765). Clairaut hypothesis was superseded by those of Thomas Young (1773-1829) and Pierre-Simon Laplace (1749-1827); Young believed that the bounding meniscus of a liquid was an elastic surface that acted by its tension to elevate or depress the column (Young, 1805), and Pierre-Simon Laplace (1749-1827) attributed the rise or fall of liquids to the attraction of a thin layer of the liquid immediately adjacent to the walls of the tube (Laplace, 1798). The adhesion of a glass plate to the surface of different liquids was assumed to originate from the same cause as the rise of those liquids in glass tubes. For this reason, Draper's first experiments were devoted to determine the force required to separate a glass plane from mercury. After many trials, he found that the only way to get repetitive results was to employ highly pure mercury and a glass that had been kept for some time at 500ºF. If the glass was left to cool, if it was touched lightly by the finger, or by a particle of lead, tin or bismuth, the results were instantly discordant.

Draper found that on connecting the mercury to a gold leaf electroscope its leaves hung parallel to each other and a strong force was required to separate them. Separation was accompanied by the development of a large amount of electricity; the leaves were strongly put apart by the violence of the repulsion, the mercury becoming negative and the glass disk positive. The conclusion was clear: the mercury and the glass were strongly attracting one another (Draper, 1834a). He repeated the experiment with a disk of copper of the same size, carefully and thoroughly amalgamated, washed in distilled water and dried completely. The weight required for separation was regarded as measuring the cohesion of the mercury itself. Although the experiments contradicted Clairaut's claims that the attraction of mercury for glass should amount to half the cohesion of the mercury, it was clear that the adhesion was greater than the cohesion of mercury. Not only that, the electroscope results indicated that adhesion must be an electrical attraction. To verify the latter conclusion Draper repeated the experiments using disks of gum lac, crown glass, sealing wax, sulfur, and beeswax, and proved that in every case the electrification, as measured with the torsion balance, was proportional to the adhesion as measured by the force required for separation (Draper, 1834a).

Draper went on to associate his results on capillarity with the phenomenon of endosmosis described in 1827 by Dutrochet and explained as the result of electrical currents generated in a galvanic experiment (Dutrochet, 1827). According to Draper, Dutrochet's explanation was mistaken and his results could be justified by a much simpler explanation: The liquid, whatever it may be, that has the greater attraction for the bladder or other porous substance, passes through by common capillarity; as soon as it reaches the upper surface of the system of tubes it blends with the other liquid. Draper proved his contention with a very simple experiment: He stretched a disk of bladder over a metallic ring and suspended it horizontally in equilibrium from the arm of a balance. By determining the force required to detach the bladder from the liquids (water, alcohol, and their mixture) he determined their relative cohesion. His results indicated that water passed through the bladder with a force represented by 33, while alcohol attempted the passage with a force of only 20. Water prevailed and passed through, forming on the other side a compound presenting a counter pressure of 23. Hence, water continued to rise. Draper proved that gases exhibited the same phenomena (Draper, 1834a).

In a following paper he described additional experiments on endosmosis, which were based on the assumption that any substance in contact with any other tends to diffuse into it (Draper, 1836ab). He found that ammonia gas penetrated almost instantly films of shellac, gold leaf and mica, and especially liquid films, whether they were thin, as in a soap bubble, or were composed of a very thick layer of water. In one experiment, he filled a glass tube with a mixture of 100 parts of atmospheric air and 42 of hydrogen (the proportion of oxygen and hydrogen was very near to the one to form water), and covered it with a film of natural rubber. In the course of a few days only a trace of hydrogen remained in the tube, and the composition of the remaining gas differed very slightly from that of atmospheric air (Draper, 1836ab).

With regard to liquid osmosis of a binary solution, Draper showed that it only took place when both liquids wetted the barrier, when each liquid rose to different heights in tubes made of it, and when the liquids were capable of uniting chemically with each other. A liquid unable to wet the pores of a barrier would not pass through it, nevertheless, the results could be modified by electricity, as shown by his experiments with water and mercury. He showed that water may be separated from litmus through a membrane having alcohol on its other side, a result which proved that osmosis "is only a refined kind of filtration, which, probably, may hereafter become of considerable importance in its applications in the arts, as in the separation of coloring matter from solutions, or the preparation of medicines, such as the vegetable alkalis, which should be formed from colorless solutions" (Barker, 1886).

In a paper published in 1846 Draper applied these principles to explain the circulation of the sap in plants and the blood in animals: "If two liquids communicate with one another in a capillary tube, or in a porous or parenchymatous structure, and have for that tube or structure different chemical affinities, movement will ensue; that liquid which has the most energetic affinity will move with the greatest velocity and may even drive the other fluid entirely before it… and this is due to common capillary attraction, which, in its turn, is due to electric excitement… Hence that one, which has the greatest affinity for the solid and wets it most perfectly passes most rapidly through it and drives the other one before it. The descent of the elaborated sap is therefore quite as positive an action as the ascent or the unelaborated" (Draper, 1846b).

"In animals the blood in the arterial capillaries of the systemic circulation is charged with oxygen, which has an intense affinity for the carbon and hydrogen of the walls. In the venous capillaries the blood is charged with CO_2 having no affinity for these tissues. The arterial blood will drive the venous blood before it, therefore. In the pulmonic system the venous blood is presented to the air cells, for the oxygen in which it has a strong affinity, while the arterial blood, which has absorbed this oxygen has no longer any. Movement ensues as before, but as now the affinities are reversed the flow is from the veins to the arteries. The systemic circulation is due therefore to the oxidizing action of the arterial blood and the flow is from the artery to the vein. The pulmonary circulation is due to the oxidation of the venous blood and the flow is from the venous to the arterial side. Both arise from the common principle that a pressure will always be exerted by the fluid which is ready to undergo a change upon that which has already undergone it, a pressure which, as there is no force to resist it, will always give rise to motion in a direction from the changing to the changed liquid" (Draper, 1846b, 1856; Barker, 1886).

2. Photochemistry

Some of the earliest of Draper's investigations were directed to the determination of the various forms of energy present in solar light. The few papers that had been published were mostly related to the influence of light on silver salts. In 1727 Johann Heinrich Schulze (1684-1744) examined for the first time the photosensitivity of the silver salts and in 1737 Jean Hellot (1685-1766) reported that a solution of silver in aqua fortis made an invisible ink, which kept in the dark did not become visible before three or four months but appeared within one hour if exposed to the sun (the long developing time of the silver was due to its being in solution) (Hellot, 1737). In 1777 Carl Wilhelm Scheele (1742-1786) distinguished between radiant heat and light. He observed that silver nitrate exposed to the prismatic spectrum became blackened more in the violet than in any other kind of light (Scheele, 1777). In 1801 Johann Wilhelm Ritter, demonstrated that such chemical action on the silver salts occurred even beyond the violet end of the visible spectrum and concluded from this the existence of 'chemical rays'. In 1802 William Hyde Wollaston (1766-1828) made the same discovery independently of Ritter and also called these rays, which were predominantly located in the violet region of the spectrum, 'chemical rays' because of their chemical effect on silver salts, among others. In Wollaston's words: "Although what I have described comprises the whole of the prismatic spectrum that can be made visible, there also pass on each side of it other rays whereof the eye is not sensible… From Herschel's experiments we learn that on one side there are invisible rays occasioning heat, that are less refrangible than red light, and on the other I have myself observed… that there are likewise invisible rays of another kind, that are more refracted that the violet. It is by their chemical effects alone that the existence of these can be discovered and by far the most delicate test of their presence is the white muriate of silver… It would appear that this and other effects usually attributed to light, are not in fact owing to any of the rays usually perceived, but to invisible rays that accompany them… " (Wollaston, 1802).

Draper first studied the chemical action of sunlight using photography techniques, which had recently, became known and had strongly caught his attention. He was one of the first to succeed in taking photographs of the human face, using a specially prepared silver bromide and silver iodide plate (Draper, 1840bcd), and of the moon's surface, which showed clearly the places of the dark spots, *lunar maria* (Draper, 1840b). This was followed by the first photographic exposure of the normal spectrum of the sun. For the latter work, Draper used a special diffraction grating, cut and ruled for him by Joseph Saxton (1799-1873), a mechanician at The United States Mint in Philadelphia (Draper, 1877).

He then studied the action of the chemical rays by the effect they produced upon chlorine. In 1843 he announced to the British Association that under the influence of sunlight chlorine was able to react with hydrogen, a property it did not possess when kept in the dark. He interpreted this result by stating that sunlight, in addition to light and heat, possessed a new imponderable responsible for producing the chemical reaction. He named this new imponderable *tithonicity* and described it as follows: "The chemical rays are associated with the rays of light, accompanying them in an their movements, originating with them, and unless disturbed, continuing to exist along with them. But should a compound beam like this fall upon a sensitive surface the chemical rays sink into it as it were, and lose all their force, and the rays of light are left alone. Photographic results thus obtained from the reposing of the chemical rays on the sensitive surface are not however, in themselves durable, for the rays escape away under some new form (Draper, 1841, 1842, 1843a, 1845, 1878).

In 1809 Joseph-Louis Gay-Lussac (1778-1850) and Louis-Jacques Thénard (1777-1857) reported the results of their study of the influence of light on the reaction between equal volumes of chlorine and hydrogen. The change in color of the gases enabled them to follow the course of combination over several days in hazy sunshine, keeping meanwhile another mixture of the reactants in the dark as a control. Their results indicated that in bright sunlight the gases reacted violently, shattering the flasks used; with a less intense light the combination proceeded more slowly. The mixture lost its color, and converted into HCl, readily soluble in water (Gay-Lussac and Thenard, 1809). In 1843, Draper made use of this property for the construction of an actinometer (to which he gave the name of tithonometer) for measuring the chemical force of the *tithonic rays*, which are found at a maximum in the violet space, and from there gradually fade away to each end of the spectrum (Draper, 1843bcdef; 1851b). The apparatus consisted of an inverted siphon tube, having a closed shorter limb and a long one, drawn out and graduated. The shorter limb was filled with an aqueous solution of hydrogen chloride, which could be decomposed into hydrogen and chlorine, by a voltaic current passing through platinum electrodes. The gaseous mixture was collected in the longer limb. When the image of a flame, formed by a convex lens was projected upon the short limb, the liquid in the longer limb began instantly to descend, moving regularly over the scale as long as the exposure was sustained. The rays entering the device caused the mixture of hydrogen and chlorine to combine into hydrogen chloride, which became absorbed in the liquid. Draper became convinced that light affected the chlorine alone, converting it from a passive to an active state (Draper, 1844a). Bunsen and Roscoe succeeded in constructing an apparatus which obviated the defects of Draper's tithonometer and allowed not only accurate comparative determinations, but also reducing the chemical action of light to an absolute measurement (Bunsen and Roscoe, 1857).

The third viewpoint was based on the action of sunrays on the growth of plants. Draper wrote that seeds germinated in the dark generate shoots that are pale and their total weight does not increase beyond the original weight of the seed. The development has occurred at the expense of the seed, its substance supplying the nourishment. If germination takes place in the open day, the parts merging into the light turn green, they no longer use the material provided by the parent plant. The weight increases, the new plants become independent of the seed and obtain carbon and hydrogen from the air and the ground (Draper, 1837ab). He now germinated seeds under colored light and found that the plants under the red and the violet glasses behaved the same as those kept in the dark, while those under the yellow glass promptly assumed a green color and developed rapidly. A successful attempt was then made to effect the decomposition of CO_2 by the green parts of plants also placed in the solar spectrum. Water was first degassed by boiling and then saturated with CO_2. Grass leaves, which had been carefully freed from adhering bubbles or films of air, were now immersed in the water and brought under the action of a dispersed solar spectrum. In a few minutes after the beginning of the experiment the tubes on which the orange, yellow, and green, and the yellow rays fell commenced giving off minute bubbles of gas, and in an hour and a half sufficient was collected for its accurate measurement. The volume of gas released was used as a measure of the activity of a particular ray. The results indicated that CO_2 was decomposed by the orange, the yellow and the green rays, and that the extreme red, the blue, the indigo, and the violet rays exerted no perceptible effect. Draper proved the correctness of his results by acting on the leaves with a beam of light that had passed previously through a solution of potassium bichromate (which absorbs the blue, the indigo, and the violet rays): The decomposition of CO_2 took place as before. He concluded, "the decomposition of carbonic acid by the leaves of plants is brought about by the rays of light and that the calorific and so-called chemical rays do not participate in the phenomenon". Draper also analyzed the composition of the gas released and reported that oxygen was never released without the simultaneous appearance of nitrogen. An additional result was that leaves exposed to the yellow light decompose alkaline carbonates and bicarbonates (Draper, 1843d, 1844b).

In 1841 Draper enunciated the principle that only absorbed rays produce chemical change, long known as Draper's law but eventually renamed the Grotthuss or Grotthuss-Draper law from its formulation by Theodor Johann Dietrich Grotthuss (1785-1822) in 1817 (Grotthuss, 1819).

Draper summarized his many findings as follows: "These general results lead us, therefore, to suppose that there exist in the solar beam a variety of distinct principles, and when that beam is acted upon by a prism of glass, those principles are parted out from each other. Among them some are visible, affecting the eye with the sensation of the various colors of light, red, yellow, blue, &c., and others are invisible, affecting the thermometer, or producing chemical decompositions." The general idea which we gather from these remarks is, that there are three separate principles coexisting in the solar ray, light, heat, and a principle of chemical action: and when this ray is dispersed by a prism, three several spectra arise, of which two are invisible, and one can be seen… We gather that the chemical effect produced by a given ray has no relation to the quantity of light which is in it; that a satisfactory explanation of the phenomena can only be given by assuming the existence and presence of another agent besides the light, and to which agent the chemical effect is due; that media are known which in their absorptive action bear relations which are totally different for these two agents; and, finally, that, as prismatic analysis has also previously shown, no explanation can be given of these results by imputing them to the agency of light, we are forced to admit the existence of another imponderable principle, the same as that which passes in these papers under the name of tithonic rays" (Hentschel, 2002).

3. Radiant heat

With a memoir published in 1847, Draper started his significant contribution on the properties of radiative heat (Draper, 1847b). He claimed that although the phenomenon of the production of light by all solid bodies, when their temperature was raised to a certain degree, was very familiar, no one had attempted a critical investigation of it because of the inherent experimental difficulties. Many distinguished scientists had tried to determine the temperature at which bodies became self-luminous, and achieved very different results. For example, Newton fixed the temperature at which bodies become self-luminous as 635º; not only that, he wrote "Is not Fire a Body heated so hot as to emit Light copiously"? (Newton, 1730). Davy fixed the shining temperature at 812º, Josiah Wedgwood (1730-1795) at 947º and John Frederic Daniell (1790-1845) at 980º. Wedgwood, a china maker, was the first to notice that all objects when heated (regardless of chemical constitution or physical proportions) turned red at the same temperature. There were also similar contradictions regarding the nature of the light emitted. Some said that when a solid began to shine it first emitted red and then white rays; others claimed that a mixture of blue and red light was the first to appear.

By the middle of the nineteenth century the science of spectroscopy had developed enough to prove that all glowing solids emitted continuous spectra when heated unlike heated gases which emitted bands or lines. Eventually, Gustav Robert Kirchhoff (1824-1887) would discover that the power emitted was proportional to the power absorbed, that the proportionality constant was some function of the temperature and frequency, and the definition of a perfectly black body as that one which absorbs all the radiations which fall upon it, of whatever wavelength they may be. For a black body the power absorbed was one so that the power emitted was a function of the temperature and frequency alone (Kirchhoff, 1860).

Draper performed some ingenious experiments with incandescent platinum in order to determine (a) the point of incandescence of platinum, and to "prove" that different bodies become incandescent at the same temperature, (b) the color of the rays emitted by self-luminous bodies at different temperature, and (c) the relation between the brilliancy of the light emitted by a shining body and its temperature. His results indicated that the point of incandescence of platinum was 977ºF and to his conviction, this was the temperature at which *all* solids begin to shine. Additional experiments with an assortment of substances, such as brass, antimony, gas carbon, and lead, showed that they became luminous at the same temperature, which was that of the gun barrel in which they were enclosed. In addition, he concluded that as the temperature of an incandescent body increased, it emitted rays of light of an increasing refrangibility, and that the apparent departure from this law was due to the special action of the eye in performing the function of vision. The true order of the colors was red, orange, yellow, green, blue, indigo, and blue. The luminous effects were due to a vibratory movement executed by the molecules of platinum and the frequency of these vibrations increased with temperature. In addition, if the quantity of heat radiated by platinum at 980ºF was taken as unity, it increased to 2.5 at 1440º, to 7.8, at 1900º, and to about 17.8 at 2360º. Draper examined the rays emitted by the incandescent platinum strip by receiving them on a flint glass prism, and after dispersion, viewing them in a small telescope. As reference he determined the position of the fixed lines of a spectrum formed by a ray of reflected daylight. The strip had to be heated to 1210ºF before a satisfactory observation could be made. At this temperature the spectrum extended from the position of the fixed line B in the red almost as far as the line F in the green. The temperature was gradually raised by the electric current and showed that when it reached 2130ºF, the spectrum had extended itself toward the violet; rays of an increasing refrangibility being successively produced, the frequency of the vibrations increasing with the temperature. Draper concluded his paper with the following words: "Among writers on Optics it has been considered a desideratum to obtain an artificial light of standard brilliancy. The preceding experiments furnish an easy means of supplying… what may be termed "a unit lamp". A surface of platinum of standard dimensions raised to a standard temperature by a voltaic current will always emit a constant light. A strip of that metal one inch long and one-twentieth of an inch wide, connected with a lever by which its expansion might be measured, would yield at 2000º a light suitable for most purposes. Moreover, it would be very easy to form from it a photometer by screening portions of the shining surface. An ingenious artist would have very little difficulty, by taking advantage of the movements of the lever, in making a self-acting apparatus, in which the platinum should be maintained at a uniform temperature, notwithstanding any change taking place in the voltaic current" (Draper, 1847b).

In 1848 Draper published a memoir on the production of light by chemical action (Draper, 1848). It was known that the combustion of different substances was accompanied by the emission of rays of different colors and many opinions had been expressed to explain the phenomenon. Draper asked what were the chemical conditions that determine these differences and if any connection could be found between the chemical nature of a substance or the conditions under which it burns and the nature of the light which it emitted. With a slit, a prism, and an observing telescope he examined the flames of a variety of substances (oil, alcohol, alcoholic solutions of boric acid and strontium nitrate, of phosphorus, of sulfur, of carbonic oxide, of hydrogen, of cyanogen, and of phosphine), and found "notwithstanding this diversity of color, all these flames, as well has many others that I have tried, yield the same result; every prismatic color is found in them. Even in those cases where the flame is very faint, as in alcohol and in hydrogen gas, not only may red, yellow, green, blue, and violet light he traced, but even bright Fraunhofferian lines of different colors." The special tint of a particular flame arose from the preponderance of one class of rays over another. The prismatic analysis of a solid burning at different temperatures proved that a rise in temperature led to the appearance of the more refrangible rays. He concluded that there was a connection between the refrangibility of the light emitted by a burning body and the intensity of the chemical action taking place, and that the refrangibility always increased as the chemical action increased. In Draper's words: "Do not the various facts here brought forward prove that chemical combinations are attended by a rapid vibratory motion of the particles of the combining bodies, which vibrations become more frequent as the chemical action is more intense?" (Draper, 1848, 1881).

In a following paper he went further in relating the spectrum of a substance with its chemical composition: "In other cases dark lines are replaced by light ones, as in the well-known instance of the electric spark between metallic electrodes. The occurrence of lines, whether bright or dark, is hence connected with the chemical nature of the substance producing the flame. For this reason these lines merit a much more critical examination, for by their aid we may be able to ascertain points of great interest in other departments of science. Thus, if we are ever able to acquire certain knowledge respecting the physical state of the sun and other stars, it will be by an examination of the light they emit" (Draper, 1857b).

Draper published several papers on the law of the distribution of light (Draper, 1857a, 1879). Ottaviano Fabrizio Mossotti (1761-1863) had shown that in a perfect spectrum the most luminous portion of the yellow should be in the center, and from this the intensity of the light should gradually decline, fading on one side in the red and in the other, in the violet (Mossotti, 1843). At equal distances from the middle yellow point the intensity of the light should be equal. In 1879 Draper built a spectrometer based on the same principle, which should measure light-intensity. His results indicated that the colors of the spectrum of a gas flame and of sunlight disappeared in the inverse order of their refrangibility, the red being the last to disappear. When the shutter admitting the daylight was gradually opened, the extreme violet disappeared first, and then the other colors in the inverse order of refrangibility as before. On closing the shutter the red first came into view, and then the other colors successively. On diminishing the intensity of the extraneous light he observed that they all came into view apparently at the same time (Barker, 1886).

Draper also studied the phenomenon of phosphorescence. In 1844 he had already determined that the special phosphorogenic rays of the spectrum were the violet rays In 1851 he gave a historical review of the knowledge known about the phenomenon and then described his experiments using fluorspar. This material was selected because it could be obtained perfectly transparent or nearly opaque, could be easily cut and polished to any figure, and has very high phosphorescent powers. Draper found that a fluorspar at its maximum of glow did not change its volume perceptibly, that the evolution of light was accompanied by a slight release of heat but not by any molecular changes detectable in polarized light, or by electrical change. The results were not affected by the presence of a powerful magnetic field. In addition, Draper noticed that the quantity of light emitted by a phosphorescent body was proportional to the intensity of the light to which it had been exposed (Draper, 1851a).

4. Electrical and galvanic phenomena

In 1840 Draper published a paper discussing the electromotive force developed in pairs of different metals as the temperature rises and gave values for copper-iron, silver-palladium, iron-palladium, platinum-copper, iron-silver, and iron-platinum thermocouples, obtained with one junction kept at 32º and the other raised either to 212º or 662ºF (Draper, 1840b). His results were also presented as curves of the electromotive force generated and the temperature. The curves of the iron-platinum and copper-silver thermocouples are concave toward the axis of abscissas, while those of iron-platinum, copper-platinum, and silver-platinum are convex toward this axis. He observed also that the "developments of electricity did not increase proportionally with temperature, but in some with greater rapidity and in others with less… the quantity of electricity (electromotive force) evolved at any temperature is independent of the amount of surface heated, a mere point being as efficacious as an indefinitely extended surface… and the quantities of electricity evolved in a pile of pairs are directly proportional to the number of the elements" (Draper, 1840a). He called attention to the anomalous results given by thermocouples in which one of the elements is iron, and gives the diagram of a copper-iron couple, the maximum ordinate of which is at 650º and the neutral point is at a temperature at which an alloy of equal parts of brass and silver melts. At the end of his paper Draper gave recommendations regarding the shape that should be given to the components of a thermocouple, for example, that the surfaces united by soldering should not be too massive. One of the best forms for a thermocouple corresponded to one in which two semi-cylindrical bars, one of antimony and the other of bismuth, were united together by the opposite corners of a lozenge-shaped piece of copper. From its exposing so much surface, the copper becomes hot and cold with equal promptitude, and may be made very thin without affecting the current (Draper 1840b).

In 1834 Draper studied the action of the galvanic battery and published an account of some improvements in its construction, which allowed determining the most appropriate construction for the case of four constructing elements. It was possible to combine the power of a battery of the old structure with an additional quantity of electricity developed during the diffusion of liquids into each other (Draper, 1834b). In 1835 Draper repeated the experiments of Domenico Lino Morichini (1773-1836) and Mary Somerville (1780-1872) who had claimed that the more refrangible rays of light were capable of rendering iron and steel magnetic. According to Somerville, sewing needles became magnetic when exposed to a violet ray. After a series of carefully experiments Draper concluded that there was no evidence whatever to sustain the opinions of these experimenters (Draper, 1835a). In 1839 he published a paper on the use of a secondary wire as a measure of the relative tension of electric currents, describing the construction and use of a torsion galvanometer and discussing a method of measuring electro-motive force by the fall in the deflection when a wire of high resistance was included in the circuit (Draper, 1839). In 1843 Draper published a short paper discussing the laws of the conducting power of wires, a research he undertook to help his colleague, Samuel Finley Breese Morse (1791-1872, the inventor of the Morse code) in perfecting his electro-magnetic telegraph (Draper, 1843f). Here Draper proved that signals may be dispatched through very long wires, and that this law was the basis of operation of the galvanic multiplier (built of a wire making several convolutions around a needle). He proved that for telegraphic dispatches, with a battery of given electromotive force, the diminution of effect for an increased distance became negligible, and that, in general, the conducting effect of wires could be represented by a logarithmic curve.

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