Platinum and the Standard of Light

A SELECTIVE REVIEW OF PROPOSALS WHICH LED TO AN INTERNATIONAL UNIT OF LUMINOUS INTENSITY

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The properties of platinum make it very suitable for many exacting applications where absolute consistency must be maintained in fluctuating conditions over long periods of time. One of the earliest uses of platinum and its alloys was for the manufacture of standard weights and measures, while the platinum resistance thermometer is still used to fix a wide range of temperatures on the International Practical Temperature Scale. Additionally, for a long period platinum contributed to the definition of the candela, the international unit of luminous intensity. This article gives a brief account of some of the pioneering work carried out by people seeking to establish a primary standard of light by utilising the unique properties of platinum.

The use first of platinum and then of platinum-iridium for metrology standards has been published in this journal (1, 2, 3), as has the story of the development of the platinum resistance thermometer and the acceptance of a practical scale of temperature based upon it (4). However, it is not widely known that the standard unit of photometry, another of the quantities covered by the International System of Units, was until recently also defined in terms of platinum. The approved English translation of "Le Système International d'Unités", the official document published in 1977 by the International Bureau of Weights and Measures, gave the following definition of the unit of luminous intensity:

> *"The candela is the luminous intensity, in the perpendicular direction, of a surface of* 1/600 000 *square metre of a black body at the temperature of freezing platinum under a pressure of* 101 325 *newtons per square metre"* (5).

This simple statement was the result of deliberation and experimentation carried out over a long period of time in several countries.

From the early years of the nineteenth century coal gas had been used for illumination, first for factories and later for homes, but the low temperature gas flame was an inefficient source of light. Towards the end of the 1870s, when there was great interest in the new electric carbon arc, a German electrician named (Carl) Louis Schwendler (1838–1882) was "under orders of the Secretary of State for India to inquire into the feasibility and practicability of lighting up Indian Railway stations by the electric light" (6).

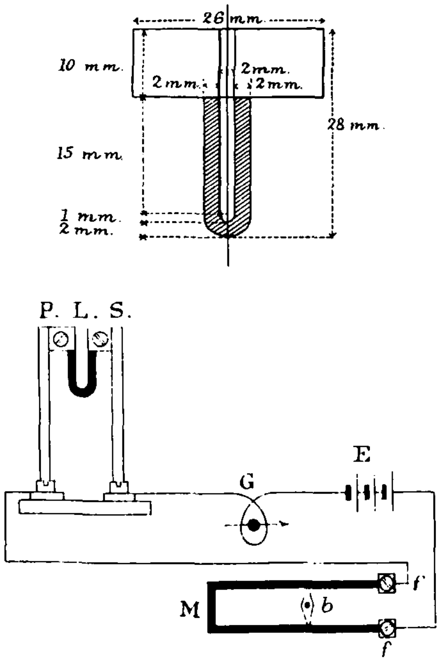
The Proposition of Schwendler

After studying at the Berlin Academy and then at Berlin University, Schwendler had been engaged by Dr. Werner Siemens to undertake tasks concerned with the manufacture and laying of submarine telegraph cables in the Mediterranean. In 1866 he was working at Siemens Brothers' telegraph works at Woolwich, England, but early in 1868 he was seconded as Assistant Electrician to Colonel Robinson, Director-General of Telegraphs in India, and in 1870 he accepted a high position in the Government service becoming Chief Instructor of Indian Telegraphs. In 1877, when on sick leave in England, Schwendler was requested by the Board of Directors of the East-India Railway Company to undertake a detailed study of electric lighting (7). In order to compare the light emitted by different types of lamp, Schwendler considered the use of two standard sources of illumination then accepted in Europe.

In England the Metropolitan Gas Act of 1860 defined the unit of light as that emitted by a Standard Candle when burning steadily at a rate of 120 grains an hour. These candles were made of spermaceti, a glistening white wax produced from the head of the sperm whale, and were manufactured to weigh six to the pound. However, the French standard of light was based upon the Carcel Burner, the unit being that emanating from a lamp burning pure colza oil at a defined rate; colza oil being vegetable oil obtained from the seed of the plant Brassica campestris. Although it was accepted that ten Standard Candles were about equal to one Carcel burner there were a number of disadvantages associated with both, and Schwendler formed the opinion that a flame did not constitute a very satisfactory standard of illumination.

In his view a more scientific method would be to use the light produced by the heating effect when a constant current was passed through a conductor of given mass and dimensions. He considered that the high melting point, freedom from oxidation and the fact that it could be obtained in a very pure form were features that made platinum the most suitable metal for the conductor of his light standard. He therefore made and tested a number of platinum photometric standards. A U-shaped resistance element cut from a piece of platinum sheet produced the light, while the electrical connection was made to two large lugs attached to the ends of the limbs, so ensuring that the contact resistance was small.

His investigations terminated, Schwendler was unable to finish a comprehensive report of his work before his return to India, but he produced a précis for the Board of Directors, which was dated 1 November 1878. In this he concluded that, on balance, the results of his experiments favoured the introduction of electric light in Indian railway stations, and he recommended that either Allahabad or Howrah Station should be lit with carbon arc lamps (8).



The form of the platinum conductor used by Schwendler is shown here at approximately actual size (top). In the circuit diagram, *M* is a mercury rheostat and *b* a copper bridge. He claimed that if *G*, the current-measurer was well made the current strength could be executed as accurately as weight could be measured on a chemical balance

Now when Schwendler had started his inquiry the idea of using as a standard the light produced when a strong current was passed along a conductor seemed to him to be so obvious that he could not understand why it had not been thought of and acted upon before. He therefore wrote an appendix to his report in which he discussed his platinum standard of light, concluding that:

> ". . . the Platinum Light Standard fulfils all the conditions of a good standard, and I therefore propose it should be used in future as the Standard of light in England, in lieu of the Standard Candle".

The following year more detailed accounts of Schwendler's work on this new standard of light were published in the scientific literature, including his proposal that:

> "6.15 webers passing through a piece of platinum 2 millims. broad, 36.28 millims. long and 0.017 millims. thick, weighing 0.0264 grms., having a calculated resistance = 0.109 S.U. and a measured resistance = 0.143 S.U. AT 66°F, gives the unit for light-intensity" (9)

which he established was equal to 0.69 Sugg's candle: Mr. Sugg being one manufacturer of Standard Candles.

However, by this time Schwendler had learnt that his idea was not original. A footnote to his paper discloses that two other people, at least, had already written on the use of incandescent platinum as a standard source of light.

First he recorded that his attention had recently been drawn to the writing of Zöllner. Johann Karl Friedrich Zöllner (1834–1882) was a notable astrophysicist, who also had studied at Berlin University before moving to Basel where he obtained his doctorate for work on photometric problems. In the preface to his inaugural dissertation, written in 1859, Zöllner remarked that despite the many practical difficulties the most suitable light source for establishing a photometric unit was still a platinum wire brought to an incandescent state with a galvanic cell.

Earlier Work in America by John Draper

Secondly, Schwendler acknowledged that as early as 1844 Dr. Draper had proposed a "unit lamp" consisting of a platinum strip heated by the electric current from a nitric acid battery, which he claimed was capable of supplying artificial light of standard brilliance. On 27 February 1847 John William Draper, who was then Professor of Chemistry at the University of New York, wrote a paper "On the Production of Light by Heat" in which he related experiments that he had conducted between the years 1844 to 1847. This was published first in the *Philosophical Magazine* (10) and later in the year it was reprinted in the *American Journal of Science and Arts* (11). In time this paper came to be recognised not only as one of Draper's most important scientific memoirs but also as the first published work on a platinum standard of light.

John William Draper
1811–1882

Born in St. Helens, Lancashire, in 1829 Draper gained a "certificate of honours" in chemistry at the academic establishment that later became University College, London. Here he studied chemistry under Edward Turner and gained an interest in the chemical effects of light. After emigrating to Virginia in 1833, Draper took a degree in medicine at the University of Pennsylvania and then served as a professor at Hampden-Sidney College before accepting in 1839, a post as professor of chemistry at New York University. His scientific interests were not confined to the study of heat and light. His contributions to the advancement of photography were considerable and in 1840 he announced his success in obtaining a representation of the moon's surface on a daguerreotype plate. He was one of the first people, if not the first, to produce photographic portraits and in addition he used photomicrographs to illustrate some of his lectures. Coincidentally, he died two days before Louis Schwendler

During 1835 and 1836, while studying medicine at the University of Pennsylvania, Draper also worked in the laboratory of Robert Hare who, in the early years of the century, was the first person to melt substantial quantities of platinum by means of his oxy-hydrogen blowpipe (12).

Hare's interest in the fusion of the platinum metals continued for many years, and in 1847 he claimed to be the first person to have melted pure iridium and rhodium, this being "by the hydro-oxygen blowpipe properly employed" (13). He was also greatly interested in the nature of electricity, the achievements made possible by it, and its further application. With galvanic apparatus that he had developed he conducted numerous experiments, including the fusion of platinum (14). It therefore seems reasonable to speculate that Draper would have observed the brightness of platinum heated to the point of fusion and learnt something of its properties while working in Hare's laboratory, although this writer knows of no documentary evidence to support this suggestion.

Draper's experiments had included a critical examination of the production of light by solid bodies when their temperature was raised to a certain degree. He had determined the point of incandescence of platinum, concluding that other bodies became incandescent at the same temperature. By the use of a flint-glass prism he had analysed the colour of the rays emitted by self-luminous bodies at different temperatures, and in addition he had established the relationship between the brightness of the light emitted by a shining body and its temperature.

For his later investigations Draper selected platinum because of "its indisposition to oxidize, and its power of resisting a high temperature without fusion"; his source of light being a very thin strip of platinum 1.35 inch long and 0.35 of an inch wide heated by the passage of an electric current from a voltaic battery:

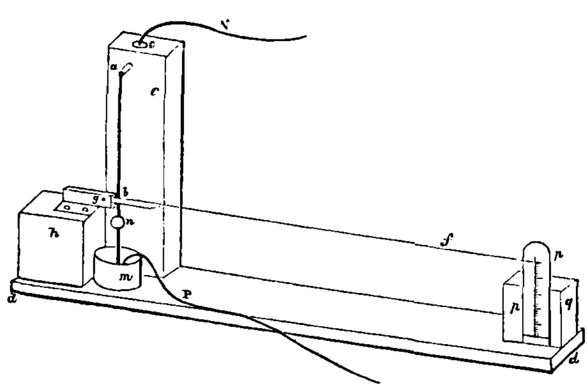
> "The Grove's battery I have employed has platinum plates three inches long and three quarters wide; the zinc cylinders are two inches and a half in diameter, three high and a third thick. As used in these experiments it could maintain a current nearly uniform for an hour. I commonly employed four pairs" (15).

A sensitive lever enabled the expansion of the platinum strip to be measured and from this the temperature of the light source was calculated. Draper tabulated the temperature of the platinum against the intensity of the light produced, showing that although the increase in intensity was low at first it became very rapid as the temperature increased, the brilliance at 2590° being more than thirty-six times as great as it was at 1900° (F). The concluding paragraph of his paper reads, in part:

> "Among writers on Optics it has been a desideratum to obtain an artificial light of standard brilliancy. The preceding experiments furnish an easy means of supplying that want, and give us what might 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 1/20 of an inch wide connected with a lever by which its expansion might be measured, would yield at 2000° a light suitable for most purposes."

Although this took place at a time when there was a great interest both in science and in its

In this drawing of Draper's apparatus *ab* represents the strip of platinum firmly attached to a copper terminal at *a*, while *b* is fastened to a delicate lever *bf* which moves on an axis at *g*, a weighted copper wire providing electrical contact with a mercury bath *m*. When the current was applied the platinum expanded and the index *f* moved across a graduated ivory scale *pp*



application for useful purposes, it was to be many years before any progress was made with Draper's idea. This was probably due, at least partly, to the lack of constancy of the electric sources then available.

In 1876, Draper received the Rumfold medals in gold and silver from the American Academy of Arts and Science for his researches on radiant energy. After this his major articles on the topic, supported with later comments and some additional illustrations, were published as a book in 1878 (16). It is perhaps significant that in the following year Schwendler's article appeared carrying the footnote which acknowledged Draper's work, first reported some thirty years previously.

Violle's Platinum Standard

In addition to Schwendler, other scientists were aware of the need for a totally reliable standard of illumination. As well as the Standard Candle and the Carcel lamp, which had been developed from the earlier Argand burner, other flame standards which later found considerable commercial use included the Vernon Harcourt lamp which burnt a mixture of pentane vapour and air and was favoured in England, and a smaller lamp devised by F. von Hefner Alteneck in 1884 which burnt pure amyl acetate, and which was to form the German standard from 1893 to 1940. However for a variety of reasons none of these possessed all the qualities required of an absolute standard.

The standard of light was considered by the Congrès International des Electriciens meeting in Paris in 1881, and again in 1884. During the latter reference was made to Schwendler's proposition but it received little support (17); the conference preferring an idea put forward by the French physicist M. Violle, who had suggested at the earlier congress that the radiation from platinum at its melting point could form a light standard.

Jules (Louis Gabriel) Violle was very interested in the temperature of the sun and designed an actinometer to measure the solar constant of radiation, from which the temperature of the sun could be determined. As a result of this work he became involved in several other topics relating to the determination of high temperatures. For example, he established the specific heat of platinum at 787, 1000 and 1200°C and by extrapolating the relationship between specific heat and temperature he determined the melting point to be 1779°C. In 1879 he reported his work in determining the intensity of red light emitted by platinum at temperatures between 900 and 1775°C, its fusing point, and suggested "that the temperature of a furnace might be ascertained by the easily made photometrical determination of the intensity of light given off by a piece of platinum placed in it" (18).

During the following years Violle continued his work on the luminous intensities of the

Jules Louis Gabriel Violle
1841–1923

A graduate of the École Normale Supérieure at Paris, Violle taught at the Universities of Grenoble and Lyons, then at the École Normale and later at the Conservatoire des Arts et Métiers, Paris. In August 1875 he made the first high altitude determination of the solar constant, at the top of Mont Blanc. In addition to his high temperature work, other interests included the theory of geysers and the origin of hail, while for some twenty years he contributed to studies on the velocity and propagation of sound

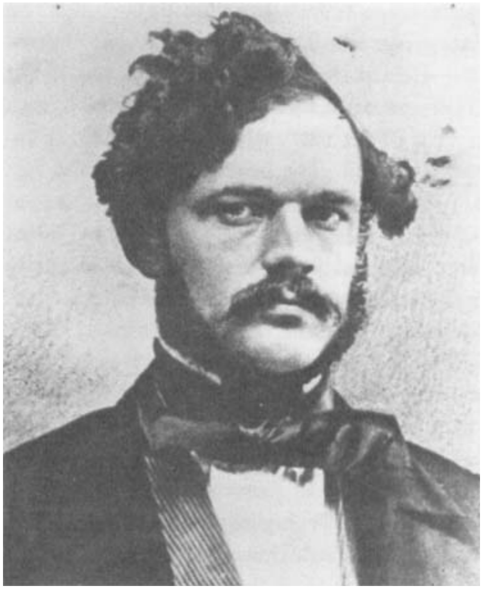
radiation emitted by incandescent platinum and the conclusion of one of his papers which had been presented to l'Académie des Sciences in 1884 by M. Debray reads, in translation:

> "To sum up, at its melting point platinum fulfils the conditions required of an absolute light standard: it is based on a perfectly defined and constant physical phenomenon, is a suitable size and constitutes a practical term of comparison with usual standards" (19).

According to Violle (20), preliminary research which he had undertaken with silver had established that the radiation from a metal at its melting point was constant during the entire period of solidification, and after further work he proposed that the unit of light should be the radiation emitted by one square centimetre of platinum at its point of solidification. The basis of his standard was considered to be sound, and his work was so highly regarded that when the Conférence Internationale pour la Détermination des Unités Electriques met in Paris on 2 May 1884 the delegates determined that:

> "L'unité de chaque lumière simple est la quantité de lumière de même espèce émise en direction normale par un centimètre carré de surface de platine fondu, à la température de solidification. L'unité pratique de lumière blanche est la quantité totale de lumière émise normalement par la même source" (21).

Although the adoption of the Violle standard was confirmed by succeeding congresses it was noted in 1908 that "in no country are photometric measurements generally expressed in terms of this unit" (22).



Werner von Siemens
1816–1892

Born in Lenthe near Hanover, Siemens became one of the greatest nineteenth century pioneers of industrial technology, particularly in the field of electrical engineering. While at the Berlin Artillery and Engineering School he developed an interest in mathematics, physics and chemistry which was to influence the remainder of his life. Working closely with his brothers William and Carl, he later undertook many international ventures including the construction of long-distance overland telegraph lines and the laying of submarine cables. His contribution to the primary standard of light was not confined to his proposal to fix the test temperature by the melting of a platinum ribbon, as in 1884 he donated a large sum of money towards the foundation of the Physikalisch-Technische Reichsanstalt at Charlottenburg, where much important work on the topic was later undertaken

Werner Siemens of Berlin

There were, unfortunately, difficulties associated with Violle's use, and with other uses of incandescent platinum as a standard source of light. These resulted mainly from the need to ensure constancy in both the emissivity from the radiating platinum surface and also in the temperature of the platinum surface. The former was greatly influenced by even minor amounts of impurities gathered on the surface while it was established that a variation of only one per cent in the temperature resulted in a change of between 12 and 18 per cent in the light emitted, this depending upon the temperature.

To avoid the possibility of the solidification temperature of the platinum being lowered by impurities picked up from the containment materials while the metal was molten, and to reduce the amount of platinum required, in 1884 Dr. Werner von Siemens suggested another form of standard which also made use of the change of state of platinum. A strip of platinum foil, to be heated by electrical resistance, was arranged within a container. As the current was slowly increased light emitted by a selected area of the glowing foil passed out of the apparatus through a fixed aperture, with an area of 0.1 cm^2, which was positioned opposite the foil. The brightness of the foil just before it gave way due to melting was to constitute his standard (23). However, it was found that Siemens' apparatus was not accurate enough to constitute a standard of illumination. Mechanical stresses, which contributed to the failure of the strip before true melting took place, were just one of the factors that could result in a variation of ten per cent between successive melts (24).

Later Charles R. Cross of the Massachusetts Institute of Technology reported on the possibility of substituting platinum wire for Siemens' ribbon (25), but another disadvantage of this and of all the standards based upon the melting of platinum was that they required instantaneous photometric comparisons (26).

Sir Joseph Ernest Petavel
1873–1936

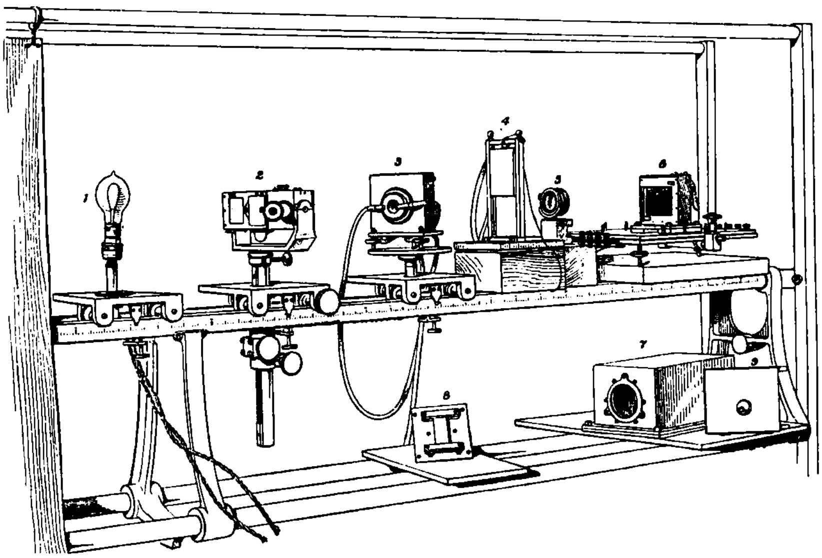
Born in London, Petavel studied engineering at both Lausanne University and at University College, London. His work on a standard of light was only one of his many accomplishments, which included the design of an indicator for measuring the high pressures in exploding gas mixtures. He worked for a time as a research fellow at Manchester University, where some years later he accepted the chair of engineering. Elected F.R.S. in 1907, he was appointed director of the National Physical Laboratory, Teddington, in 1919 and knighted the following year

Temperature and the Distribution of Radiant Energy

These difficulties were avoided in a platinum lamp devised by Otto R. Lummer (1860–1925) and Ferdinand Kurlbaum (1857–1927) at the Physikalisch-Technische Reichsanstalt in Berlin. They also made use of a strip of electrically heated platinum, although this was not raised to its melting point. Instead, to establish their fixed point they made use of the fact that the distribution of energy in the spectrum emitted by a glowing solid varies with temperature, an increase in temperature resulting in more of the radiant energy being in the short wave region. Thus if short and long wave radiation can be measured and compared the ratio of the measurements will define a particular temperature.

Lummer and Kurlbaum therefore took two measurements of the energy passing through a fixed aperture arranged in front of a strip of platinum foil 25 mm wide and 0.015 mm thick enclosed in a water-cooled box and brought to incandescence by an electric current. They measured the total energy radiated and also that transmitted through a water-filled quartz cell of specified dimensions, and they selected as their fixed temperature the point where the radiation through the water cell was exactly 1/10 of the total radiation. In 1894 they claim that their unit was reproducible to within one per cent (27), but Petavel found that their light was "impracticable as a working standard" (28).

In 1899 Joseph E. Petavel, who was later to become director of the National Physical Laboratory, Teddington, communicated the results of an experimental study of some standards of light which had lasted nearly three years. Working at the Davy-Faraday Laboratory with funds provided by the Royal Institution and with platinum loaned by Johnson Matthey, he examined both the flame standards that were actually in use and possible



The apparatus used by Petavel to confirm the findings of Lummer and Kurlbaum took three months to construct. The main parts are: *1*. Incandescent lamp serving as standard of reference. *2*. Lummer and Brodhun photometer head. *3*. Enclosure in which the incandescent platinum foil is placed. *4*. Screen to cut off the radiation from the bolometer. *5*. Water-trough. *6*. Bolometer with the cover removed to show the films. *7*. Bolometer cover. *8*. Clips for holding the incandescent platinum foil, this plate fits on to the back of the enclosure *3*. *9*. One of the water circulation diaphrams used to keep any extraneous radiation from the bolometer

incandescent standards, including the Lummer-Kurlbaum platinum standard. The experimental difficulties associated with the latter were considerable, some being associated with the condition of the surfaces both of the platinum and of the bolometer used to measure the radiation. Additionally "the spectral composition of the light is unsatisfactory, the colour being much too red" and he concluded that the light did not possess all the qualities required of a primary standard (29).

However he continued to work on the topic, now with the support of funds awarded by the Government Grant committee of the Royal Society, and pursued the idea of regulating the temperature of a platinum radiator by comparing the energy emitted at two different wavelengths. He established that a most sensitive temperature fixing would be obtained by balancing the energy transmitted through a water trough with that transmitted through a plate of black fluorspar, the former being nearly opaque to long wavelength radiation while the latter is opaque to the visible spectrum. When the temperature was carefully controlled in this way the variation in the intensity of the light emitted did not exceed ±0.5 per cent. However, after tests lasting for several months the experimental difficulties were thought to outweigh the improved accuracy and the system was not considered practicable (30).

Indeed the Violle standard lamp was also criticised for being non-portable, too complicated and too expensive for general use. However, much of this was unfounded and resulted perhaps from a lack of understanding of the proper function of a primary standard. The growth of the electric lamp industry which followed the development of a practical form of carbon filament lamp in 1879, and progress by the competing gas industry—after the introduction of the Welsbach incandescent gas mantle in

1883—increased still further the need for a totally reliable standard source.

Black Body Radiation

A most significant advance in the evolution of the primary standard of illumination arose from a suggestion made in 1908 by Charles William Waidner and George Kimball Burgess of the National Bureau of Standards in Washington who proposed as a standard of light a black body immersed in a bath of pure platinum at the point of solidification (31).

Many years earlier Gustav Kirchhoff had introduced the concept of a "black body" which he had defined as being one that would absorb all radiation falling upon it; that is none of this radiation was either reflected or transmitted. The radiation from such a black body is a function of its temperature alone. He had even suggested that a closed box with black inside walls and having a negligibly small opening through which the radiation could pass from the inside to the outside, would form such a body. However, this was not achieved until the end of the century when Lummer, Kurlbaum and Ernst Pringsheim (1859–1917) working at the Reichsanstalt used such an enclosure to investigate various aspects of black body radiation. Indeed two of them suggested a new temperature scale which could be checked against the radiation from a black body at definite wavelengths (32).

Charles William Waidner
1873–1922

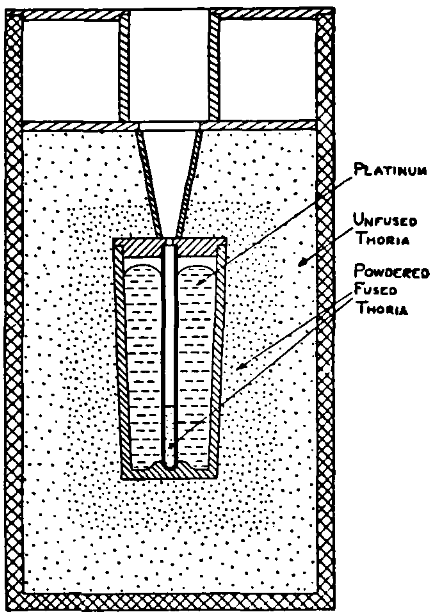
A graduate of John Hopkins University, Dr. Waidner joined the staff of the National Bureau of Standards in August 1901, just months after it was created by Act of Congress. As head of the division concerned with heat and thermometry, the quality and exstent of his work in collaboration with Dr. Burgess, resulted in the Bureau becoming recognised as one of the leading estabishments for pyrometric research

Reproduced by courtesy of the National Bureau of Standards

Waidner and Burgess wished to retain the most desirable feature of Violle's standard, which was the reproducible temperature and to supplement it with the advantages of a black body source. These were the elimination of the uncertainties that result from inconsistent surface properties and the avoidance of radiation emitted or reflected by any surrounding apparatus. However, the lack of a suitable high temperature refractory made it impossible for them to achieve their objective at that time. Nevertheless the idea was taken up and developed by a number of people.

In 1910 C. E. Mendenhall of the University of Wisconsin sought to use the fact that conditions approximating to those of a black body could be obtained within a hollow metal wedge, due to multiple reflections from the two sides providing the angle of the wedge was small enough. By electric heating the platinum wedge could be slowly raised in temperature as the brightness was observed through an aperture of fixed size arranged in front of the wedge, until at the point of fusion the light was suddenly extinguished (33). Advantageously, such a wedge was less prone to mechanical failure than Siemens' ribbon, and it required considerably less platinum than Violle's method. Indeed Waidner and Burgess also proposed that Siemens' fusion method could be improved by placing the radiating platinum strip in a hemispherical reflector pierced by a small aperture through which the platinum could be viewed. In this way the radiation from the platinum approximated to that of black body radiation (31).

Another interesting contribution to the evolution of the platinum standard was the work of Herbert E. Ives (1882–1953) who at various times was employed in the three American bodies most concerned with the standard of light, namely the gas and electric lamp industries and the Bureau of Standards. He sought to combine the best of previous proposals. Following Violle, his fixed temperature was the melting point of platinum but he avoided the possibility of contamination of the melt by adapting Siemens' method, while to eliminate the usual errors that result when an emitting metal surface is observed, he devised a simple platinum black body. This took the form of a hollow cylinder of thin platinum sheet 95 mm long, and 12.5 mm in diameter. A narrow opening along one side enabled the interior of the cylinder to be viewed, providing an approximation to a black body (34).



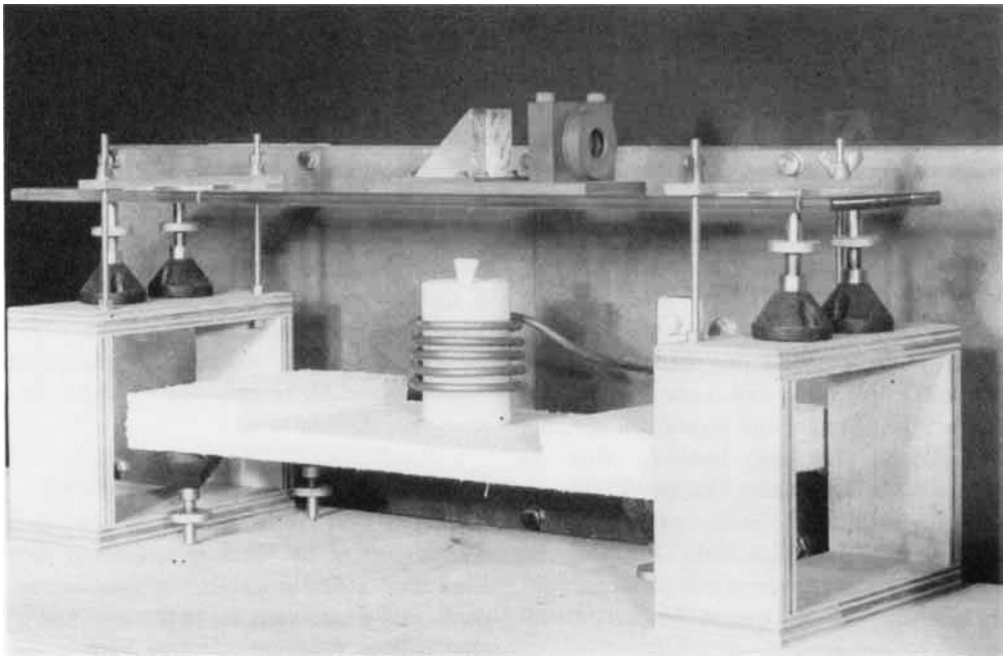
This cross-section shows the arrangement of the black body in the crucible assembly used at the National Bureau of Standards. Some 185 g of platinum surrounded the very pure thoria sight tube, and was insulated by two layers of ground thoria (35)

In use the cylinder was heated by electrical resistance until failure occurred approximately half way along due to fusion of the platinum. Unfortunately, due to temperature gradients within the cylinder the radiation observed through the slit was not all emitted by platinum at the melting point, some multiply reflected components originating at colder parts of the surface. However, it was said that this source "was reproducible to a higher degree than any previously devised" (35).

The Waidner-Burgess Standard

In 1930, over twenty years after it had first been suggested by Waidner and Burgess, a black body radiation standard of light was experimentally realised at the National Bureau of Standards in Washington, where Burgess was now director. The source consisted of a hollow enclosure of thoria immersed in freezing platinum and the brightness was determined as 58.84±0.09 candles per square centimetre (36).

The general arrangement of the source is shown in the illustration below. A fused tube of thorium oxide some 45 mm long and with an internal diameter of approximately 2.5 mm has the lower third of its length filled with powdered fused thoria, and is arranged vertically in a fused thoria crucible about 20 mm in diameter. This in turn is supported within another thoria-packed refractory container. Some 185 g of platinum in the crucible surrounds the radiator tube and the whole is heated by a high-frequency induction heater which can be precisely regulated. In use the container and its contents are initially heated above the melting point of platinum, they are then allowed to cool very slowly through the period of solidification of platinum while a small central hole in the lid of the crucible acts as the source of light. As has been said previously, at the temperature employed, a very slight error in the fixed temperature results in a significant change in the luminous intensity. Therefore to ensure that the



A primary standard of the form once used at the National Physical Laboratory. The thoria black-body radiator tube is located beneath a 1.5 mm diameter sight hole in the centre of the conical lid. An outer cylindrical silica pot about 11 cm high is surrounded by five water-cooled turns of the high-frequency induction heating coil. Above the crucible assembly is the right-angled reflecting prism, the lens and the fixed aperture which serve to image the radiating cavity onto a photometer, which is not shown here

temperature at which solidification is taking place is indeed that of pure platinum, the purity of the metal is checked by determining its electrical resistance at 100 and 0°C, both before and after use. At the time this standard source was believed to be reproducible in any suitably equipped laboratory to within 1 part in 10,000 (37). However it subsequently became clear that this was a very optimistic estimate. Indeed, as late as 1962 the National Research Council of Canada could claim an accuracy of only 0.3 per cent for its realisation of the candela, despite all efforts to eliminate possible sources of error. These included heating the platinum indirectly, in vacuo, by a tantalum susceptor (38).

Wide International Agreement

Following prolonged experimentation and deliberation, in 1937 the International Commission on Illumination proposed a new standard to replace the International Candle which had been agreed upon in 1909 by the national standards laboratories of France, Great Britain and the United States of America. This was to be based upon a perfect black body at the freezing point of platinum, the brightness being defined as 60 new candles per cm^2. The proposal was promulgated by the International Committee of Weights and Measures at its meeting in 1946, and in 1948 the Ninth General Conference of Weights and Measures ratified this decision and gave the name "candela" to the unit of luminous intensity (39).

Thus almost one hundred years after Draper had proposed that platinum could be employed to provide a standard source of light its use was confirmed when the new international standard was agreed upon by an organisation representing over forty nations. During that time many investigators in several countries had striven to improve the manner in which the properties of platinum could be used to provide a means of establishing an absolute standard of luminous intensity.

This was not to be the end of the story, however. Due to the practical difficulties in the realisation of the definition it was suggested that an alternative to the black body at the freezing point of platinum might be preferable as the primary standard of light (40). Later, the 16th Conférence Générale des Poids at Mesures adopted in 1979 the following detector-based definition (41):

> *"The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency* 540×10^{12} *hertz and that has a radiant intensity in that direction of* (1/683) *watt per steradian* (16th CGPM (1979), Resolution 3)".

This present definition, based upon measurements of optical power, opened the way to a much more accurate realisation of the unit of luminous intensity.

Acknowledgements

The writer's interest in this topic was increased greatly when he read a paper entitled "Platinum and the Standard of Light", written some seventy years ago by the American physicist Herbert Eugene Ives (42). Grateful thanks are due to Dr. O. C. Jones of the National Physical Laboratory, Teddington and to Dr. T. J. Quinn of the Bureau International des Poids et Mesures, Sèvres for reading the manuscript of this article. Thanks are also due to the historians of science and to the librarians who have contributed information.

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