The Origin of the Platinum Resistance Thermometer

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Since the beginning of this century the platinum resistance thermometer has been relied upon as a most convenient means of temperature measurement and control in industrial applications, while its accuracy in precision thermometry has contributed largely to the definition of the International Temperature Scale. Its origin stems, however, from the early years of the costly and hazardous attempts to lay underwater telegraph cables, before even a standard unit of resistance had been generally adopted.

The many millions of platinum resistance thermometers in use for the measurement of temperatures from well below zero up to those of the order of 1000°C testify to the accuracy and the versatility of these instruments. Their reliability depends first upon the simple relationship between the resistance of the platinum element and its temperature, and secondly upon the high purity and stability of the specially prepared platinum employed. Neither of these factors was simple or easy to establish, however, in their earlier years.

The discovery that the electrical resistance of a metal varies with temperature was first made

Sir William Siemens
1823–1883

Born Carl Wilhelm Siemens near Hanover, he came to England when not yet twenty and quickly made a reputation in the early days of the electrical industry. In 1860 he devised the first resistance thermometer, using copper wire, to check the temperature of coils of submarine cables, a step that saved an expensive cable from destruction by spontaneous overheating. Ten years later he introduced a platinum resistance thermometer for the measurement of high temperatures. He was the first president of the Society of Telegraph Engineers, later re-named the Institution of Electrical Engineers, and shortly before his death was knighted by Queen Victoria

Reproduced by courtesy of the BBC Hulton Picture Library by Humphry Davy at the Royal Institution in 1821. In the course of a paper read to the Royal Society he reported that:

> "The most remarkable general result that I obtained . . . was that the conducting power of metallic bodies varied with the temperature, and was lower, in some inverse ratio, as the temperature was higher. Thus a wire of platinum of 1/220 and three inches in length, when kept cool by oil discharged the electricity of two batteries, or of twenty double plates: but when suffered to be heated by exposure in the air, it barely discharged one battery." (1).

This phenomenon was investigated some years later by Emil Lenz in St. Petersburg (2), by Professor A. F. Svanberg at the University of Uppsala (3) and by the Norwegian physicist Adam Arndtsen (4), but the very low purity of the copper and other metals then available handicapped these workers in establishing a relationship between temperature and increasing resistance. In any case the concept of "resistance" was then wreathed in uncertainty and there was no unit or fixed standard in which to express it, while the simplest application of Ohm's law to practical problems was hardly understood.

Standards of Resistance

In 1860 Werner Siemens, much engaged with the new electric telegraph in Germany and elsewhere, proposed that a column of mercury of 1 square millimetre in cross section and 1 metre in length at the freezing point of water be adopted as the unit of resistance (5), while he also published a paper at the same time on the effect of increasing temperature on electrical resistance (6).

The advent of the telegraph, the only industrial application of electricity at that time, with many miles of copper wire of indifferent purity and poor conductivity strung alongside the railway lines, and then the beginning of international telegraphy by means of long and expensive submarine cables, focused attention much more actively on the problem of resistance in conductors and the great need for an established and internationally agreed unit was recognised in 1860 by the Council of the British Association for the Advancement of Science. Acting on a suggestion put forward in a paper by Sir Charles Bright and his partner in the Atlantic Telegraph Company, Joseph Latimer Clark, that names should be adopted for standards of resistance, current and electromotive force, William Thomson, later Lord Kelvin, Professor of Natural Philosophy at Glasgow and also a director of the Atlantic Telegraph Company, proposed the formation of a committee to report on standards of electrical resistance. The committee appointed comprised Thomson himself, A. W. Williamson, Professor of Chemistry at University College, London, Professor Wheatstone of King's College, London, Professor W. H. Miller of Cambridge, H. C. Fleeming Jenkin, then in the submarine cable industry and Dr. Augustus Matthiessen who had already carried out a massive series of researches on the resistance of metals and alloys in Kirchhoff's laboratory at Heidelberg, an activity he continued after his appointment as lecturer in chemistry at St. Mary's Hospital in London in 1862.

In the following year the committee was strengthened by the addition of Sir Charles Bright, Professor Clerk Maxwell of Aberdeen University, Balfour Stewart, then Director of the Kew Observatory and later Professor of Physics at Owens College, Manchester, and C. W. Siemens, while in 1863 Thomson's collaborator J. P. Joule and C. F. Varley, also of the Atlantic Telegraph Company, were co-opted.

The Committee's report submitted to the British Association meeting in Newcastle in that year includes for the first time the term "ohm", or "ohmad" as it was originally called, this being defined as 10^9 C.G.S. units.

Carl Wilhelm Siemens

The first suggestion for making use of the effect of temperature on the resistance of a metal for the determination of that temperature was due to Carl Wilhelm Siemens. Arriving penniless in London from Germany in 1843, just before his twentieth birthday and after an education in physics, chemistry and mathematics at Göttingen, Siemens had two ambitions in life—to make sufficient money to be able to support himself as an inventor and consultant and to support his five orphaned young brothers in Germany, then aged between seven and seventeen years, and then to be able to indulge in scientific research.

Encouraged by his elder brother Werner, the primary object of his visit was to sell the latter's invention of a process for gold plating to the Elkingtons of Birmingham. In this he was quickly successful, receiving the then considerable sum of £1600, less £110 for the costs of a British patent which the Elkingtons filed on his behalf. His half share of this money with Werner was enough to establish him in London.

Underwater Telegraph Cables

His arrival in prosperous early Victorian England could not have been timed to better advantage. The great railways boom was at its height, to be followed by the spectacular growth of the electric telegraph as well as the replacement of sail by steam in the British mercantile marine. In Berlin elder brother Werner formed a company in 1847 with a young engineer called Johann Georg Halske to manufacture telegraph equipment, a venture in which they were immediately successful, and Wilhelm was appointed their London agent. By 1850 the firm was well established in the telegraph business, and had laid a line, among others, from Berlin to Cologne which involved crossing both the Elbe and the Rhine with armoured underwater cables. Werner Siemens quickly became an acknowledged authority in the new and exciting world of submarine telegraphy, and encouraged his brother Wilhelm, now heavily occupied with his regenerative furnace, to give more of his time to this fast growing industry.

In 1858 the firm of Siemens and Halske of London was founded, the partners being the Berlin company, Wilhelm Siemens and the cable manufacturer Newall and Company of Birkenhead, but the Newall connection was not a lasting one and the break occurred in 1863 when Siemens and Halske set up as independent cable manufacturers.

In the meantime Wilhelm became naturalised as Charles William Siemens in 1859, and was called upon to give evidence to the Commission of Enquiry set up by the British Government into the failure of the first Atlantic cable. Finally laid in August 1858 after some unsuccessful attempts in the previous summer, this was in operation, with great difficulty and delays in the transmission of signals, only until the following October when the insulation had completely deteriorated. One result of the enquiry was that in 1860 the Siemens Company was appointed by the Government to superintend the manufacture and laying of submarine cables and it was in this context that the birth of the resistance thermometer took place.

During the autumn a cable intended for laying between Rangoon and Singapore was made and loaded into the "Queen Victoria" for despatch to the Far East. Siemens was on board, and was concerned that spontaneous generation of heat in the coils of cable in the hold of the ship could possible lead to its deterioration. (In fact this cable never reached its destination; after the ship had been forced to seek shelter in Plymouth harbour the project was abandoned and the cable was eventually laid from Malta to Alexandria in 1861.)

The First Resistance Thermometer

On his arrival back in London in December Siemens wrote to Professor John Tyndall at the Royal Institution about his problem and its solution. The letter includes the following paragraph:

> "As it would have been impossible to introduce mercury thermometers into the interior of the mass, I thought of having recourse to an instrument based upon the well-ascertained fact that the conductivity of a copper wire increases in a simple ratio inversely with its temperature."

The letter goes on to describe the instrument, a rod wound with silk-covered copper wire in several layers, covered with rubber, and connected to a battery and a galvanometer in the cabin. It continues:

> "The ratio of increase of resistance of copper wire with increase in temperature may be regarded as perfectly constant within the

ordinary limits of temperature; and being able to appreciate the tenth part of a unit in the variable resistance coil employed, I have the means of determining with great accuracy the temperature of the locality where the thermometer resistance coil is placed. Such thermometer resistance coils I caused to be placed between the layers of the cable at regular intervals, connecting all of them with the same measured apparatus in the cabin.

After the cable had been about ten days on board (having left a wet tank on the contractors' works), very marked effects of heat resulted from the indications of the thermometer coils inserted into the interior of the mass of the cable, although the coils nearer the top and bottom surfaces did not show yet any remarkable excess over the temperature of the ship's hold, which was at 60° Fahr. The increase of heat in the interior progressed steadily at the rate of about 3° Fahr. per day, and having reached 86° Fahr., the cable would have been inevitably destroyed in the course of a few days, if the generation of heat had been allowed to continue unchecked."

The letter was published in the *Philosophical Magazine,* of which Tyndall was then one of the editors, headed "On a New Resistance Thermometer" (7). It concluded with the suggestion:

"By substituting an open coil of platinum for the insulated copper coil this instrument would be found useful also as a pyrometer."

In 1862 William Siemens was elected a Fellow of the Royal Society, a mark of the eminence he had achieved as a scientist, and although he continued to be actively engaged in the cable industry for the next few years—the firm of Siemens and Halske was dissolved in 1865 and Siemens Brothers founded with only Werner and William as partners—he was eventually able to devote much of his energy to research.

In the year 1871 he was invited to give the Bakerian Lecture to the Royal Society and chose for his subject "On the Increase of Electrical Resistance in Conductors with Rise of Temperature and its Application to the Measure of Ordinary and Furnace Temperatures". This was unfortunately published only in abstract (8) but the manuscript is preserved in the archives of the Royal Society.

In his opening paragraph Siemens emphasised that the researches of Arndtsen, Matthiessen, his brother Werner and others had been limited to the range of temperatures between the freezing and the boiling points of water and that platinum, the most suitable metal for extending the range, had been left out of consideration. In carrying out his own investigations he had used

"platinum wire of 0.021 inch diameter prepared by Johnson and Matthey by the old welding process, which gives a much more conductive and therefore purer wire than the more recent process by fusion in a De Ville furnace."

He continued by referring to the great utility of his first resistance thermometer in saving from destruction the Malta to Alexandria and subsequent cables and then described his new instrument in which the platinum wire was wound in helical grooves on a cylinder of pipe clay contained in an iron tube

"for measuring with great accuracy the temperature at distant or inaccessible places including the interior of furnaces where metallurgical or other smelting operations are carried on."

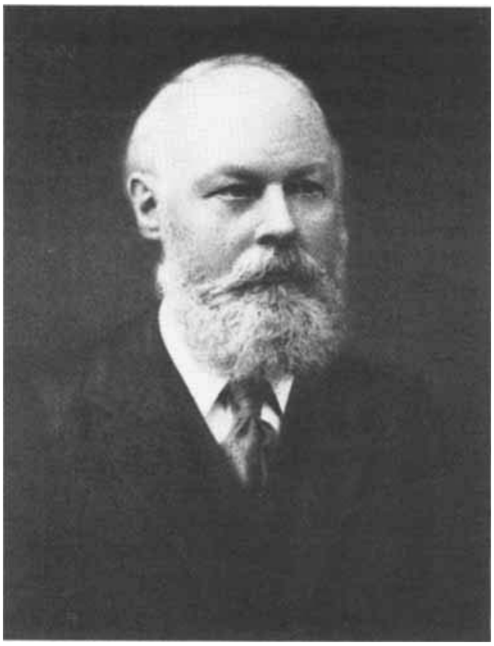
Siemens also gave a lecture, "On Measuring Temperature by Electricity", to the Royal Institution in March 1872, in which he described his instrument as

"the result of occasional experimental research, spread over several years, and it aims at the accomplishment of a double purpose, that of measuring high temperatures, and of measuring with accuracy the temperatures of inaccessible or distant places"(9)

while earlier he had presented a paper to the Iron and Steel Institute at its meeting in Merthyr Tydfil in September 1870, in which he proposed the use of the new pyrometer for measuring the temperature in annealing ovens and of the hot blast supplied to blast furnaces and emphasised that he was not "seeking for any commercial reward, through the Patent Office or otherwise"(10).

The British Association's Adverse Report

Siemen's lecture to the Royal Society naturally attracted the attention of the Council of the British Association, who promptly recommended at their meeting in Edinburgh in 1871 that a committee be formed, with power to add



Professor George Carey Foster
1835–1919

The first professor of experimental physics to be appointed at University College, London, in 1868, Carey Foster carried out the investigations on behalf of the British Association committee appointed to test the reliability of Siemens' resistance thermometer and had to give an adverse report because of contamination of the platinum wire by silica from the fire-clay cylinder on which it was wound

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to its number, for "the purpose of testing the new pyrometer of Mr. Siemens".

This committee represented the scientific establishment of the day and included several members of the Electrical Standards Committee that had been dissolved at its own request in 1870: Professor A. W. Williamson, Sir William Thomson, James Clerk Maxwell, just appointed Professor of Physics at Cambridge, George Carey Foster, the first Professor of Physics at University College, London, F. A. Abel (later Sir Frederick, chemist to the War Department) H. C. Fleeming Jenkin, by now Professor of Engineering at Edinburgh, C. W. Siemens himself and Robert Sabine, one of Siemens' former assistants.

The work of investigating the constancy of resistance of the platinum coil was delegated to

Sir J. J. Thomson
1856–1940

Elected to the chair of physics at Cambridge in 1884 when only 27, Thomson was responsible in the following year for assigning a research project to his new student Callendar. Aware of the problems faced by the British Association in establishing standards of electrical resistance, he proposed a study of the variation of resistance of platinum with temperature

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Carey Foster and carried out in the Physics Department of University College between March 1872 and August 1874 by him and his assistant W. Grant as well as by one or two research students working under Carey Foster's supervision. One of these was the young Oliver Lodge who many years later described how impressed he was with

> "the consummate care and scrupulous accuracy demanded by the Professor in this comparatively simple research."

Actually Carey Foster had at his disposal only two rooms (one of them his own study) and a basement known as "The Dungeon" and it was in this last rather uncomfortable place that the investigation was conducted. Four instruments were supplied by Siemens, and it was found that while repeated measurements—generally taken after inserting the pyrometers in an open coal fire—often gave almost identical results if made within a few days of each other, measurements made after an interval of a few months sometimes differed markedly from earlier results.

The committee's unfavourable report was presented at the meeting of the British Association in September 1874 (11) and seemed to dispose of the new pyrometer as a reliable instrument. In the course of the report, however, Professor Williamson, the only chemist on the committee, was recorded as considering that the deterioration of the platinum wire could have resulted from contamination by the reduction of silica from the fire clay cylinder on which the coil was wound—a highly probable cause of the trouble, as Claus had pointed out in 1847 (12).

Deleterious Effects of Platinum-Silicon Eutectic

While silica itself cannot contaminate platinum, when converted to silicon in a reducing atmosphere it rapidly forms a low melting eutectic that penetrates along the grain boundaries and causes severe embrittlement, as well of course as a change in resistivity. Further, in the presence of sulphur-containing fuels, such as would have been abundant in Carey Foster's coal fire, a volatile compound SiS_2 is formed which attacks platinum even more vigorously, as was shown very many years later in the Johnson Matthey Research Laboratories in the course of studying early problems in the measurement of liquid steel temperatures by means of the immersion platinum:rhodium-platinum thermocouple (13).

Callendar's Rehabilitation of the Resistance Thermometer

Siemens' resistance thermometer thus remained in disfavour for a number of years, sadly until after his death in 1883. Its rehabilitation was due to the foresight and then to the experimental skill of two remarkable men in the University of Cambridge. In 1884 J. J. Thomson was appointed, at the age of only 27, Professor of Physics and Director of the Cavendish Laboratory in succession to Lord Rayleigh, holding these posts, as is well known, with great distinction until his retirement in 1919. Thomson had been one of Balfour Stewart's research students at Manchester, and would undoubtedly have heard of all the British Association's activities in the measurement of electrical resistance. In the autumn of 1885 he received into his laboratory a new research student, H. L. Callendar, who had taken his degree in classics and mathematics, had never carried out any practical work in physics and had read scientific works only as a hobby. After a few weeks in the laboratory Thomson realised that Callendar had considerable gifts as a skilful experimenter and set about finding him a suitable research project that would give full play to his strong points and yet minimise his lack of experience. He decided that the most suitable work would be the accurate measurement of the resistance of platinum, its variation with temperature, and thus its use for the measurement of temperature. Many years later he wrote:

> "Siemens had actually constructed a thermometer on this principle, but this was found to have grave defects which made accurate determinations of temperature impossible. The simplicity and convenience of using a piece of wire as a thermometer was so great that it seemed to me very desirable to make experiments to see if

the failure of Siemens' instruments was inherent to the use of platinum as a measure of temperature, and not to a defect in the design of the instrument. Callendar took up this problem with great enthusiasm and showed that, if precautions are taken to keep the wire free from strain and contamination from vapours, it makes a thoroughly reliable and very convenient thermometer. This discovery, which put thermometry on an entrely new basis, increasing not only its accuracy at ordinary temperatures, but also extending this accuracy to temperatures far higher and far lower than those at which hitherto any measurements at all had been possible, was made with less than eight month's work." (14)

By taking care to avoid strain or contamination of the platinum wire Callendar established that its resistance was always the same at a given temperature—"at least this was the case with the specimens used in these experiments, obtained from the well-known firm of Johnson Matthey & Co". His work was carried out in most difficult conditions, on a window-sill in a passage between two rooms in the Cavendish Laboratory, but by sealing his platinum coil, wound on a piece of mica, inside the glass bulb of the air thermometer he was using as a standard he completely overcame the earlier troubles and developed a reliable formula relating change in resistance to temperature. In June 1886 he read a long paper to the Royal Society on his findings (15) a contribution that earned him a Fellowship of Trinity College, and in the following year he filed his first patent on the resistance thermometer (16).

Unknown to Callendar however, there was another research about to start along similar lines, also in Cambridge. In 1888 those two founding fathers of physical metallurgy C. T. Heycock and F. H. Neville, studying the depression of the freezing points of metals by alloying additions and confined in their work to very low melting point solvents by the limitations of mercury thermometers, appealed for help to E. H. Griffiths, one of Neville's colleagues at Sidney Sussex College. Working in a crude wooden laboratory that had been built against the outside wall of the college grounds (until he was driven to build his own small laboratory in his garden to avoid vibrations from passing traffic) Griffiths constructed a number of platinum resistance thermometers for Heycock and Neville and collaborated with them in calibrating these at a number of fixed points, including those of ice, steam, the boiling points of several organic compounds, and finally at the boiling point of sulphur, then taken as

Hugh Longbourne Callendar
1863–1930

Taking a first class degree in classics and mathematics and with no knowledge of physics, Callendar entered the Cavendish Laboratory in 1885. Within only eight months he developed a platinum resistance thermometer that proved to be accurate and reliable. At his suggestion the first temperature scale was established with the platinum resistance thermometer used to define a major portion of the range. In later years he was professor of physics at University College, London, and then at the Royal College of Science

Ernest Howard Griffiths
1851–1932

Unknown to Callendar, Griffiths was also developing a platinum resistance thermometer at Sidney Sussex College, Cambridge, primarily in order to assist Heycock and Neville in their early researches on alloy systems. In 1889 he and Callendar combined forces and established fixed points for the calibration of the instrument. In 1901 Griffiths was appointed Principal of the University College of South Wales

Photography by courtesy of the Royal Society

448.38°C, a determination made by Regnault in the year 1862.

Heycock and Neville used these resistance instruments initially to calibrate their mercury thermometers, but by 1895 they felt able to rely completely upon Griffiths' apparatus to determine much higher temperatures, including the freezing points of gold and silver, their values being 1061.7° and 960.7°C, close indeed to modern determinations (17).

In the meantime, in the autumn of 1889, Griffiths had become aware of Callendar's work, but, after reading a paper on his resistance thermometer to the Royal Society in June 1890 (18) he found that his values for temperatures above about 350°C were significantly different from those of Callendar. This led to the conclusion that Regnault's figure for the boiling point of sulphur was probably too high, and the two now joined forces to establish a better value, arriving at 444.53°C, a fixed point then used by Heycock and Neville and by other workers for many years to come (19). Extrapolation from this point then made it possible to rely upon the resistance thermometer for determining temperatures up to 1100°C.

The accuracy and reliability of the device were now established, and Callendar and Griffiths approached Horace Darwin, the head of the Cambridge Instrument Company, who readily agreed to its manufacture, together with the necessary indicating equipment. These were quickly introduced into iron and steel making and into other industries where they have proved their usefulness over the years (20).

The First Temperature Scale

The success of the platinum resistance thermometer, and then of the recording instrument developed in 1897 by Callendar, led him to propose to the British Association the establishment of a standard scale of temperature based upon it (21). The proposal was accepted by the Electrical Standards Committee which had been re-formed in 1880 and was now under the chairmanship of Lord Rayleigh. A discussion was mounted at the Dover meeting in 1899, opened by Callendar and with contributions from J. A. Harker of the Kew Observatory (the temporary home of the National Physical Laboratory, just established with R. T. Glazebrook as Director) and from Pierre Chappuis of the Bureau International des Poids et Mesures where the gas thermometer had been adopted as an international standard. These workers had carried out a co-operative investigation to compare the two instruments and had shown that platinum thermometers could be repeatedly heated and cooled between 0 and 1000°C for three months without discernible change in zero (22).

Both Griffiths and Callendar were co-opted to the Committee, which then set up a Sub-Committee on Platinum Thermometry, adding Roberts-Austen and George Matthey to its numbers. This met in the spring of 1900 and proposed that platinum thermometers be constructed to serve as standards and that Callendar and Glazebrook be asked to consider the details of the selection of platinum wires and to consult George Matthey. Two specimens of very pure platinum were duly supplied by Matthey and were tested at the National Physical Laboratory at Kew, giving ratios of R_{100} to R_0 of 1.3883 and 1.3884 respectively. In the following year he put a larger stock of wire at the Sub-Committee's disposal, this giving a ratio of 1.3892.

By the 1903 meeting of the British Association the Committee could report that its work had been transferred to the National Physical Laboratory, now installed at Bushy House in Teddington, where a room had been specially equipped for the accurate measurement of resistance, and that the construction of standard platinum resistance thermometers was proceeding.

So the platinum resistance thermometer was confirmed as a sensitive and stable instrument both for industrial temperature measurement and control and for precise laboratory work. The first International Temperature Scale was agreed upon in 1928, revised in 1948 and 1968, and amended in 1975. Successive versions have relied upon it, and it is now the instrument used to define the very wide range from −259.34°C, the triple point of equilibrium between the solid, liquid and vapour phases of hydrogen, and 630.74°C, the freezing point of antimony.

Over the past three quarters of a century designs have improved to meet industrial needs, more manufacturers have engaged in its production, new techniques have been introduced, including the replacement of the coil of wire by thick films, and smaller and more robust thermometers have been made available. Production of platinum resistance thermometers for industrial use now runs to several millions a year (23), while the accuracy of the temperature-resistance characteristics is ensured by the continuing availability of the special Thermpure platinum upon which the functioning of the instrument is based.

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