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TOTAL RADIATION FROM NICKEL AND COBALT

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Abstract

Measurements have been made on the total radiation from nickel between 630°K and 1600°K and from cobalt between 672°K and 1590°K. The radiation was measured by means of a platinum-tellurium thermocouple and a high sensitivity galvanometer. A constant deflection method was used. The temperature of the metal was measured by means of a Holborn-Kurlbaum type of optical pyrometer, calibrated at the gold and palladium points, and by means of a platinum platinum-rhodium thermocouple. A comparison of the radiation with other properties of the metals is given.

IN A study of the total radiation of metals, Suydam[1] found that the radiation from nickel could be fairly well represented, between 463°K and 1283°K, by an equation of the Stefan-Boltzmann form, and that the exponent of T in

$$E = cT^n \tag{1}$$

has a constant value.

Kahanowicz[2] determined that, between 273°K and 903°K, the same form of equation could be used for nickel but the value of the exponent was very different from that found by Suydam.

In the present work observations have been made on the radiation from nickel, extending the temperature nearer the melting point. Observations have been made on the radiation from cobalt.

The method employed in this experiment consisted in allowing the radiation from the metal to fall on the thermocouple and, by means of a rotating sector, comparing the energies at the different temperatures.

The metallic radiators were in the form of a V-shaped wedge as described by Mendenhall.[3] The characteristic radiation of the metal was taken from the outer surface of the wedge. Two methods were used to determine the temperature of the radiators. A platinum platinum-rhodium thermocouple, as described by Spence,[4] was used for temperatures extending from 630°K to the gold point. Temperatures extending from 1200°K to 1600°K were measured by means of an optical pyrometer. This gave a range of 135°, from 1200°K to 1335°K, for which the temperatures were measured with both the pyrometer and the thermocouple.

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[1] V. A. Suydam, Phys. Rev. **5**, 497 (1915).

[2] M. Kahanowicz, Accad. Lincei. Atti. **30**, 132 (1921).

[3] C. E. Mendenhall, Astrophys. J. **33**, 91 (1915).

[4] B. J. Spence, Astrophys. J. **37**, 194 (1913).

A water-jacketed brass base, *U*, about 20 cm in diameter and 4 cm deep was mounted as shown. A water-jacketed cylinder, *A*, contains a platinum tellurium thermocouple, *T*. The blackened receiver of the couple is at the center of curvature of a hemispherical silver mirror, B. The mirror is to better the black body conditions of the receiver. *A* is connected by means of a curved brass tube to a fixed diaphragm, *E*, the latter being mounted by means of the brass tube, *F*, extending through the bottom of the base. A movable diaphragm, *H*, also water cooled, was mounted directly in front of the fixed diaphragm.

The V-shaped metal strip, *L*, was about 4.5 cm long 1 cm wide and 0.0025 cm thick and has an opening of about 8 degrees. This strip was mounted in such a manner that the expansion of the strip, when heated, could be taken up from the outside of the apparatus. The supports for the filament were insulated from the base and served also as conductors for the current used to heat the filament. Storage cells were used for the heating current.

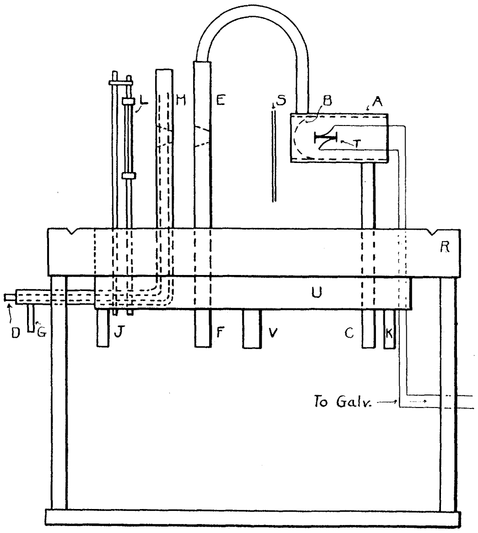

Fig. 1. A diagram of the apparatus.

A rotating sector, *S*, having two known apertures, was mounted on the shaft of a small motor. The motor was mounted on a rod which extended through a packed joint to the outside of the tank. By this means the sector could be placed in such a position that the full beam of radiation through the diaphragms could fall on the thermocouple or, so that this radiation was reduced by passing through either of the apertures of the sector. The motor operating the sector was driven by two dry cells placed outside the base.

The base was provided with a solid brass ring, *R*, 3 cm square, in which was cut an annular V-shaped groove. A brass cover was provided which had a similar ring so cut that when the cover was in position the two grooves were in exact register. A solid ring of solder was placed in the lower groove, the cover placed in position, and the solder squeezed into the grooves by means of 0.5″ cap screws which were threaded into the base.

The vessel was evacuated through the tube *V* by means of a mercury vapor pump which was backed by a Cenco oil pump. The working pressure, as measured by a McLeod gauge, was never more than 3×10^{-5} mm of mercury and frequently during the observations lower pressures were obtained.

The cover of the tank was provided with a side tube having a glass window through which optical pyrometer measurements of the temperature were taken.

METHOD OF MAKING OBSERVATIONS

The wedge of the metal to be studied was mounted in the supports. The thermocouple was connected to a Leeds and Northrup galvanometer which had a sensitivity of 482 megohms and a resistance of 20 ohms.

After the apparatus had reached equilibrium, which required from two to four hours, the metal strip was heated to some desired temperature. The full beam of radiation was allowed to fall on the thermocouple and the deflection of the galvanometer was adjusted to some convenient value, usually around 20 to 30 cm.

The receiver of the couple was exposed to the beam of radiation for one minute, then the beam was cut off for one minute by means of the movable diaphragm, thus enabling a correction for any slight shift in the zero position of the galvanometer during an exposure. After recording the deflection and the temperature, the rotating sector was moved into such a position that the beam of radiation from the metal passed through the first aperture of the sector, thus reducing the energy falling on the receiver of the couple by a known fraction of its original value. The temperature of the filament was then raised until the galvanometer showed the *same deflection* as before. Then the second, (smaller), aperture of the sector was moved into the beam of radiation and the temperature again raised until the galvanometer gave the *same deflection* as before. A sector having but two apertures could be used. To proceed to higher temperatures, the last observed temperature of the filament was kept constant, the sector moved out of the beam of radiation, and the deflection of the galvanometer was adjusted to nearly its original value. No attempt was made exactly to reproduce the last deflection although in some cases it was possible to do so. This adjustment of the deflection was accomplished by means of several resistances placed in parallel and in series with the galvanometer coil. The temperature of the filament was again raised by two steps, keeping the deflection of the galvanometer *constant* by means of the rotating sector as before. These operations were repeated as many times as necessary to cover the temperature range being studied. A great many such sets of observations were made both for nickel and for cobalt. The initial, or starting, temperature was selected in many instances so that the data from one set of observations would overlap the data of other sets of observations. A typical set of observations is shown in Table I.

TABLE I. *A set of observations for cobalt in the temperature range for which the optical pyrometer was used.*

Pyrometer current	Temp (°K)	Deflection	Sector H_1
0.2688		31.24	Full aperture
0.2689		31.24	
0.2688	1208	31.26	
0.2853		31.24	Second aperture
0.2853		31.24	
0.2855	1278	31.23	
0.3021		31.22	Third aperture
0.3023		31.25	
0.3019	1338	31.23	
0.3020		30.15	Full aperture
0.3022	1338	30.17	
0.3281		30.16	Second aperture
0.3282		30.15	
0.3281	1424	30.15	
0.3525		30.14	Third aperture
0.3522		30.15	
0.3522	1495	30.15	

Two sectors were used. H_1 had apertures of 215° 41′ 20″ and 269° 51′ 40″. Sector A_1 had apertures of 52° 07′ 40″ and 34° 09′ 00″. These apertures were measured on a Societe Genevoise spectrometer which read to ten seconds of arc. In order further to investigate the possibility of having introduced some cumulative error in the process of building up the temperatures, another sector, H_2, having apertures of 80° 40′ 10″ and 81° 33′ 00″ was used. These apertures were calculated so that the following relations held,

$$(2\pi/{}^1H_1)^2<2\pi/{}^1H_2$$

and

$$2\pi/{}^2H_2<(2\pi/{}^1H_1)^2$$

where ${}^1H_1$ refers to the first aperture of sector H_1, etc. That no error was found is evidenced by the fact that the points determined by the use of sector H_2 fell exactly on the energy-temperature curve obtained with the other sectors. From the known apertures of the sectors the energy corresponding to each temperature was computed. The logarithm of the energy is plotted in Fig. 2 against the logarithm of the corresponding temperature.

The curve for nickel is a straight line from 653°K to about 1400°K. Over this temperature range n in Eq. (1) is found to be 5.29. From 1450°K to 1600°K the curve is also a straght line but of different slope. The value of n for this range is 4.75. From around 1400°K to 1450°K the value of n changes rapidly from 5.29 to 4.75. Similar results obtain with cobalt. The value of n, for cobalt, is constant from 672°K to about 1320°K and equal to 5.20. From this latter temperature to around 1380°K n is not constant but decreases in value to 4.62. Above 1380°K the value of n remains constant and equal to 4.62 up to 1590°K. The following equations express the relation between energy and temperature:

For nickel $E=C_1T^{5.29}$ for all values of T from 650 to 1400°K
$E=C_2T^{4.75}$ for all values of T from 1450 to 1600°K
For cobalt $E=C_3T^{5.20}$ for values of T from 672 to 1320°K
$E=C_4T^{4.62}$ for values of T from 1380 to 1590°K

The results of these experiments are not in agreement with those of Suydam[1] or Kahanowicz.[2] The first of these experimenters finds an average value of n for nickel, between 463°K and 1283°K, to be 4.648 with the individual values varying from 4.6 to 4.7. It is stated that an equation of the form of Eq. (1) does not hold very well for nickel over the range studied. In Suydam's experiments the radiation was not directly measured but was computed from the energy put into the sample. This, in comparison with the method of the present experiments, is not so direct and might easily lead to differences in results.

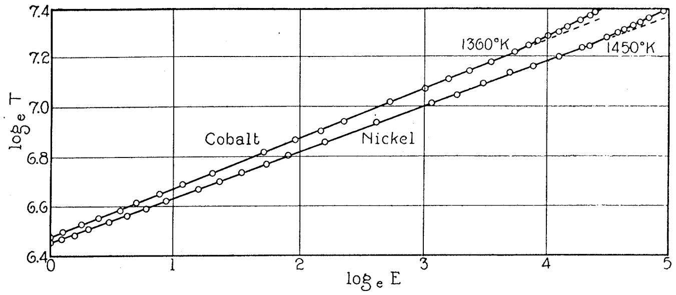

Fig. 2. Logarithmic plot of energy against temperature.

Kahanowicz also finds that an equation of the form of Eq. (1) will hold for nickel between 273°K and 905°K and that the average value of n for that region is 5.5. The writer's value of n over the lower temperature range is in fair agreement with this, while for temperatures nearer the melting point it is more nearly in agreement with the value found by Suydam.

So far as the writer knows, no observations have been made on cobalt.

The internal structure is one of the factors affecting the radiation and as this varies with the temperature, especially so at the Curie point, it is not to be expected that the emission from these metals can be simply expressed. At the Curie point for cobalt, 1348°K, a rapid change in the emission is indicated by the curve in Fig. 2. It is known that at this temperature, the susceptibility, the permeability, the resistance, and thermal expansion undergo rapid changes and it is to be expected that the specific heat, at this point, behaves in a similar manner. The fact that a sudden decrease in the specific heat may be expected at this temperature is a direct consequence of the Langevin-Weiss theory of magnetism.

There is no known transition point for nickel in the region of rapid variation of n, that is, around 1400°K. However some internal change may occur here. The possibility that such might be the case is indicated, not only by the present data, but also by measurements of other experimenters.

Terry[5] finds that around 1430°K susceptibility measurements show a change in the β form of nickel. His results are in general agreement with those of Foëx[6] and of Weiss and Foëx[7] who also find a change in the β form of nickel.

The fact that n is found to have a smaller value for the higher temperatures is in general agreement with the work of Hagen and Rubens.[8] These authors arrive at the result that the radiation from metals, with increasing temperature, approaches black-body radiation.

The above results are in agreement with that of Aschkinass[9] who, in a treatment of the radiation of metals, shows that the radiation approaches that of a perfect radiator as the temperature rises.

Hase,[10] in some not very precise measurements, finds that the radiation from iron, up to 1200°C approaches black body radiation with rising temperature.

Jones[11] has computed the rate of emission of energy from tungsten for various temperatures. His results show an approach toward black-body radiation as the temperature nears the melting point.

It is proposed to make a further study of the properties of nickel in the region of temperature where the radiation is changing.

The greater part of this work was done at the University of Wisconsin. This opportunity is taken to express my appreciation to Professor C. E. Mendenhall for his helpful suggestions and for his interest in the work.

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[6] Foëx, Ann. d. Physik **16**, 174 (1921).

[7] Weiss and Foëx, Arc. Des Sc. Phys. et Nat. **31**, 89 (1911).

[8] Hagen and Rubens, Ann. d. Physik **11**, 873 (1903).

[9] E. Aschkinass, Ann. d. Physik **17**, 960 (1905).

[10] Hase, Zeits. f. Physik **15**, 54 (1923).

[11] H. A. Jones, Phys. Rev. **28**, 206 (1926).