THE TRUE TEMPERATURE SCALE OF CARBON

By C. H. Prescott Jr. and W. B. Hincke

Abstract

Spectral emissive power of Acheson graphite at 0.660μ.—The spectral emissive power of Acheson graphite for the wave-length 0.660μ has been determined for the temperature range from 1250°K to 2700°K. The observations were made on a small tubular graphite resistance furnace with a hole in the wall and are best summarized by the relation: $\epsilon=0.984-5.8\times10^{-5}T$. Measurements of the temperature distribution along the furnace afford determinations of the *ratio of resistivity to thermal conductivity* at three temperatures.

Plan of the Investigation

THE present work has been prosecuted as part of the fundamental basis of a program of research in high temperature physical chemistry. Its purpose is to make possible the determination of the true thermodynamic temperature from observation made with an optical pyrometer. The preliminary results have been used to calculate temperature corrections for studies on the chemical equilibria between zirconium oxide and carbon,[1] and between thorium oxide and carbon.[2]

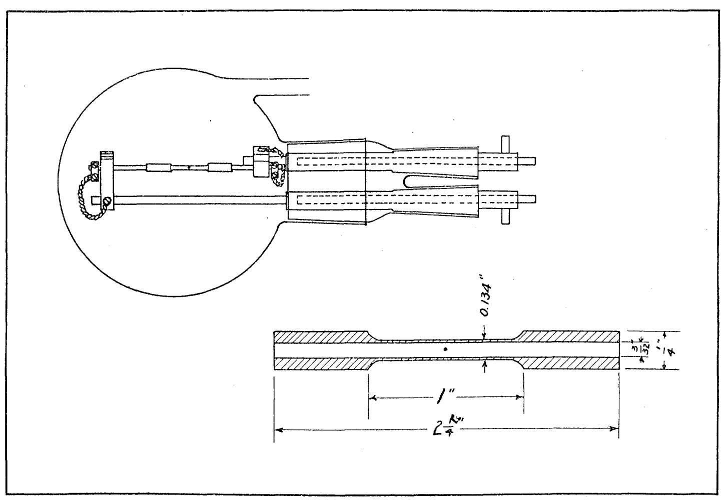

Fig. 1. Diagram of furnace.

Apparatus and Procedure

The furnace shown in Fig. 1 (where the dimensions are stated in inches) is a tube of Acheson graphite 5.7 cm long, 0.635 cm in diameter at the ends,

[1] Prescott· J. Amer. Chem. Soc. **48**, 2534 (1926).
[2] Prescott and Hincke J. Amer. Chem. Soc. **49**, 2744 (1927).

and 0.318 cm in the central section for a length of 2.54 cm, with a 0.04 cm wall. The tube is supported on tungsten rods pressed into the ends of the tube. The furnace was horizontal, the tungsten rods resting in steel guides clamped to water-cooled copper leads. Electrical connection was made by flexible copper wire fastened to steel clamps on the ends of the tungsten rods. The outer ends of the water-cooled leads were tapered to fit ground-glass seals in a Pyrex plug which was ground to fit a 1-liter Pyrex flask. Seals were made with Dennison's banker's specie sealing wax and the flask could be evacuated or filled with carbon monoxide to suppress the volatilization of the furnace at higher temperatures.

The temperature measurements were made with an optical pyrometer of the disappearing filament type made in the laboratory shop after a design by Forsythe.[3] Two thicknesses of Corning red glass were used for a monochromatic screen, and an absorption screen of shade six noviweld glass. These were calibrated through the courtesy of the Nela Research Laboratory. The effective wave-length of the red screen was approximately 0.660μ. The pyrometer was calibrated against a standard ribbon filament lamp, also obtained from the Nela Research Laboratory.

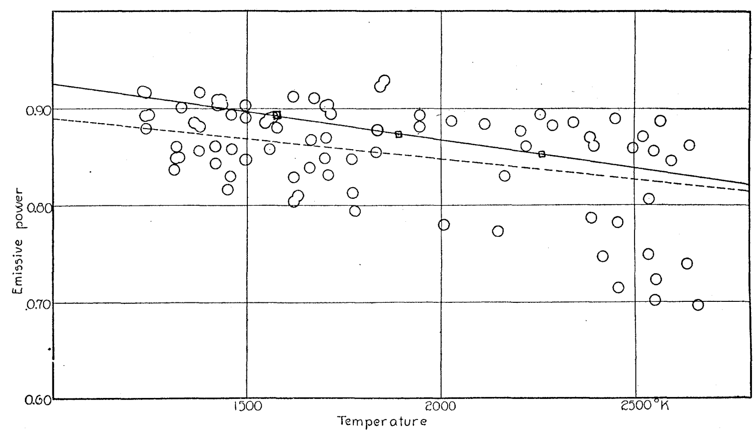

Fig. 2. Emissive power of graphite.

Measurements of the emissive power were made on six different furnaces. Each had three holes 0.38 mm in diameter in its wall, 120° apart around its circumference, and 1.6 mm apart along its axis in the center where the temperature was most uniform. The hole served as an experimental black body, and a comparison of the temperature T of the inside of the furnace as seen through the hole, with the apparent brightness temperature S of the adjacent wall afforded a determination of the effective emissive power η of the graphite. This is calculated from the Wien radiation law by the formula

$$1/T-1/S=\lambda ln\eta/c_2$$

where λ is the effective wave-length of the screen and c_2 is 14330μ degrees. As noted later, η is not the true emissive power.

[3] Forsythe Astrophys. J. **43,** 295 (1916).

The pyrometer current was read when the filament disappeared from being darker than the furnace, and from being brighter. On the average four such pairs were taken for a temperature determination. For an emissive power determination readings were taken on the hole, on the wall to the left (in the direction of the axis of the furnace), on the wall to the right, and again on the hole. The readings averaged for the hole and the wall were then corrected for the transmission of the Pyrex flask (89.7 percent). Approximately equal numbers of determinations were made on each of the three holes in each furnace.

The resulting values of η are plotted in Fig. 2 as points in circles where the dotted straight line represents a least square solution of the data which gave the relation $\eta = 0.930 - 4.2 \times 10^{-5} T$.

The True Emissive Power from the Temperature Gradient

To obtain the true emissive power ϵ from the considerations of the last paragraph it is necessary to correct η for the difference between the true temperature of the inside of the furnace and the true temperature of the outside where the brightness temperature was measured. In the center of a long furnace where no heat is lost by conduction this difference is given by the equation:

$$T - T_0 = (\rho j^2/2k)\left[(r^2 - r_0^2)/2 - r_0^2 ln(r/r_0)\right]$$

where ρ is the resistivity, j is the current density, k is the thermal conductivity, and r and r_0 are the radii of the outer and inner surfaces. This condition is approximated by the center of the actual furnace close enough for the calculation of a correction, but no existing values of ρ and k gave a temperature difference of the right order of magnitude. The ratio of ρ and k is, however, related to the variation of temperature along the furnace. From the considerations developed by Worthing[4] the following approximate relation may be developed giving the distribution of temperature near the center of the furnace:

$$(T_m - T)/T_m = e^{\pm P(x - x_0)} \qquad P = (4\rho j^2/kT_m)^{1/2}$$

where T_m is the maximum temperature in a long furnace running at the same current, and x_0 is a constant of integration. The distribution in a short furnace is a combination of the two exponential functions giving the distribution at the ends of the long furnace.

The temperature distribution was determined at three temperatures on a selected furnace, traversing its length by turning the pyrometer with a micrometer screw. The true temperatures were obtained closely enough from the values of η, and are plotted against x in Fig. 3. The values of T_m were estimated from these curves and the values of $\log_{10}(T_m - T)$ plotted against x in Fig. 4. From the limiting slopes of these curves values of P were obtained and from them the values of $\rho j^2/k$ which permitted the calculation of the temperature correction required. The values of T_m, ρ/k, etc., are presented in Table I.

[4] Worthing J. Franklin Inst. 597 (Nov. 1922).

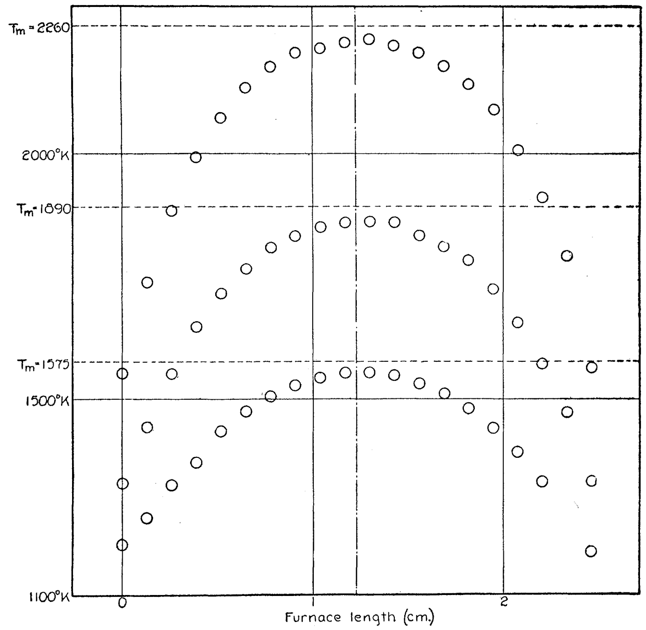

Fig. 3. Temperature distribution along the length of the furnace.

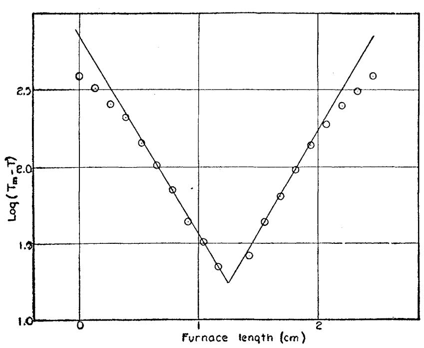

Fig. 4A. $T_m = 1575$°K.

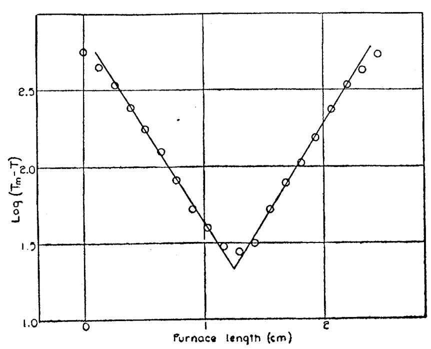

Fig. 4B. $T_m = 1890$°K.

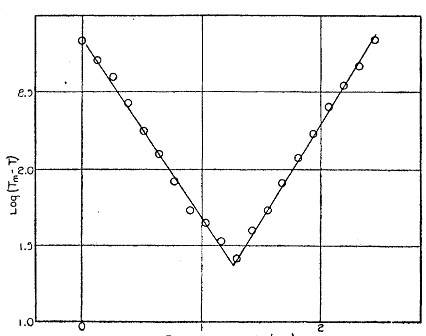

Fig. 4C. $T_m = 2260$°K.

Fig. 4. Variation of log $(T_m - T)$ along the length of the furnace.

TABLE I

Values for the true emissivity of Acheson graphite and of some of the intermediate constants necessary for its computation ($r=0.1700$ cm, $r_0=0.1243$ cm).

T_m	P	$\rho j^2/k$	ρ/k	$T-T_0$	η	ϵ
2260°K	2.85	4470	1.103×10^{-3}	4.25°	0.837	0.852
1890	2.94	4100	1.670	3.90	0.852	0.873
1575	3.02	3590	2.305	3.41	0.866	0.892

The corresponding values of the true emissive power ϵ of graphite are plotted in Fig. 2 as points in squares, and the solid straight line through them gives the true emissive power which is expressed by the equation: $\epsilon=0.984-5.8\times10^{-5}T$.

Fig. 5 gives the temperature differences corresponding to (1) the determinations of Mendenhall and Forsythe,[5] (2) preliminary published values,[1] (3) η, (4) ϵ, the true emissive power of graphite from the present work. The

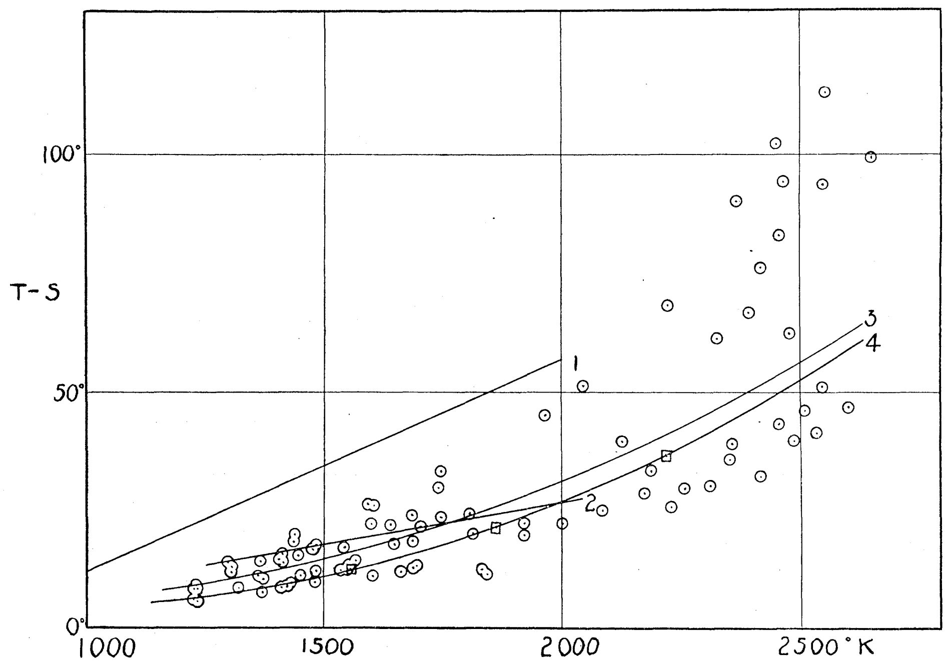

Fig. 5. True temperature as a function of brightness temperature for carbon ($\epsilon=0.984-5.8\times10^{-5}T$).

points give the experimental values corresponding to those in Fig. 2. The emissive power of a high grade of gas carbon has been determined by Mendenhall and Forsythe,[5] but, no doubt because of a difference in surface conditions, their results are somewhat higher than ours.

Acknowledgment is due to Dr. W. E. Forsythe of the Nela Research Laboratory for assistance with the pyrometric standards. This investigation has been aided financially by a grant made to Professor A. A. Noyes by the Carnegie Institution of Washington.

GATES CHEMICAL LABORATORY,
CALIFORNIA INSTITUTE OF TECHNOLOGY,
August 10, 1927.

[5] Mendenhall and Forsythe Astrophys. J. **37,** 380 (1913).