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THERMAL EXPANSION OF ARTIFICIAL GRAPHITE AND CARBON

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ABSTRACT

The linear thermal expansion of longitudinal sections cut from 14, 3, 1¼, and 1 inch artificial graphite electrodes and of transverse sections cut from 14 and 3 inch electrodes, were investigated at various temperatures between 20 and 1,000 C. A comparison of the average expansion curves of the longitudinal and transverse sections is shown in figure 3, and the ranges of the coefficients of expansion for various temperature ranges are given in table 4. The coefficients of expansion of the transverse sections are larger than the coefficients of expansion of the longitudinal sections. For example, for the range from 20 to 1,000 C, the linear expansion of the transverse sections cut from 3-inch graphite is about 110 percent greater than the expansion of the longitudinal sections cut from 3-inch graphite electrodes. Other conclusions are listed in section V of this paper.

The linear thermal expansion of two types of carbon which are used for expansion elements in temperature regulators for domestic gas ovens, were investigated at various temperatures between 20 and 350 C. The coefficients of expansion of carbon made with lampblack are about three times as large as the coefficients of carbon made with petroleum coke.

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I. INTRODUCTION

During the past few years there has been a demand for data on the thermal expansion of artificial graphite at elevated temperatures for the following purposes:

1. To calculate the volumes of graphite crucibles used in determining the specific volumes of molten metals and alloys.

2. For a reference standard in the determination of the thermal expansion of refractory materials. During the past few years, expansion data to 600 C by Hidnert and Sweeney [1] have been extrapolated and used for these purposes.

[1] Hidnert and Sweeney B.S. Technologic Paper 335.

In 1927 Hidnert and Sweeney published in B.S. Technologic Paper 335 a table of data on the thermal expansion of graphite (natural [2] and artificial) and of other forms of carbon by Fizeau, Muraoka, Dewar, Day and Sosman, and Sieglerschmidt. Available data by other observers are given in table 1.

TABLE 1.—*Expansion data by previous observers on graphite and other forms of carbon* [a]

Observer	Date	Material	Temperature or temperature range	Coefficient of linear expansion per degree centigrade	Remarks
			° C	×10⁻⁶	
Fizeau [b]	1865	Diamond	20	0.85	
			30	1.00	
			40	1.14	
			50	1.29	
Fizeau [c]	1866	do	40	1.18	Same diamond as used by Fizeau in 1865.
Monckman [d]	1888	Carbon	13–614	6.66	Experiment 1.
			14–645	6.6	Experiment 2.
			15–300	5.6	Experiment 3.
			300–645	8	
			15–143	4.5	Experiment 4.
			143–263	7.7	
			263–282	14.0	
			282–602	9	
Joly [e]	1898	Diamond	0–400	[f] 2.8	At a temperature of 850 C the diamond began to burn rapidly. Its surface soon became stepped in a manner characteristic of certain crystals. Once commenced, the combustion continued till the oven was cooled down to about 712 C.
			400–580	[f] 4.4	
			580–686	[f] 6.8	
			686–750	[f] 11.4	
Stewart [g]	1908	Carbon in the form of films made of commercial lampblack and a lacquer called "zapon L".			The result obtained shows the coefficient of carbon in the form of lampblack to be about 0.0002, which is from 10 to 30 times that of the pure metals.
National Carbon Co. [h]	1911	Electrodes:			
		Coal	220–1,820	11.0	
		Coke	180–1,920	7.2	
		Graphite	440–1,720	10	
		Arc carbon of lampblack.	25–1,000	6.0	
Röntgen [i]	1912	Diamond	−188 to −79	0.18	
			−79 to 0	.58	
			0 to +23	.97	
			+23 to 55	1.17	
			55 to 78	1.45	

[a] For data by other observers (Fizeau, Muraoka, Dewar, Day and Sosman, and Sieglerschmidt), see Hidnert and Sweeney, B.S. Technologic Paper 335, table 1.
[b] Fizeau, Comptes Rendus, vol. 60, p. 1161, 1865.
[c] Fizeau, Comptes Rendus, vol. 62, pp. 1101, 1133, 1866.
[d] Monckman, Proc. Royal Society of London, vol. 44, p. 220, 1888.
[e] Joly, Scientific Trans. Royal Dublin Society, vol. 6 (series 2), p. 283, 1898.
[f] Computed by Hidnert in 1934 from expansion data given by Joly.
[g] Stewart, Physical Review, vol. 26, p. 333, 1908.
[h] See Chaney, International Critical Tables, vol. 2, p. 303, 1927.
[i] Röntgen, Sitzungsberichte der mathematisch-physikalischen Klasse der K. B. Akademie der Wissenschaften zu München, vol. 42, p. 381, 1912.

[2] For graphite from Batongol, Fizeau (Comptes Rendus, vol. 68, p. 1125, 1869) reported 7.86×10⁻⁶ for the coefficient of linear expansion at 40 C, and for graphite from Cumberland, Dewar (Proc. Roy. Soc. London, vol. 70, p. 237, 1902) obtained 73.3×10⁻⁶ for the average coefficient of cubical expansion between −186 and +17 C.

In the present investigation, thermal expansion measurements were made on longitudinal and transverse sections of artificial graphite at various temperatures between 20 and 1,000 C. A neutral atmosphere was used in order to prevent oxidation of the graphite samples at elevated temperatures. Two other types of carbon which are of importance from the standpoint of expansion, were included in this investigation.

The author expresses his appreciation to H. D. Batchelor of the National Carbon Co., Cleveland, Ohio, and M. S. May of the Speer Carbon Co., Saint Marys, Pa., for their cooperation in this investigation. Acknowledgment is also due to the following members of the staff of the National Bureau of Standards: H. W. Bearce, W. Souder, and C. G. Peters, for valuable suggestions; to H. S. Krider for assistance during the measurements; and to S. Alpher for aid in the preparation of the figures.

II. MATERIALS INVESTIGATED

The following materials were investigated: (1) artificial graphite, longitudinal and transverse sections; and (2) carbon. A description of these materials is given in tables 2, 3, and 5. Information about the preparation of 14-inch artificial graphite electrode, chemical composition and density, have been published[3] in 1927.

In 1927, Chaney[4] stated "Manufactured carbon articles in the form of rods, plates, blocks, tubes, etc., in a wide variety of shapes are made by molding or extruding specially prepared mixtures of pulverized carbon 'flours' with binding materials of tar or pitch, and subsequently carbonizing the binder at high temperatures. The resulting products always consist of a porous mass of carbon particles knit together by the residual carbon resulting from the decomposition of the binding materials. Because of the variations inherent in all manufacturing processes the physical properties of commercial carbons are subject to characteristic variations, the allowable range of which is determined by the service and cost requirements of the consumer. A high degree of precision in the individual determinations is therefore valueless, the typical range of variation being alone significant. Individual values where given must be regarded merely as representative."

Mantell[5] in 1928 described the manufacture and uses of graphite and other forms of carbon. He stated that "The particular field of graphite is that of electrolytic work, where its low resistance and long life are very important. Graphite electrodes are extensively used in the electrolytic production of chlorine and caustic, the chlorination of gold ores, the recovery of copper, nickel, and zinc, the production of hypochlorites and many other similar applications." In a later publication, Mantell[6] stated that "carbon has shown its suitability in equipment employed in five different fields: (1) Acid manufacture, (2) papermaking, (3) the electrochemical industries, (4) combustion equipment, and (5) machinery operating under corrosive conditions."

[3] See footnote 1.
[4] Chaney, Commercial Carbons for Electrical Uses, International Critical Tables, vol. 2, p. 303, 1927.
[5] Mantell, Industrial Carbon, Industrial Chemical Monographs, D. Van Nostrand & Co., Inc., 1928.
[6] Mantell, Industrial and Engineering Chemistry, vol. 24, p. 1255, 1932.

III. APPARATUS

Figure 1 of B.S. Scientific Paper 524 shows part of the apparatus used in the investigation. The samples of artificial graphite were investigated at various temperatures between 20 and 1,000 C in the white furnace shown at the left end of the figure. The same furnace was used for the samples of carbon which were investigated at various temperatures between 20 and 350 C. Micrometer microscopes were sighted on fine wires suspended from the ends of the sample. The samples of graphite were mounted in the furnace as illustrated in figure 5 of the paper mentioned, but the samples of carbon were mounted as shown in figure 4 of the same paper. Each sample was 300 mm long.

Since graphite oxidizes in air at about 640 C, it was necessary to use a neutral atmosphere in the furnace at elevated temperatures. The neutral atmosphere consisted of a mixture of nitrogen and hydrogen gas (about 5 percent hydrogen). A combination reducing valve and flow meter was attached to the cylinder containing the mixture of nitrogen and hydrogen gas. The large gage indicated the pressure (pounds per square inch) of the gas in the cylinder and the small gage indicated the flow (liters per minute) of the gas from the cylinder. The gas was passed through copper gauze contained in a long copper tube supported horizontally in a tube furnace heated electrically to about 700 C, in order to remove oxygen. The hot gas was cooled by passing it through a copper coil surrounded by flowing water. The cooled gas was then passed through bottles or drying tubes containing calcium chloride and magnesium perchlorate trihydrate, in order to remove moisture. The dry gas was passed through another flow meter and finally into the furnace at both ends. The reducing valve was adjusted so that the gas flowed at a rate of about 5 liters per minute. The gas was allowed to flow into the furnace containing the graphite sample, during the time the sample was heated from 400 to 1,000 C and cooled to 600 C or less.

The samples of carbon were not heated in a neutral atmosphere, for measurements were only made to 350 C.

IV. RESULTS

The results obtained on artificial graphite and carbon are given in subsections 1 and 2, respectively.

1. ARTIFICIAL GRAPHITE

The linear thermal expansion of longitudinal sections cut from 14-, 3-, 1¼-, and 1-inch graphite electrodes and of transverse sections cut from 14- and 3-inch graphite electrodes, were investigated at various temperatures between 20 and 1,000 C. The results obtained on the longitudinal sections are given in figure 1 and in table 2, and the results on the transverse sections in figure 2 and table 3.

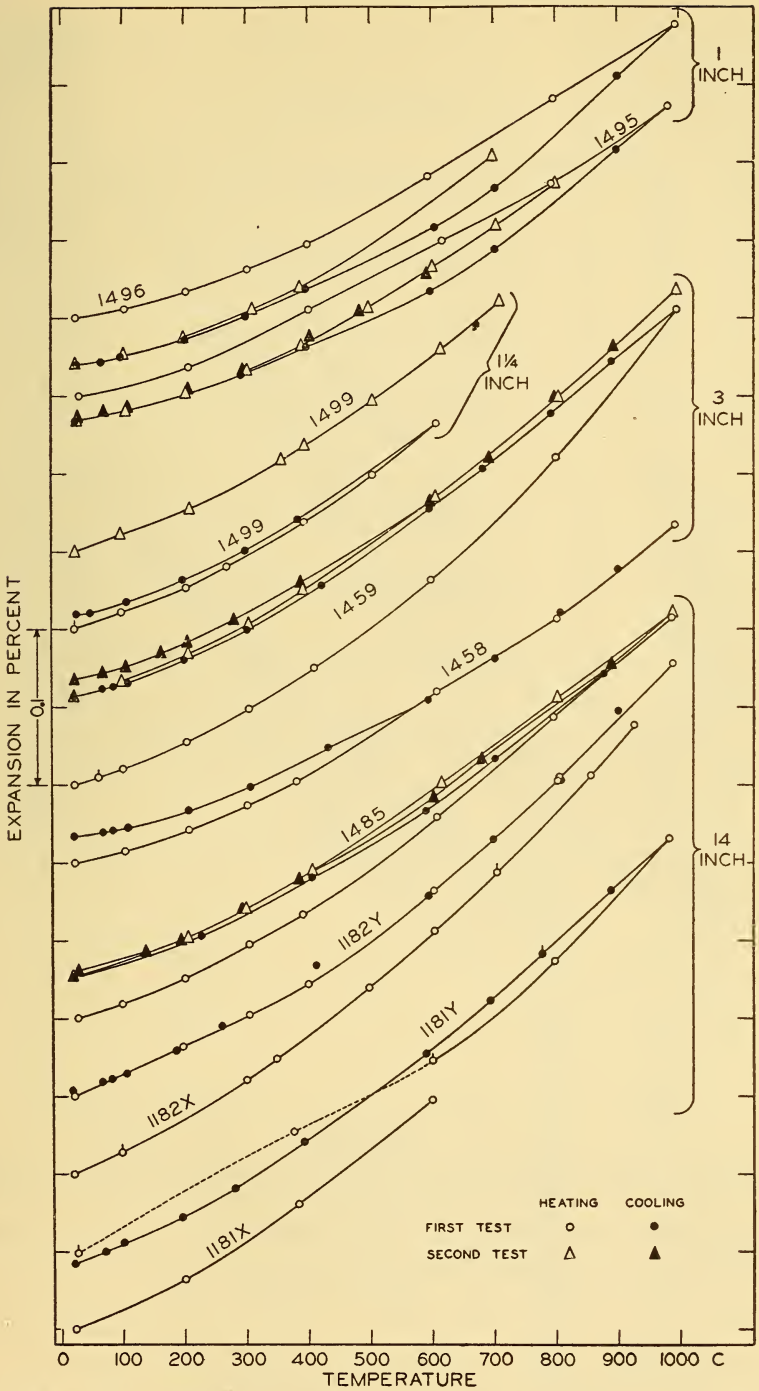

FIGURE 1.—*Linear thermal expansion of longitudinal sections cut from 14-, 3-, 1¼-, and 1-inch diameter artificial graphite electrodes.*

NOTE.—A tagged symbol indicates more than one observation.

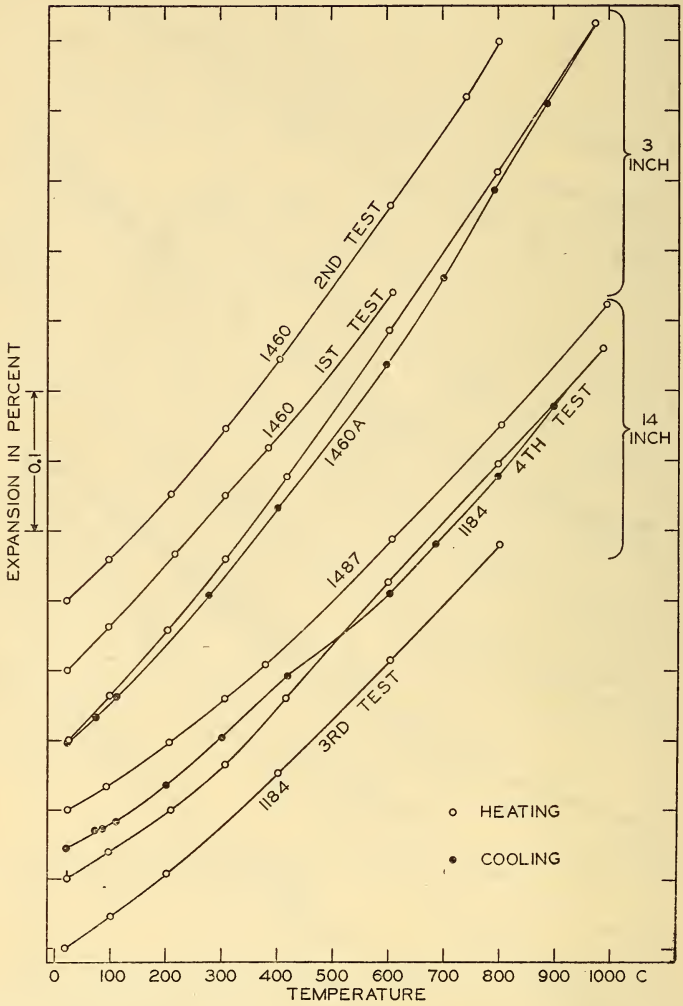

FIGURE 2.—*Linear thermal expansion of transverse sections cut from 14- and 3-inch diameter artificial graphite electrodes.*

(Expansion curves for first and second tests of sample [1184] have been given in B.S. Technologic Paper 335.)

NOTE.—The tagged symbol indicates more than one observation.

TABLE 2.—*Average coefficients of expansion of longitudinal sections of artificial graphite*

Sample	Description	Test number	Average coefficients of expansion per degree centigrade										Change[1] in length after heating and cooling
			20 to 100 C	20 to 200 C	20 to 300 C	20 to 400 C	20 to 500 C	20 to 600 C	20 to 700 C	20 to 800 C	20 to 900 C	20 to 1,000 C	
			×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	*Percent*
1180 A [2]	Longitudinal section cut from 14-inch graphite electrode	1	1.9	2.0	2.2	2.4							(3)
		2	1.9	2.0	2.2	2.4	2.6						
		3			2.1		2.5	2.7					
1181 [2]	do	1	2.2	2.1	2.3	2.4							
1181 X [4]	do	1		1.8		2.3		2.6		(5)			
1181 Y [4]	do	1				2.2		2.2		2.4		2.8	−.006
		[6] 1	1.6	1.7	1.9	2.1		2.4	2.5	2.7	2.8	2.8	
1182 [2]	do	1	1.8	1.9	2.1	2.3							
1182 X [7]	do	1	1.8		2.2		2.5	2.7	2.8		3.1	(8)	
1182 Y [7]	do	1		1.8	1.8	1.9		2.3		2.6		2.9	+.004
1485 [9]	do	1	1.3	1.4	1.7	1.8		2.2		2.5		2.7	+.027
		[6] 1		1.2		1.6		1.9	2.0		2.3	2.4	
		2		1.4	1.6	1.8		2.1		2.3		2.4	+.003
		[6] 2		1.2	1.5	1.6		1.9	2.1		2.3	2.4	
1458 [10]	Longitudinal section cut from 3-inch graphite electrode	1	0.9	1.1	1.3	1.5		1.9		2.0		2.2	+.017
		[6] 1	.6	0.9	1.1	1.3		1.5	1.7	1.8	2.0	2.1	
1459 [11]	do	1	1.3	1.5	1.7	1.9		2.3		2.7		3.1	+.057
		[6] 1	1.0	1.3	1.5	1.7		2.1	2.2	2.4	2.5	2.6	
		2	1.4	1.5	1.7	1.9		2.2		2.5		2.7	+.012
		[6] 2	0.9	1.3	1.5	1.7		2.0	2.1	2.3	2.5	2.6	
1499 [12]	Longitudinal section cut from 1¼-inch graphite electrode	1	1.4	1.5	1.7	1.9	2.0	2.2					+.009
		[6] 1	0.9	1.3	1.5	1.7		2.1					
		2	1.5	1.5	1.6	1.9	2.0	2.2	2.3				

[1] The plus (+) sign indicates an increase in length and the minus (−) sign a decrease in length.
[2] Data by Hidnert and Sweeney, B.S. Technologic Paper 335.
[3] Less than 0.012 percent (Hidnert and Sweeney, B.S. Technologic Paper 335, p. 226).
[4] Cut from sample 1181 after first test (cross section of original sample, semicircle, diameter 63 mm; cross section of sample 1181 X, 22 mm diameter, and of sample 1181 Y, 14 × 10 mm).
[5] Observation wire (Pt – Ir) broke at about 800 C.
[6] Cooling.
[7] Cut from sample 1182 after first test (cross section of original sample, semicircle, diameter 63 mm; cross section of sample 1182 X, 21 mm, and of sample 1182 Y, 14×10 mm).
[8] Observation wires (Pt – Os) broke below 1,000 C.
[9] Graphite electrode manufactured recently, submitted by Acheson Graphite Corporation, Niagara Falls, N.Y. in 1932.
[10] Graphite electrode purchased in 1930 from Acheson Graphite Corporation. Density 1.528 g/cm³, determined by E. L. Peffer of the National Bureau of Standards, by same method as described in footnote 4 of table 2, B.S. Technologic Paper 335.
[11] Graphite electrode purchased from Acheson Graphite Corporation. (Different date from that mentioned in footnote [10].)
[12] Graphite (grade 580) submitted by Speer Carbon Co., Saint Marys, Pa., in 1932. Made by hot extrusion process. Composed of artificial graphite throughout, formed partly by the graphitization of the pitch coke acting as the bonding material. Baked to approximately 2,500 C. Used as anodes in large mercury arc rectifiers developed for the conversion of alternating to direct current for railway service and in other applications where an unusually strong artificial graphite product is required. The maximum operating temperature in rectifiers is understood to be in the neighborhood of 760 C.

TABLE 2.—*Average coefficients of expansion of longitudinal sections of artificial graphite*—Continued

Sample	Description	Test number	Average coefficients of expansion per degree centigrade										Change[1] in length after heating and cooling
			20 to 100 C	20 to 200 C	20 to 300 C	20 to 400 C	20 to 500 C	20 to 600 C	20 to 700 C	20 to 800 C	20 to 900 C	20 to 1,000 C	
			×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	*Percent*
1495[13]	Longitudinal section cut from 1-inch graphite electrode	1	--------	1.0	--------	1.5	--------	1.7	--------	1.8	--------	2.0	−.016
		[6] 1	--------	--------	1.1	1.3	--------	1.4	1.6	--------	2.0	2.1	
		2	0.8	1.0	1.2	1.3	1.5	1.7	1.8	2.0	--------	--------	+.003
		[6] 2	.7	1.0	1.1	1.4	1.5	1.6	--------	1.9	--------	--------	
1496[14]	do	1	.7	0.9	1.1	1.3	--------	1.6	--------	1.8	--------	1.9	−.030
		[6] 1	.7	.9	1.1	1.3	--------	1.5	1.7	--------	2.1	2.3	
		2	.9	1.0	1.2	1.4	--------	--------	2.0	--------	--------	--------	--------

[1] The plus (+) sign indicates an increase in length and the minus (−) sign a decrease in length.
[6] Cooling.
[13] Graphite electrode purchased from Acheson Graphite Corporation, in 1932.
[14] Graphite electrode purchased from Acheson Graphite Corporation, before 1932.

TABLE 3.—*Average coefficients of expansion of transverse sections of artificial graphite*

Sample	Description	Test number	Average coefficients of expansion per degree centigrade										Change[1] in length after heating and cooling
			20 to 100 C	20 to 200 C	20 to 300 C	20 to 400 C	20 to 500 C	20 to 600 C	20 to 700 C	20 to 800 C	20 to 900 C	20 to 1,000 C	
			×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	*Percent*
1183[2]	Transverse section cut from 14-inch graphite electrode	1	3.1	3.2	3.4	3.6	--------	--------	--------	--------	--------	--------	(3)
		[2] 1	2.8	3.0	3.2	3.4	--------	--------	--------	--------	--------	--------	
		[2] 2	2.9	2.8	3.1	3.4	3.6	3.7	--------	--------	--------	--------	
1184	do	3	2.8	2.9	--------	3.3	--------	3.5	--------	3.7	(4)	--------	--------
		4	2.6	2.6	2.9	3.2	--------	3.7	--------	3.8	--------	3.9	+.022
		[5] 4	2.2	2.5	2.9	3.1	--------	3.1	3.3	3.4	3.6	3.7	
1487[6]	do	1	2.4	2.6	2.8	2.9	--------	3.3	--------	3.5	--------	[7] 3.7	--------
1460	Rod composed of 7 transverse sections[8] cut from same 3-inch graphite electrode as sample 1459 (table 2)	1	4.2	4.3	4.4	4.4	--------	4.6	--------	(9)	--------	--------	--------
		2	3.9	4.0	4.3	4.5	--------	4.8	--------	5.1	--------	(10)	--------
1460 A	Duplicate of sample 1460	1	4.3	4.4	4.6	4.8	--------	5.1	--------	5.3	--------	5.4	−.001
		[5] 1	3.7	--------	4.2	4.4	--------	4.7	4.9	5.2	5.3	5.4	

[1] The plus (+) sign indicates an increase in length and the minus (−) sign a decrease in length.
[2] Data by Hidnert and Sweeney, B.S. Technologic Paper 335.
[3] Less than 0.012 percent (Hidnert and Sweeney, B.S. Technologic Paper 335, p. 226).
[4] Observation wire (Pt - Rh) broke below 900 C.
[5] Cooling.
[6] Cut from same electrode as sample 1485 (table 2).
[7] Observation wire (Pt - Rh) broke at 900 C. on cooling.
[8] One end of each section was threaded, and the other end drilled and tapped. These sections were screwed together. It is believed that the expansion data obtained on this sample are reliable, for expansion determinations on an iron-chromium alloy (1427 P) composed of 7 sections machined and screwed together in a similar manner, agreed satisfactorily with results obtained on a duplicate alloy (1427) in a single piece. The following coefficients of expansion were obtained:

Temperature range	Average coefficients of expansion per degree centigrade	
	Sample 1427 P	Sample 1427
°C		
20 to 200	10.7×10^{-6}	10.4×10^{-6}
20 to 300	11.1	10.7
20 to 400	11.3	11.1
20 to 600	11.9	11.6
20 to 700	12.1	11.8
20 to 800	12.6	12.2
20 to 900	13.1	12.8

[9] Observation wire (Pt - Rh) broke at 800 C.
[10] Observation wire (Pt - Rh) broke at 1,000 C.

Some of the tests could not be carried to 1,000 C, for one or both observation wires broke before this temperature was reached. Platinum-osmium (6 percent osmium), platinum-iridium (20 percent iridium), and platinum-rhodium (20 percent rhodium) wires, 0.002-inch diameter, were tried. None of these wires gave entire satisfaction. The platinum-rhodium (20 percent rhodium) wire was found to give the best results under the conditions of the test which required

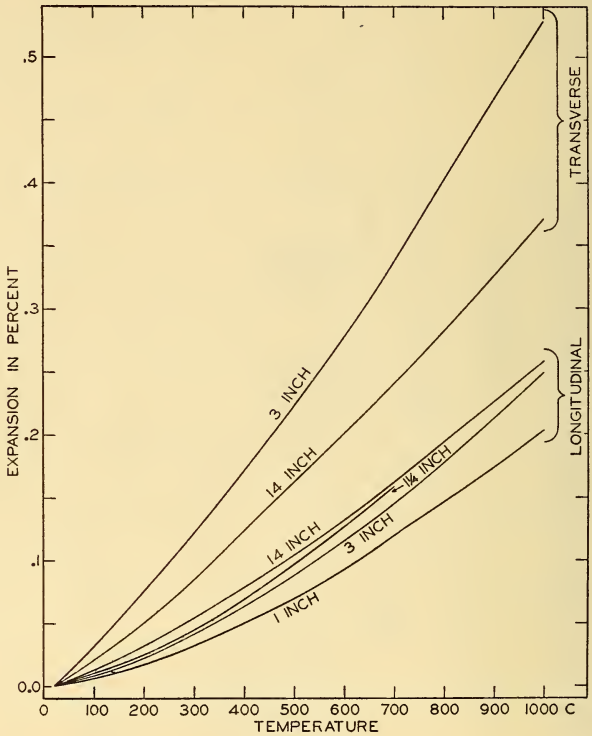

FIGURE 3.—*Comparison of average expansion curves of longitudinal and transverse sections of artificial graphite electrodes.*

that each observation wire should sustain a load of about 15 grams at temperatures up to 1,000 C in an atmosphere consisting of nitrogen and hydrogen.

From the coefficients of expansion in tables 2 and 3, average expansion curves shown in figure 3 were derived for the various longitudinal and transverse sections of graphite. A comparison of the range of coefficients of expansion of the longitudinal and transverse sections is given in table 4.

TABLE 4.—*Comparison of average coefficients of expansion of longitudinal and transverse sections of artificial graphite*

Material	Average coefficients of expansion per degree centigrade			
	20 to 100 C	20 to 200 C	20 to 300 C	20 to 400 C
Longitudinal sections:	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$
Cut from 14-inch electrode	1.3 to 2.2(7)	1.2 to 2.1(11)	1.5 to 2.3(11)	1.6 to 2.4(12)
Cut from 3-inch electrode	0.6 to 1.4(6)	0.9 to 1.5(6)	1.1 to 1.7(6)	1.3 to 1.9(6)
Cut from 1¼-inch electrode	0.9 to 1.5(3)	1.3 to 1.5(3)	1.5 to 1.7(3)	1.7 to 1.9(3)
Cut from 1-inch electrode	0.7 to 0.9(5)	0.9 to 1.0(6)	1.1 to 1.2(6)	1.3 to 1.5(7)
Transverse sections:				
Cut from 14-inch electrode	2.2 to 3.1(7)	2.5 to 3.2(7)	2.8 to 3.4(6)	2.9 to 3.6(7)
Cut from 3-inch electrode	3.7 to 4.3(4)	4.0 to 4.4(3)	4.2 to 4.6(4)	4.4 to 4.8(4)

Material	Average coefficients of expansion per degree centigrade		
	20 to 500 C	20 to 600 C	20 to 700 C
Longitudinal sections:	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$
Cut from 14-inch electrode	2.5 to 2.6(3)	1.9 to 2.7(10)	2.0 to 2.8(4)
Cut from 3-inch electrode	----------	1.5 to 2.3(6)	1.7 to 2.2(3)
Cut from 1¼-inch electrode	2.0(2)	2.1 to 2.2(3)	2.3(1)
Cut from 1-inch electrode	1.5(2)	1.4 to 1.7(6)	1.6 to 2.0(4)
Transverse sections:			
Cut from 14-inch electrode	3.6(1)	3.1 to 3.7(5)	3.3(1)
Cut from 3-inch electrode	----------	4.6 to 5.1(4)	4.9(1)

Material	Average coefficients of expansion per degree centigrade		
	20 to 800 C	20 to 900 C	20 to 1,000 C
Longitudinal sections:	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$
Cut from 14-inch electrode	2.3 to 2.7(5)	2.3 to 3.1(4)	2.4 to 2.9(7)
Cut from 3-inch electrode	1.8 to 2.7(6)	2.0 to 2.5(3)	2.1 to 3.1(6)
Cut from 1¼-inch electrode	----------	----------	----------
Cut from 1-inch electrode	1.8 to 2.0(4)	2.0 to 2.1(2)	1.9 to 2.3(4)
Transverse sections:			
Cut from 14-inch electrode	3.4 to 3.8(4)	3.6(1)	3.7 to 3.9(3)
Cut from 3-inch electrode	5.1 to 5.3(3)	5.3(1)	5.4(2)

NOTE.—The number in the parenthesis following each range of coefficients of expansion, indicates the number of determinations.

The following general conclusions may be drawn from an examination of the data:

1. The coefficients of expansion of the longitudinal and transverse sections of graphite increase with temperature.

2. The coefficients of expansion of the transverse sections are larger than the coefficients of expansion of the longitudinal sections. Figure 3 indicates that for the range from 20 to 1,000 C, the linear expansion of the transverse sections cut from 3-inch graphite is about 110 percent greater than the expansion of the longitudinal sections cut from 3-inch graphite electrodes.

3. There appears to be a tendency for the coefficients of expansion of a longitudinal section to increase [7] with increase in the diameter

[7] The longitudinal section cut from 1¼-inch graphite electrode prepared by Speer Carbon Co., is an exception. The other longitudinal sections from 1-, 3-, and 14-inch electrodes, were prepared by Acheson Graphite Co. After an examination of these results, M. S. May of the Speer Carbon Co., recently stated that the 1¼-inch graphite does not fall in line with the Acheson product because it is made by a somewhat different process.

of the graphite electrode from which the longitudinal section has been cut.

4. The coefficients of expansion of the transverse sections cut from the 3-inch graphite electrodes are larger than the coefficients of expansion of the transverse sections cut from the 14-inch electrodes. For example, for the range from 20 to 1,000 C the average coefficient of expansion of the transverse sections from the 3-inch graphite is about 40 percent greater than the coefficient of expansion of the transverse sections from the 14-inch graphite electrodes.

5. The difference between the expansion of the transverse and longitudinal sections cut from the 3-inch graphite electrodes is considerably greater than the difference between the expansion of the transverse and longitudinal sections cut from the 14-inch electrodes. Figure 3 indicates that the former difference is about 145 percent greater than the latter difference for the linear expansion between 20 and 1,000 C.

6. The coefficients of expansion of the longitudinal sections cut from the 1-inch graphite electrodes are in good agreement with the data obtained by Day and Sosman [8] on ½-inch [9] graphite electrode.

7. The longitudinal and transverse sections of graphite indicate changes in length after heating to elevated temperatures and cooling to room temperature. A second heating and cooling cause smaller changes.

It has been indicated in a previous publication [10] that the differences in expansion and tensile strength between the transverse and longitudinal sections of a 14-inch graphite electrode may be due to the fact that the graphite electrode in the process of manufacture has been compressed differently in the two directions. Attention was also directed to statements of Taylor [11] on the effects of the extrusion process by which the "green" electrodes are formed. He stated that during extrusion the outer portions are retarded by friction with the walls of the die. There is therefore a good deal of internal motion parallel to the axis of the forming electrode. This internal motion causes a marked difference in the structure in the two directions. There is a tendency for the material to have a laminated structure in the transverse direction. The aggregate particles and cell walls are more firm and continuous in a lengthwise direction of the electrode than in a crosswise direction. Voids or pores tend to form with their longer axes lengthwise of the electrode. It seems quite probable that this has an effect on expansivity in the two directions. The longitudinal increment is practically a measure of the linear expansion of the material, and the transverse change is the linear expansion plus an increment of distortion due to increased spring in the arches formed by the cell walls of the voids and pores. Taylor also believed that the lower tensile strength in the transverse direction is due to the laminated structure mentioned.

As appreciable differences were found in the thermal expansion of sections cut from different size electrodes, an endeavor was made to obtain information about the ratio of the coke and plastic organic material, and the approximate grain size of the different electrodes. Referring to the graphite electrodes prepared by Acheson Graphite

[8] Day and Sosman, Jour. Ind. and Eng. Chem., vol. 4, p. 490, 1912, or J. Wash. Acad. Sci., vol. 2, p. 284, 1912 (see also Day, Sosman, and Hostetter, Amer. Jour. Sci., vol. 37, 4th series, p. 1, 1914).

[9] Hidnert and Sweeney, B.S.Technologic Paper 335, table 1, footnote 5.

[10] Hidnert and Sweeney, B.S.Technologic Paper 335, p. 228.

[11] See reference, footnote 10.

Co., H. D. Batchelor, director of research of the National Carbon Co., Inc., Cleveland, Ohio, stated the following:

"The ratio of coke and plastic organic material is approximately the same for all sizes of graphite electrodes. It varies somewhat according to size but not to exceed 10 percent. The grain sizes of different size electrodes do vary in accordance with their size. The coarsest particles in 3- and 4-inch electrodes will all pass through a 20-mesh screen and a greater proportion of them will pass through a 200-mesh screen. In a 14-inch electrode the coarse particles are between 0.03 and 0.06 inch in diameter, the next closest lie between 0.03 and 0.015 and finally, here again, the larger portion of the particles will pass through the 200-mesh screen.

"In addition to the difference in grain size above mentioned, possibly one should take into consideration the normal variation to be expected in commercial electrodes. As to just what this variation is in terms of thermal expansion, we have no information, * * *."

M. S. May of the Speer Carbon Co., recently stated: "It appears probable that the difference in expansion between the different sized Acheson rods is because they are made from flours of different finenesses rather than because of the difference of diameter itself." As insufficient data on grain sizes of the different size electrodes are available, it was not possible to definitely determine the relation between expansion and grain size.

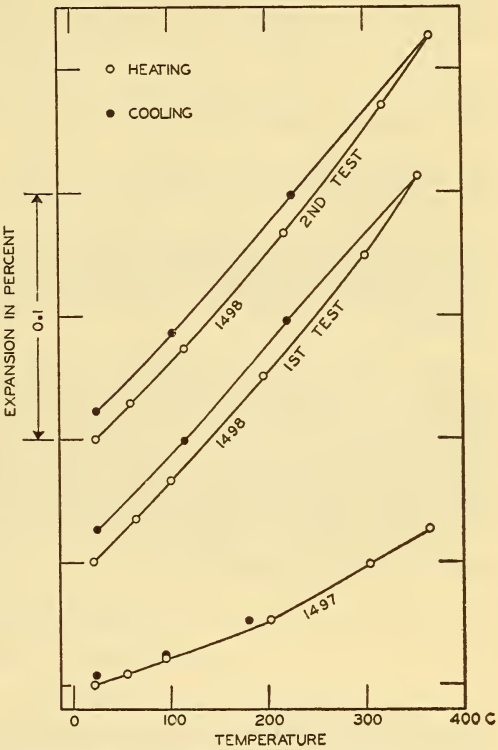

FIGURE 4.—*Linear thermal expansion of two types of carbon.*

1497 — Composed of petroleum coke, bonded with coal tar pitch coke. 1498 — Composed of lampblack bonded with coal tar pitch coke.

The linear thermal expansion of artificial graphite electrode depends on various factors indicated in this section. The direction (longitudinal or transverse) along which expansion measurements are made, appears to be the most important factor. Graphite should therefore be used with caution for the purposes indicated in the introduction of this paper.

2. CARBON

Two types of carbon [12] which are important from the standpoint of thermal expansion were included in this investigation. These types

[12] Submitted by Speer Carbon Co., Saint Marys, Pa., in 1932. Made by hot extrusion process.

of carbon are used for expansion elements [13] in temperature regulators for domestic gas ovens.

Measurements of linear thermal expansion were made [14] at various temperatures between 20 and 350 C. Figure 4 and table 5 show the results obtained.

TABLE 5.—*Average coefficients of expansion of carbon*

Sample	Description	Test number	Average coefficients of expansion per degree centigrade					Change in length after heating and cooling
			20 to 60 C	20 to 100 C	20 to 200 C	20 to 300 C	20 to 350 C	
			$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	*Percent*
1497	Carbon, grade 2079,[b] 5/16-inch diameter	1	1.4	1.5	1.4	1.7	1.8	+0.004
1498	Carbon, grade 2095,[c] 5/16-inch diameter	1	4.0	4.1	4.3	4.5	4.7	+.012
		[d] 1	-------	3.9	4.2	-------	4.3	
		2	4.1	4.0	4.3	4.5	4.7	+.011
		[d] 2	-------	3.8	4.2	-------	4.4	

[a] The plus (+) sign indicates an increase in length.
[b] Composed of petroleum coke, bonded with coal tar pitch coke; carries about 0.5 percent ash (mineral matter) and under 1 percent volatile. Baked to about 1,000 C.
[c] Composed of lampblack bonded with coal tar pitch coke; carries about 1 percent ash and under 1 percent volatile. Baked to about 1,000 C.
[d] Cooling.

The coefficients of expansion of the carbon made with lampblack are about three times as large as the coefficients of the carbon made with petroleum coke. It therefore appears that the latter carbon is more suitable for the low expanding element of temperature regulators, for the regulation depends on the difference of expansion between the carbon rod and the metal tube into which the rod is inserted.

Both samples of carbon indicated an increase in length after heating to 350 C and cooling to 20 C.

V. CONCLUSIONS

1. ARTIFICIAL GRAPHITE

1. The coefficients of expansion of the longitudinal and transverse sections of graphite increase with temperature.

2. The coefficients of expansion of the transverse sections are larger than the coefficients of expansion of the longitudinal sections. For the range from 20 to 1,000 C, the linear expansion of the transverse sections cut from 3-inch graphite is about 110 percent greater than the expansion of the longitudinal sections cut from 3-inch graphite electrodes.

3. There appears to be a tendency for the coefficients of expansion of a longitudinal section to increase with increase in the diameter of the graphite electrode from which the longitudinal section has been cut.

4. The coefficients of expansion of the transverse sections cut from the 3-inch graphite electrodes are larger than the coefficients of expansion of the transverse sections cut from the 14-inch electrodes. For example, for the range from 20 to 1,000 C, the average coefficient

[13] Maximum temperature in service 600 F (316 C).
[14] In the longitudinal direction.

of expansion of the transverse sections from the 3-inch graphite is about 40 percent greater than the coefficient of expansion of the transverse sections from the 14-inch graphite electrodes.

5. The difference between the expansion of the transverse and longitudinal sections from the 3-inch graphite electrodes is considerably greater than the difference between the expansion of the transverse and longitudinal sections from the 14-inch electrodes. Figure 3 indicates that the former difference is about 145 percent greater than the latter difference for the linear expansion between 20 and 1,000 C.

6. The coefficients of expansion of the longitudinal sections cut from the 1-inch graphite electrodes are in good agreement with the data obtained by Day and Sosman on ½-inch graphite electrode.

7. The longitudinal and transverse sections of graphite indicate changes in length after heating to elevated temperatures and cooling to room temperature. A second heating and cooling cause smaller changes.

8. The differences in expansion and tensile strength between the transverse and longitudinal sections of a graphite electrode may be due to the fact that the electrode in the process of manufacture has been compressed differently in the two directions. Taylor has indicated that during extrusion the outer portions of the electrode are retarded by friction with the walls of the die. There is a tendency for the material to have a laminated structure in the transverse direction. The aggregate particles and cell walls are more firm and continuous in lengthwise direction. Voids or pores tend to form with their longer axes lengthwise of the electrode. It seems probable that this has an effect on the expansion in the two directions. Taylor stated that the longitudinal increment is practically a measure of the linear expansion of the material, and the transverse change is the linear expansion plus an increment of distortion due to the laminated structure.

9. The grain sizes of the different size electrodes appear to have an effect on expansion.

10. Graphite should be selected with care for the purposes indicated in section I of this paper.

2. CARBON

The coefficients of expansion of carbon made with lampblack are about three times as large as the coefficients of carbon made with petroleum coke. It therefore appears that the latter carbon is more suitable for the low expanding element of temperature regulators.

WASHINGTON, April 21, 1934.