THERMAL EXPANSION OF LEAD

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ABSTRACT

Measurements have been made on the linear thermal expansion of three samples of cast lead between room temperature and 300° C. and the results have been correlated with data obtained by other investigators between 1740 and 1931.

A curve has been derived which shows the linear thermal expansion of lead between −253° and +300° C. The summary gives average coefficients of expansion for various temperature ranges between −250° and +300° C.

A comparison of the indirect results by Kopp and Matthiessen with the direct data by other observers, indicates that lead expands the same in all directions.

CONTENTS

I. INTRODUCTION

The thermal expansion of lead has been of considerable interest for nearly 200 years. Its measurement has been the object of more than 25 investigations. A summary of available data obtained by various investigators is given in Table 1.

Between 1740 and 1831, a number of determinations of the coefficient of linear expansion were made for the range from 0° to 100° C. In 1831, Daniell reported the changes in length of a bar of lead heated from 17° to 100° C. and to the point of fusion, respectively. From that time up to 1930, no measurements on the linear thermal expansion of lead above 110° C. have been located in the literature. The present authors appear to have been the first observers after Daniell to report data on the linear thermal expansion of lead above 110° C. Their abstract giving coefficients of linear expansion on heating for various temperature ranges between 20° and 300° C. was published [1] in February, 1930. In October of the same year, Uffelmann [2] published coefficients of linear expansion for various temperatures between 80° and 280° C.

The present investigation was undertaken in order to obtain reliable data on the linear thermal expansion of lead above 100° C. The data obtained between 20° and 300° C. have been correlated with results by other observers.

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[1] Hidnert and Sweeney. (See Table 1.)
[2] See Table 1.

TABLE 1.—*Summary of expansion data on lead by various observers*

Observers	Date	Reference	Material	Temperature or temperature range	Coefficient of linear expansion per °C.	Remarks
				°C.	$\times 10^{-6}$	
Muschembroeck [1]	1740 (?)		Lead	0 to 100	14.2	
Bouguer	1745	Hist. Acad. Roy. Sci., p. 230, 1745	do	0 to 100	10.9	
Ellicot [1]	Before 1754		do	0 to 100	28.5	
Smeaton	1754	Phil. Trans., vol. 48, pt. 2, p. 598, 1754	do	0 to 100	28.7	
Herbert [1]	Before 1779		do	0 to 100	26.2	
Berthoud [1]	Before 1808		do	0 to 100	34.5	
Guyton	1811	Mém. Sci. Math. Phys. Inst. Imp. France, 2d pt., p. 89, 1811.	do	0 to 100	27.2	
Lavoisier and Laplace [2]	Before 1831		do	0 to 100	28.5	
Daniell	1831	Phil. Trans., vol. 121 (pt. 1), p. 443, 1831, or Phil. Mag., series 3, vol. 1, pp. 197, 261, 1832.	do	17 to 100	27.9	Computed in 1932 from data by Daniell.
				17 to 327	29.3	
Kopp	1852	Ann. Chem. Pharm., vol. 81, p. 1, 1852	Lead, cast	14 to 99	29.9	Coefficients of linear expansion were computed by Kopp from coefficients of cubical expansion obtained by density method
				15 to 99	27.8	
				11 to 42	31.2	
Calvert, Johnson, and Lowe	1859	Rep. Brit. Assoc., vol. 28, p. 46, 1859; Proc. Roy. Soc. (London), vol. 10, p. 315, 1859–60 and Chem. News. vol. 3, pp. 315, 357, 371, 1861.	Lead (pure)	0 to 100	30.1	
Matthiessen	1866	Phil. Trans., vol. 156, p. 861, 1866; or Ann. Physik u. Chemie, vol. 130, p. 50, 1867.	Lead, cast in a well-smoked mold and varnished.	14 to 92	[3] 28.0	$L_t = L_o(1+10^{-4}\times 0.2726t+10^{-6}\times 0.0074t^2)$, computed by Matthiessen from his data on cubical expansion obtained by weighing 2 samples of lead in water at different temperatures.
Fizeau	1869	Compt. Rend., vol. 68, p. 1125, 1869 or Ann. Physik u. Chemie, vol. 138, p. 26, 1869.	Lead, cast	40	29.2	
Buff	1872	Ann. Physik u. Chemie, vol. 145, p. 626, 1872.	Lead	0 to 100	29.5	
				0 to 100	28.5	Computed in 1932 from coefficient of cubical expansion reported by Buff.
Pfaff	1872	(Erlangen. Besold. 1872. 8° 1–20), Fortsch. Physik, vol. 29, p. 579, 1873.	Lead wire	0 to 100	29.1	
Glatzel	1877	Ann. Physik u. Chemie, vol. 160, p. 497, 1877.	Lead rod made from drawn wire.	Room temperature to 100.	29.4	
Rodwell	1877	Proc. Roy. Soc. (London), vol. 25, p. 280, 1876–77.	Lead	(?)	30.2	
Vicentini and Omodei	1888	Atti Accad. Sci. Torino, vol. 23, p. 38, 1887–88.	do	325	29.5	Computed in 1932 from coefficient of cubical expansion reported by Vicentini and Omodei.
Dorsey	1908	Phys. Rev., vol. 27, p. 1, 1908	Lead, cast	−160	24.8	
				−120	25.9	
				−80	27.2	
				−40	28.5	
				0	28.9	
				−180 to +20	27.1	

Grüneisen	1910	Ann. Physik, vol. 33, p. 33, 1910	Lead rod	−190 to +17	27.0	
				+17 to 100	29.3	
				18	28.8	
Lindemann	1911	Physik. Z., vol. 12, p. 1197, 1911	Lead, chemically pure.	−253 to −192	19.8	Determined expansion of lead by comparison with expansion of fused quartz. Lindemann states that he neglected the expansion of the latter for it is extremely small and within the experimental error.
				−190 to −183	20.3	
				−190 to +20	26.6	
Rauramo and Saarialho	1912	Öfversigt Finska Vetenskaps-Soc. Fördh., vol. 54, 1911–12, Afd. A., N:o 24.	Lead, cast	+15 to 110	29.3	
Friend and Vallance	1924	J. Inst. Metals, vol. 31, p. 75, 1924	Lead	10 to 100	29.5	
Ebert	1928	Z. Physik, vol. 47, p. 712, 1928	do	−253 to 0	24.7	Computed in 1932 from the data reported by Ebert.
				−190 to 0	26.1	
				−253 to −190	20.8	
				0 to +100	28.9	
Hidnert and Sweeney	1930	Phys. Rev., vol. 35, p. 296, 1930	Lead, cast	20 to 60	28.8	Average values obtained on 3 samples from observations on heating.
				20 to 100	29.0	
				20 to 200	30.0	
				20 to 300	31.4	
Uffelmann	1930	Phil. Mag., vol. 10, p. 633, 1930	Lead, annealed	80	28.9	
				100	29.1	
				120	29.5	
				140	29.9	
				160	30.2	
				170	30.3	
				180	30.5	
				190	30.9	
				200	31.2	
				220	31.6	
				240	32.0	
				250	32.3	
				260	33.0	
				280	34.3	
McLennan, Allen, and Wilhelm.	1931	Trans. Roy. Soc. Can., III, series 3, vol. 25, p. 1, 1931.	Lead	−268 to −246	-------	Determined relative expansion of lead and fused quartz; the curve of the relative change of length is nearly horizontal in the region of the superconductivity point of lead (−266° C.). The authors state that as there was no discontinuity observed in the thermal expansion curve for lead, it seems fair to conclude that when with the lowering temperatures the superconductivity point was passed, no sudden change in the crystal lattice of the metal accompanied the appearance of superconductivity.

[1] Cited by Guyton de Morveau (Mém. Sci. Math. Phys. Inst. France, second semestre, p. 1, 1808).
[2] Cited by Daniell (Phil. Mag., vol. 10, pp. 191, 268, 350, 1831).
[3] Computed in 1932 from Matthiessen's equation.

II. MATERIALS INVESTIGATED

Three samples of cast lead were investigated. The purity and the method of casting of the samples are indicated in Table 2. The length of each sample was about 300 mm and the cross section 10 mm square.

III. APPARATUS

The furnace shown in Figure 1 of Scientific Paper of the Bureau of Standards No. 488, was used for the measurements of the linear thermal expansion of sample 1001 and the white furnace shown at the extreme left of Figure 1 of Scientific Paper of the Bureau of Standards No. 524 was used for samples 1144 and 1215. Figure 4 of the latter paper indicates the method used in mounting samples 1144 and 1215 in the furnace.

Expansion measurements were made by means of micrometer microscopes, which were sighted on fine wires suspended from or in contact with the ends of the specimen. For a detailed description of the apparatus and the methods used the reader should refer to the publications mentioned.

IV. RESULTS

Observations were made on the linear thermal expansion of three cast samples of lead at various temperatures between room temperature and 300° C. and the results obtained are shown in Figure 1. The expansion curves are plotted from different origins to display the individual characteristics of each curve.

The average coefficients of expansion given in Table 2 were derived from the observations on heating and on cooling. This table also gives the differences in length before and after the expansion tests. The plus (+) sign indicates an increase in length and the minus (−) sign a decrease in length.

TABLE 2.—*Average coefficients of linear expansion of cast lead*

Sample	Lead content[1]	Method of casting	Test No.	Heating or cooling	Average coefficients of expansion per ° C.				Change in length after heating to 300° C. and cooling to room temperature
					20° to 60° C.	20° to 100° C.	20° to 200° C.	20° to 300° C.	
	Per cent				×10⁻⁶	×10⁻⁶	×10⁻⁶	×10⁻⁶	*Per cent*
[2] 1001	-------	Preheated steel mold	1	Heating	29.2	29.6	31.2	32.5	+0.02
				Cooling	------	29.3	30.4	31.6	
[3] 1144	99.9	Sand mold	1	Heating	28.3	28.6	29.5	31.2	.00
				Cooling	------	29.5	------	31.2	
[3] 1215	99.8	Sand mold, from same ingot as sample 1001.	1	Heating	29.0	28.9	29.7	30.9	−.01
				Cooling	------	28.8	------	31.1	
			2	Heating	------	28.8	29.4	31.0	.00
				Cooling	------	------	29.8	31.0	
		Average	------	----------	28.8	29.1	30.0	31.3	--------

[1] Analysis by H. A. Buchheit, of this bureau.
[2] See sample 1215.
[3] Density for samples 1144 and 1215, 11.310 and 11.329 g/cm³ at 25° C., respectively, determined by Miss E. E. Hill, of this bureau.

The differences obtained in the coefficients of expansion of the three samples of cast lead are probably due to variations in the methods of casting.

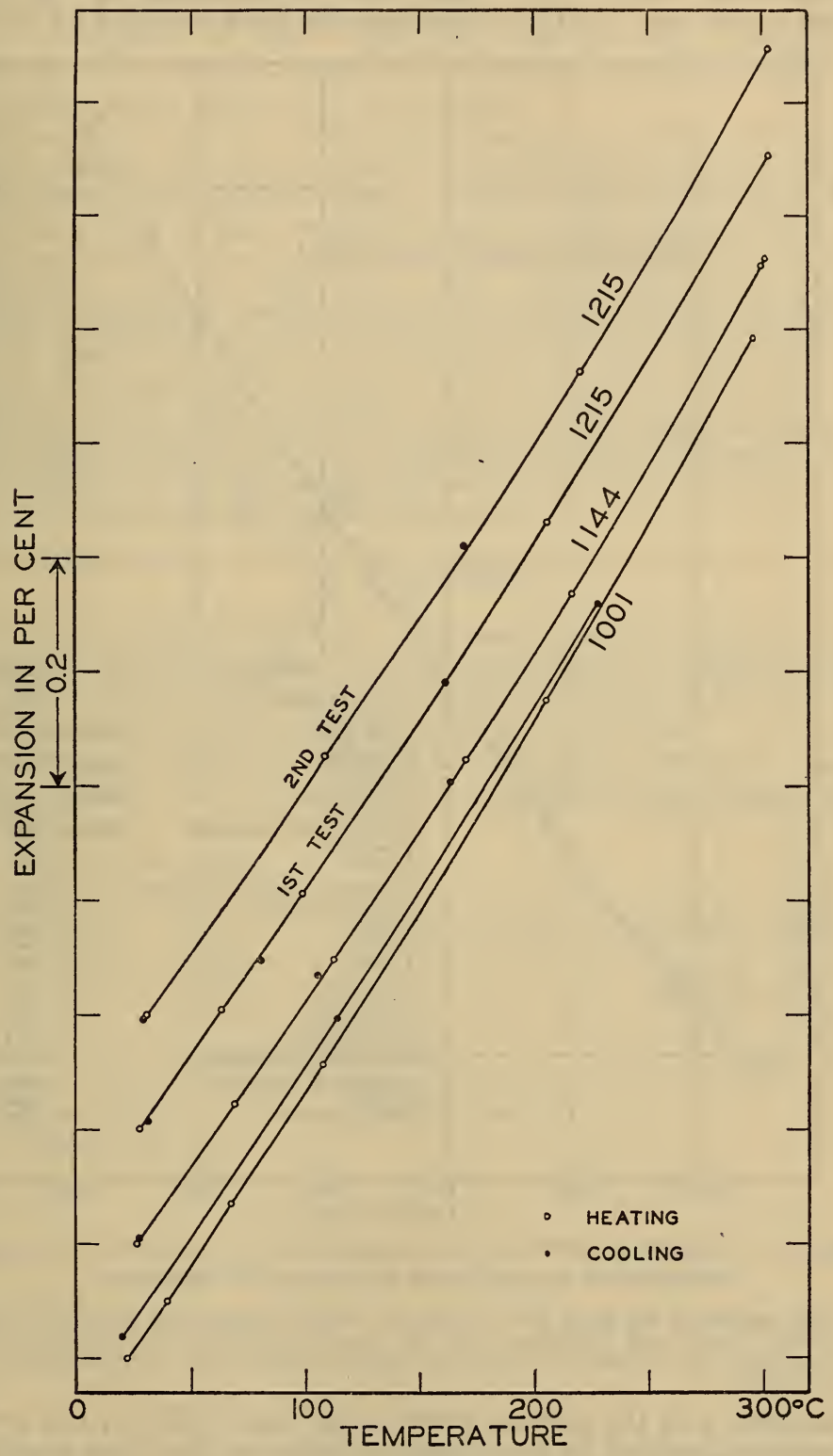

FIGURE 1.—*Linear thermal expansion of three cast samples of lead*

Sample 1001 which was cast in a preheated steel mold, has larger coefficients of expansion than the samples cast in sand molds. From the observations obtained on cooling, it appears that the coefficients

of expansion of sample 1001 on the next heating would be less than those obtained on the first heating.

The curve in Figure 2 represents the linear thermal expansion of lead between −253° and +300° C. The portion of the curve between −253° and +20° C. represents the data obtained by previous

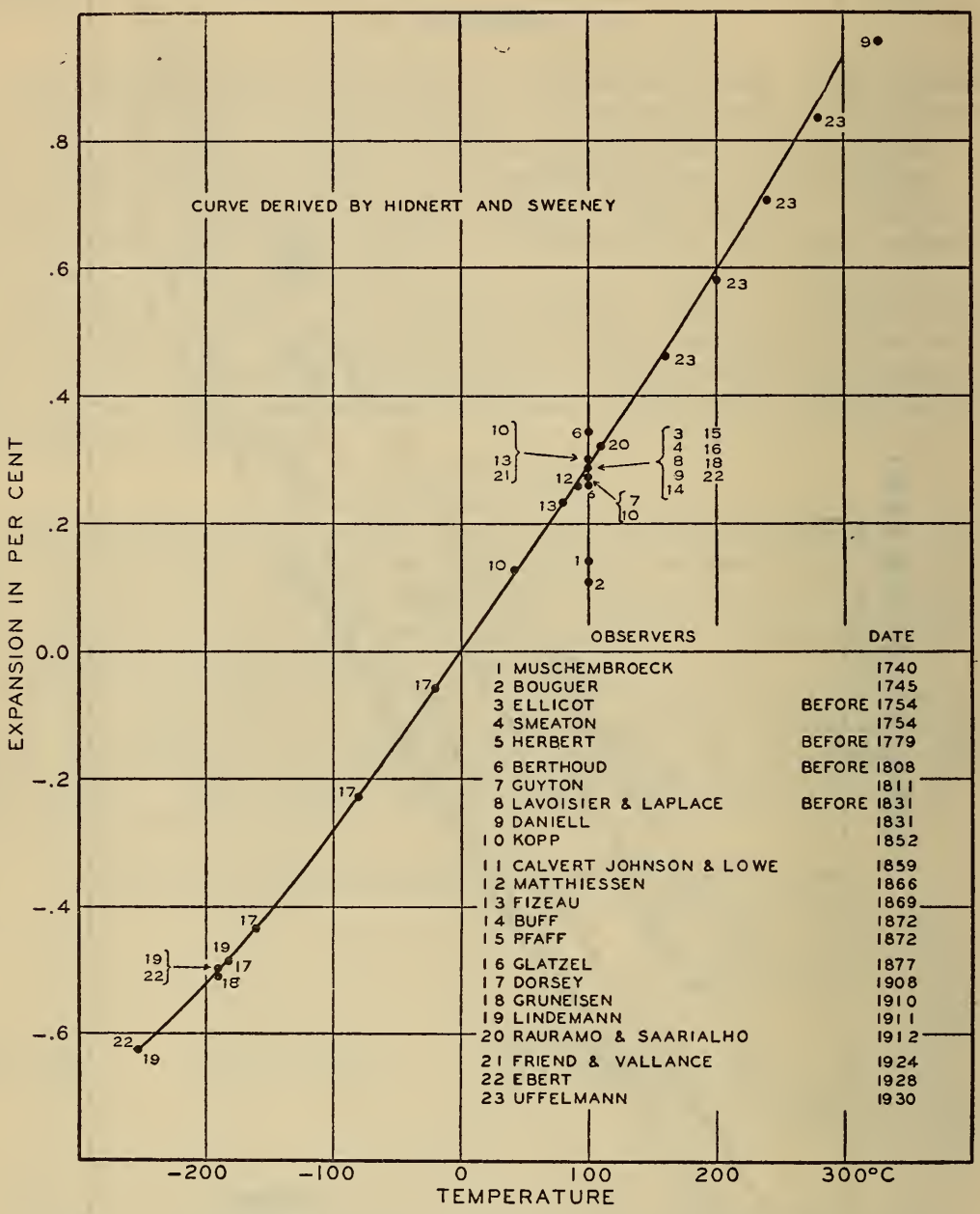

FIGURE 2.—*Comparison of the average expansion curve derived in the present investigation on lead, with data from the observers*

The lower portion of the curve from −253° to +20° C. was derived from data by Lindemann, Ebert, Dorsey, and Grüneisen, and the upper portion of the curve from 20° to 300° C. represents the average of all results obtained in the present investigation on three samples of lead.

investigators, and the portion between 20° and 300° C., the average of all results obtained by the present authors on the three samples of lead. The values obtained by other observers are included in this figure for comparison. Most of these values show good agreement. Bouguer and Muschembroeck obtained the lowest values and Berthoud the highest value at 100° C.

Kopp and Matthiessen's data for linear expansion obtained indirectly from density measurements agree closely with direct measurements made by other observers, and therefore it appears that the expansion of lead is the same in all directions.

The coefficient of linear expansion derived from Vicentini and Omodei's value for the coefficient of cubical expansion of lead near the melting point, appears to be too low.

McLennan, Allen, and Wilhelm published a curve which shows the relative change of length measured against the change of length of fused quartz near absolute zero. Their conclusion relating to the lattice structure of lead, which is based on the assumption that the expansion curve of lead is almost horizontal in the region of the superconductivity point (−266° C.), does not appear to be justified. Since the expansion of fused quartz is not known near absolute zero, it is not possible definitely to determine from their curve the actual expansion of lead in this region. It is possible that when these observers cooled lead and fused quartz in the region of the superconductivity point of lead, the contraction of the lead nearly balanced the expansion of the fused quartz [3] and thus they obtained a nearly horizontal curve for the relative expansion.

V. SUMMARY

Data have been obtained on the linear thermal expansion of three samples of cast lead. Observations were taken at various temperatures between room temperature and 300° C., and the data have been correlated with available data by other investigators.

The average coefficients of linear expansion for various temperature ranges between −250° and +300° C., as derived from the expansion curve in Figure 2 are as follows:

	$\times 10^{-6}$
−250° to + 20° C	25. 1
−200° to 20° C	26. 5
−100° to 20° C	28. 3
+20° to 60° C	28. 8
20° to 100° C	29. 1
20° to 200° C	30. 0
20° to 300° C	31. 3

WASHINGTON, September 12, 1932.

[3] Souder and Hidnert, B. S. Sci. Paper No. 524 (fig. 11).

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