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AUTOGRAPHIC THERMAL EXPANSION APPARATUS

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ABSTRACT

This paper describes an autographic thermal expansion apparatus improved and constructed by the National Bureau of Standards, and indicates the methods used in its calibration and comparison with the Bureau's precision expansion apparatus. The autographic expansion apparatus employs the optical lever method of measuring expansion and is suitable for many purposes in commercial laboratories. Continuous expansion curves can be obtained photographically or they can be observed during the progress of the test. Coefficients of expansion can be determined from these curves. Transformation regions, if present, can also be located. For ordinary materials such as steel, it may be stated that the error of the autographic expansion apparatus is about 6 percent for the range from 20 to 100° C and about 3 percent for the range from 20 to 500° C. This apparatus does not give as accurate results as the fused quartz tube expansion apparatus which was also designed at the Bureau for use in commercial laboratories. The autographic expansion apparatus yields certain information in regard to transformation regions not readily obtainable by the other type of apparatus.

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I. INTRODUCTION

In 1924 the National Bureau of Standards made tests on an autographic thermal expansion apparatus which was built abroad and submitted to the Bureau by a local firm for test. Thermal expansion tests were made on eight samples of various materials. A comparison of the coefficients of expansion determined with this apparatus and with the precision expansion apparatus [1] of the Bureau, showed that the average error of this autographic expansion apparatus was ±12 percent.

Several years later the Bureau decided to design and construct an apparatus of similar type [2] but which would give more accurate results and would be suitable for use in commercial laboratories.

The autographic expansion apparatus developed employs the optical lever method of measuring thermal expansion. With this apparatus it is possible to obtain expansion curves photographically

[1] Souder and Hidnert, BS Sci. Pap. 22,533(1927-28);S524.

[2] Autographic expansion apparatus has been employed by Chevenard (Revue de Métallurgie, 19,39(1922) and 23,92(1926), and others.

or to observe points on the expansion curves of materials during the progress of the test. The latter method is preferable in many cases, for the observer can see and follow every detail in the generation of the expansion curve during the progress of the test and can modify or stop the test whenever necessary, but with the photographic method nothing is known about the expansion curve until the test has been completed and the sensitized plate or paper has been developed.

The autographic expansion apparatus will supply data on the thermal expansion of materials, with sufficient accuracy to meet the needs of many commercial laboratories. This apparatus, however, is not as accurate as the fused quartz tube type [3] of thermal expansion apparatus, which was also designed for use in commercial laboratories. The autographic apparatus will be found especially useful in locating transformation regions. Where necessary to make complete and accurate studies of a specimen in such regions, this apparatus will be of value in locating the approximate temperature limits within which to confine measurements with precision apparatus.

The authors are indebted to E. C. Crittenden, H. W. Bearce, and C. G. Peters for valuable suggestions, to F. E. Mann for his painstaking work in the construction of the apparatus, to H. S. Krider for assistance during the calibration and the tests of the apparatus, and to S. Alpher for assistance in the preparation of the figures.

II. DESCRIPTION OF APPARATUS

Two general views of the autographic expansion apparatus are shown in the photographs, figures 1 and 2. The apparatus consists essentially of an adjustable furnace, F, mounted on a common base with a camera box, C, and an adjustable source of illumination, I. The overall length is approximately 64 in.,[4] height 19 in., and width 14 in. A description of the furnace, the optical system, and auxiliary parts is given in this section. It is planned to prepare detailed drawings later so that copies may be available to persons interested in constructing such equipment.

The heating coil of the furnace consists of chromel A wire wound on an alundum cylinder 2 in. outside diameter and 8 in. in length. The wire, about 19½ ft long and 0.0907 in. diameter (American Wire Gage no. 11), has a total resistance of 1.65 ohms. Grooves were cut in the alundum cylinder to receive the heating coil. Near the ends the coil was wound as close as possible without short circuiting, and the spacing was increased toward the center. The spacing at the central turn is ½ in. There are 15 turns of wire for the first 2 in., 15 turns for the last 2 in. and 11 turns for the central 4 in. of the coil. Asbestos cord was wrapped between the wire, and was sealed up with alundum cement. The alundum cylinder has 4 holes, each ⅝ in. in diameter, through the entire length of the cylinder. The wall space between the holes is 1/16 in. A copper tube, 8 in. long and 2¾ in. inside diameter, and machined as indicated in figure 3, surrounds the heating coil. A larger brass tube (nickel plated) about 12 in. long and 6 in. outside diameter, surrounds the copper tube. Silocel insulating powder was inserted between the copper and the brass

[3] Hidnert and Sweeney, BS J.Research, 1,771 (1928); RP29.

[4] English and metric units may appear to be used indiscriminately throughout this paper. An attempt has been made, however, to give dimensions and sizes in the units which are commonly given in catalog and shop records.

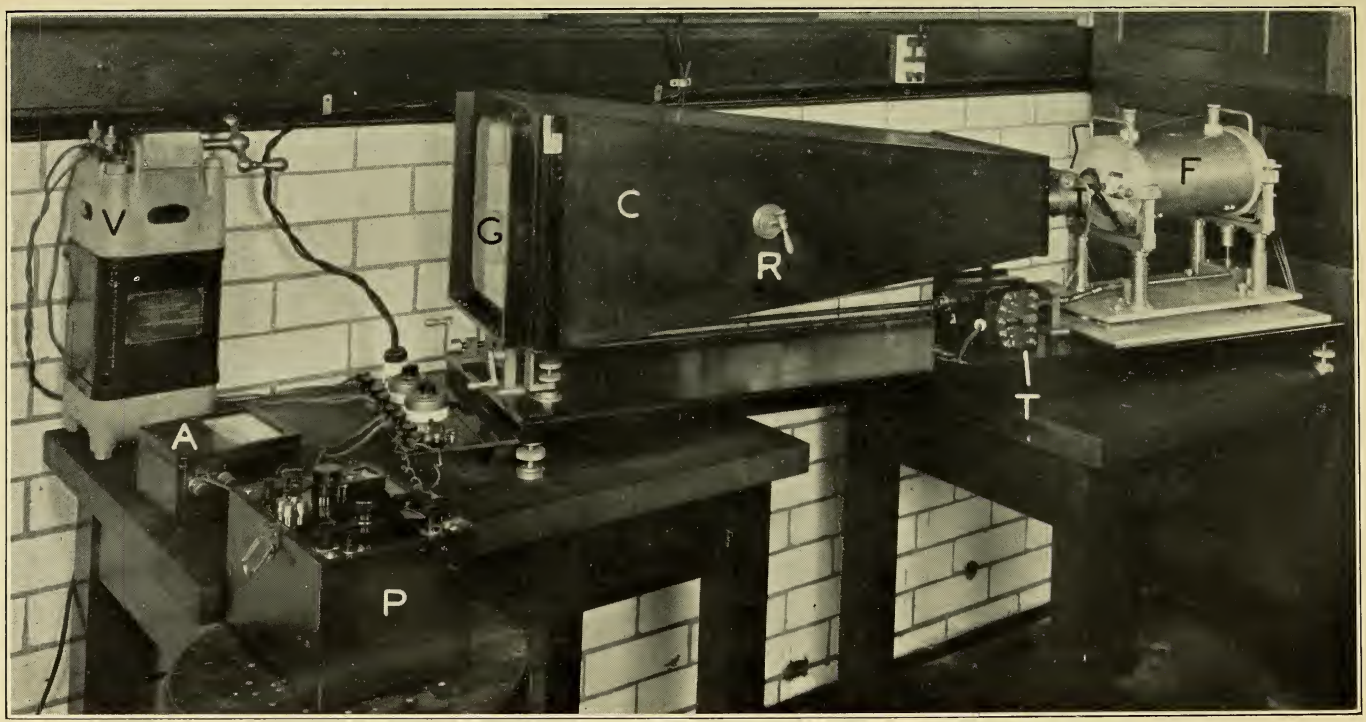

FIGURE 1.—*Autographic expansion apparatus.*

A, Ammeter; *C*, camera box; *F*, furnace; *G*, glass screen; *I*, illumination; *P*, potentiometer indicator *R*, internal reflecting mirror; *T*, transformer; *V*, induction voltage regulator.

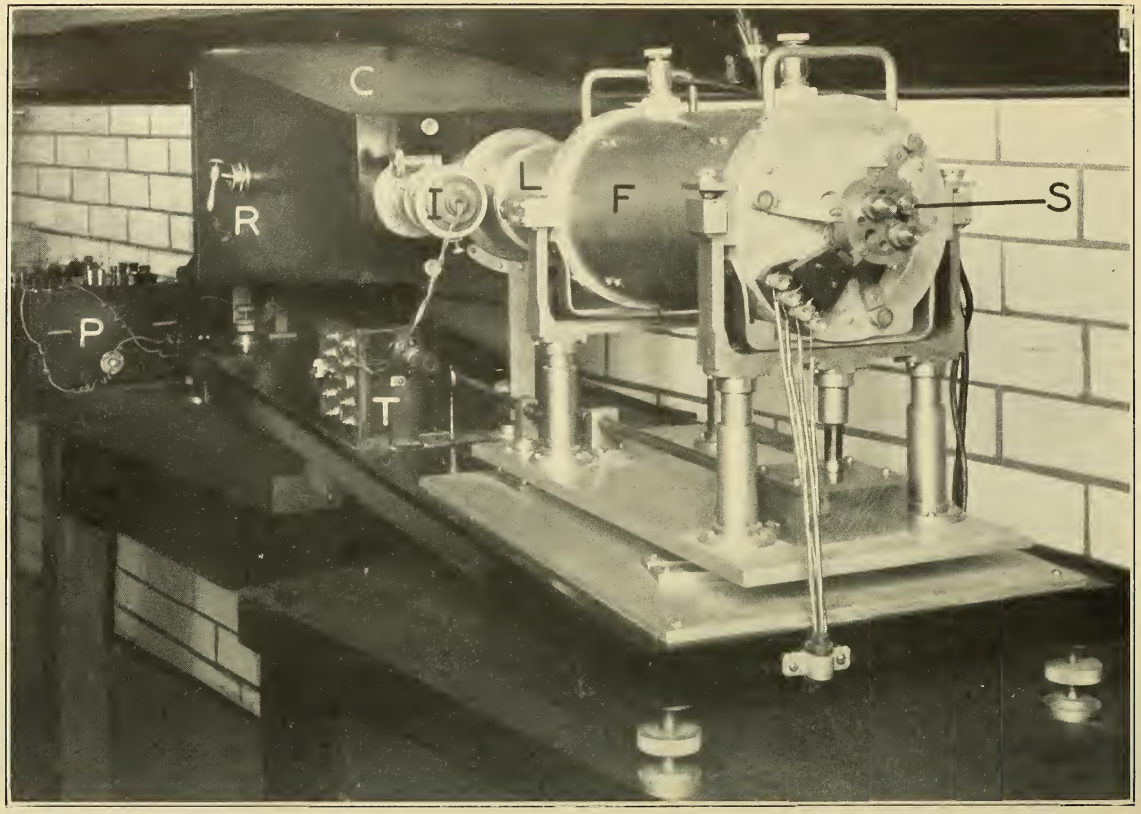

FIGURE 2.—*Autographic expansion apparatus.*

C, Camera box; *F*, furnace; *I*, illumination; *L*, lens; *P*, potentiometer indicator; *R*, internal reflecting mirror; *S*, adjusting screw; *T*, transformer.

tubes. The insulation was continued around the ends of the 8 in. copper tube. The furnace is supported in a horizontal position, with the lead-in wires at the top of the furnace.

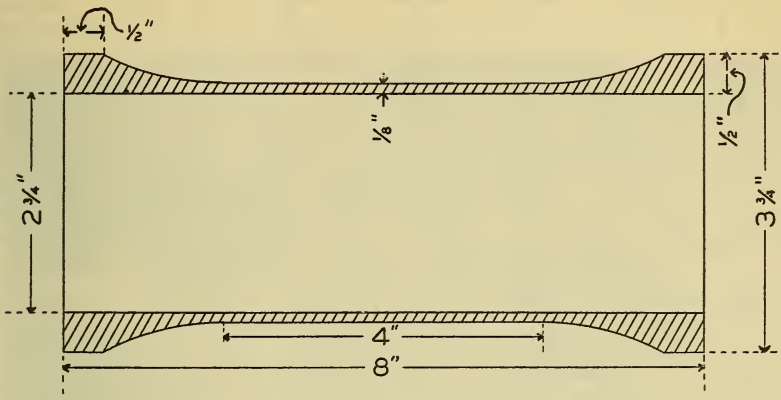

FIGURE 3.—*Copper tube surrounding the heating coil.*

Through each hole in the alundum cylinder (see fig. 4) a chromel tube was inserted. The following materials were inserted in the chromel tubes as indicated:

Hole 1.—A long, fused-quartz rod which represents a "stationary" axis. Details of the fused-quartz rod are indicated in figure 5. The finish on point (a) is smooth and suitable for making contact in a bearing similar to that shown at (b). The finish on bearing (b) is smooth and suitable for receiving a point similar to (a). The drilled relief (c) is a small hole having a smooth edge giving a circular contact closely approximating a point contact.

Hole 2.—A rod of chromel A having uniform rate of expansion, 150 mm in length, which represents a temperature axis.

Hole 3.—A specimen 150 mm in length, with pointed ends. The maximum diameter of the specimen is 12 mm.

Hole 4.—A chromel-alumel thermocouple with 3 junctions, 1 near the center of the specimen in hole 3 and the other junctions near the ends of the specimen.

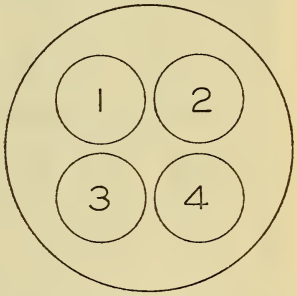

FIGURE 4.—*Cross section of alundum cylinder indicating the holes and the positions of specimen, "stationary" axis, temperature axis, and thermocouple.*

1, "Stationary" axis; 2, temperature axis; 3, specimen (expansion axis); 4, thermocouple. The observer is located at the glass screen, G, of the camera box (fig. 1) and is looking toward the furnace.

The ends of the rod of chromel and the specimen in holes 2 and 3, respectively, are pointed. The angle at each pointed end is about 80°.

A fused-quartz plug is in contact with each end of the chromel rod (temperature axis) and of the specimen. The plugs in contact with the left [5] ends (see fig. 6) of the chromel rod and the specimen have the same dimensions as the long, fused-quartz rod indicated in figure 5,

[5] Unless indicated otherwise, the direction "left" or "right" orients the observer so that he is facing the furnace, F, with the camera box, C, at his left.

except that the length is 4⅞ in. The pointed ends of these 2 plugs and of the long, fused-quartz rod ("stationary" axis) extend beyond the left face of the furnace and are in contact with the rear of a stellite mirror, M, which is held in position by means of a spring. Figure 6 shows a view of the stellite mirror in contact with the fused-quartz plugs and the "stationary" axis extending from the left face of the furnace.

The fused-quartz plugs in contact with the right ends of the chromel rod and the specimen are 4 in. long. At each end of these plugs there is a 90° pivot bearing as indicated in figure 5. The diameter of the plugs is the same as the diameter of the long, fused-quartz rod ("stationary" axis). One end of each of these plugs and one end (90° pivot bearing) of the long, fused-quartz rod extend beyond the right face of the furnace. Each of these ends is held against an adjustable screw, S. Figure 7 shows the long, fused-quartz rod ("stationary" axis), the specimen with its 2 fused-quartz plugs and the chromel rod (temperature axis) with its 2 fused-quartz plugs.

When the furnace is heated, the specimen and the chromel rod (temperature axis) expand. The mirror which is in contact with the plugs extending from the specimen, chromel rod (temperature axis) and

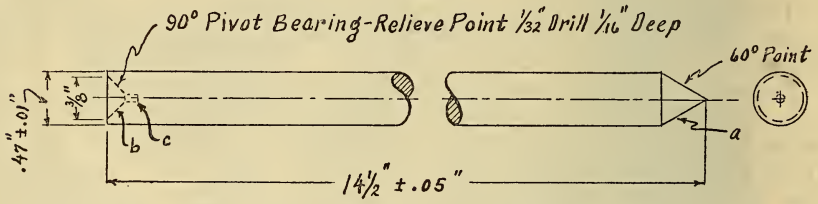

FIGURE 5.—*Details of fused-quartz rod representing "stationary" axis.*

"stationary" axis therefore moves. The expansion of the specimen causes the bottom of the mirror to move and deflect the spot of light upward. The expansion of the chromel rod (temperature axis) causes one side of the mirror to move and deflect the spot horizontally. The expansion of the fused-quartz plugs extending on each side of the specimen should balance the expansion of the fused-quartz plugs extending on each side of the chromel rod (temperature axis) and also the expansion of an equivalent length of the "stationary" axis. A spot of light focused on the mirror and reflected on a glass screen, G, or photographic plate indicates the expansion both of the specimen and of the chromel rod and describes a curve, the resultant of these two expansions. The abscissas (from right to left)[6] indicate the expansion of the chromel rod (temperature axis) and may be evaluated to represent temperature. The ordinates (from bottom to top) represent the expansion of the specimen. The curve (see fig. 9) therefore represents the expansion of the specimen versus temperature in arbitrary units. This curve may be transformed into an expansion curve in definite units after the apparatus is calibrated.

In order to attain satisfactory temperature uniformity throughout the specimen chamber and the thermocouple chamber in the alundum cylinder, a large number of experiments were carried out on three heating coils with and without a tube surrounding the heating coil. Tubes

[6] The observer is located at the glass screen, G, of the camera box and is looking toward the furnace.

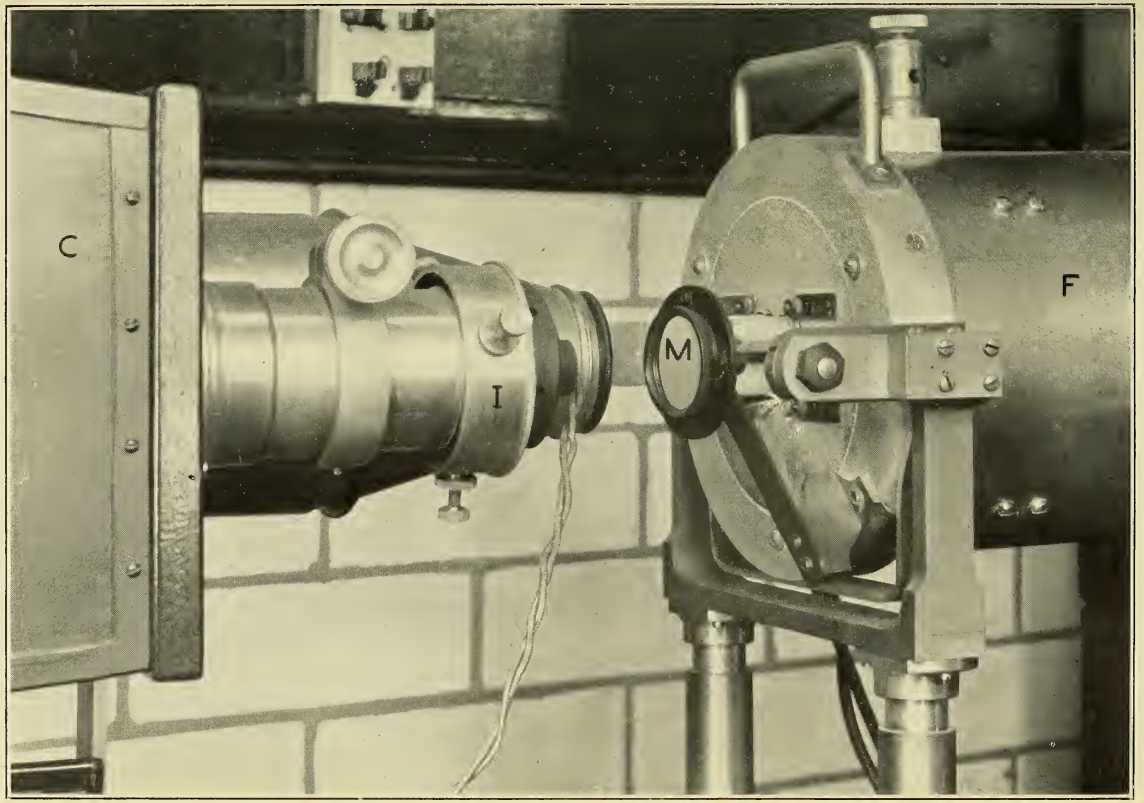

FIGURE 6.—*Stellite mirror in contact with the fused quartz plugs and the "stationary" axis extending from the left face of the furnace.*

C, Camera box; *F*, furnace; *I*, Illumination; *M*, optical lever mirror.

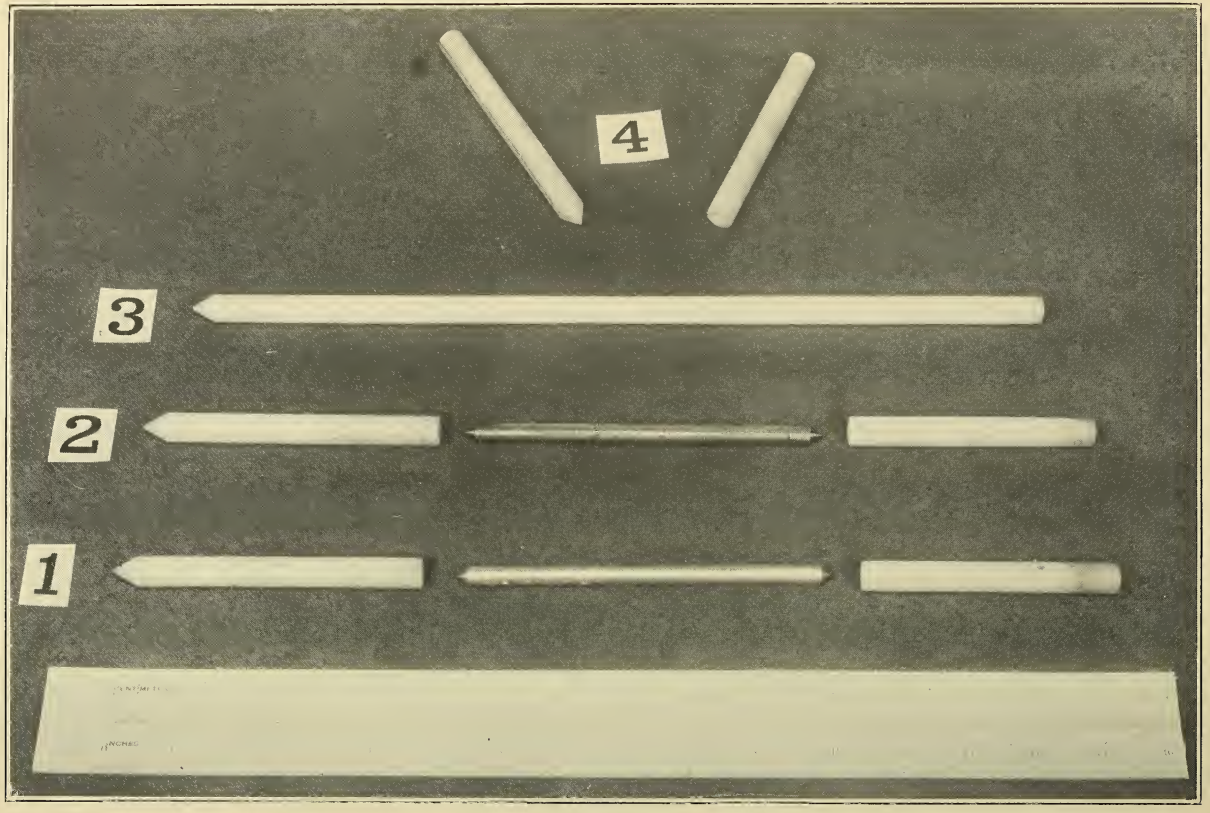

FIGURE 7.—*Specimen with 2 fused-quartz plugs, chromel rod (temperature axis) with 2 fused-quartz plugs and long fused quartz rod ("stationary" axis).*

1, Specimen and 2 plugs; *2*, chromel rod (temperature axis) and 2 plugs; *3*, long fused-quartz rod ("stationary" axis); *4*, two extra plugs showing ends.

of uniform thickness, made of iron, copper, and copper plated with nickel and a copper tube of nonuniform thickness (see fig. 3) were tried. Experiments were also made with plugs of various shapes and kinds (chromel, porcelain, and fused quartz). The best temperature uniformity was obtained with the heating coil, copper tube, and fused-quartz plugs which have been described. The temperature distribution at various points in the specimen chamber and the thermocouple chamber was explored at about 250°, 500°, and 800° C. An exploring thermocouple was used in the specimen chamber and the thermocouple (with three junctions) which was described previously was used in the thermocouple chamber. Figure 8 shows the results obtained. Position 3 represents the center of the specimen chamber and the ther-

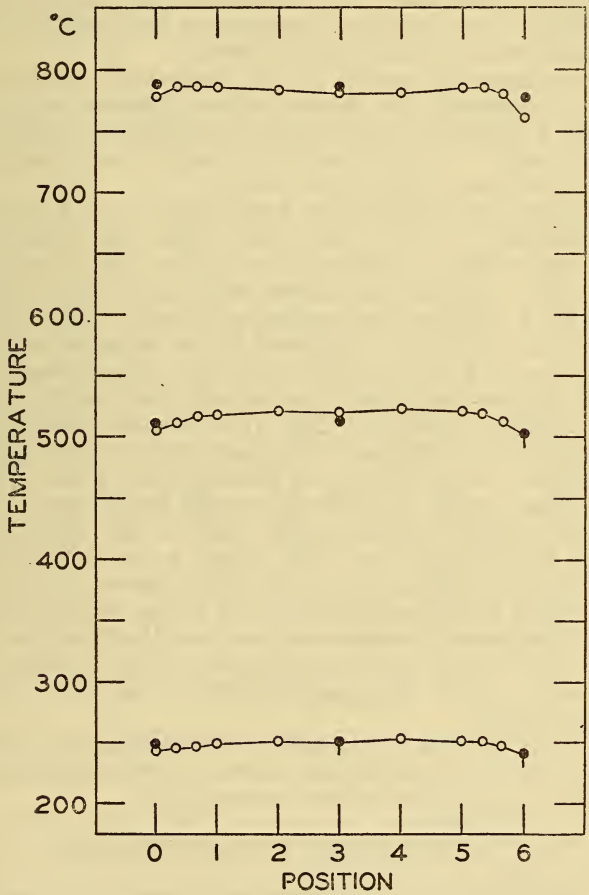

FIGURE 8.—*Distribution of temperature at various positions (position 3=center) in specimen chamber and thermocouple chamber.*

○ Specimen chamber; ● Thermocouple chamber; ♀ Specimen and thermocouple chambers.

mocouple chamber. Position 0 represents a point 75 mm to the left of position 3, and position 6 represents a point 75 mm to the right of position 3 in these chambers. Positions 1, 2, 4, and 5 are intermediate positions. Between positions 0 and 6 the distance from one position

to the next position is 25 mm. Position 3 corresponds to the center of the specimen and positions 0 and 6 correspond to the ends of the specimen in the specimen chamber. The observations in figure 8 show that the temperatures in the specimen chamber agree well with those in the thermocouple chamber. At the extreme positions (0 and 6) the temperatures are somewhat lower than at the central position.

The furnace is heated by passing electric current through the coil described. An induction voltage regulator, V (primary 110 volts, 60 cycles), and an ammeter, A, were inserted in the circuit. These instruments are shown at the extreme left of figure 1. By means of the induction voltage regulator it is possible to obtain any current required to heat and maintain the furnace at any temperature between room temperature and 1,000° C. The induction voltage regulator may be replaced by one or more rheostats or preferably by a transformer with a rheostat in the primary circuit.

The temperatures at 3 points in the thermocouple chamber are determined by means of the chromel-alumel thermocouple (with 3 junctions) and a portable potentiometer indicator, P, shown at the left of figures 1 and 2. A triple switch is used for switching from one junction of the thermocouple to the next.

A tungsten lamp (21 candlepower, 6 to 8 volts) is used with a multivolt toy transformer, T (110 volts, 60 cycles, 100 watts type) to produce the light which is allowed to pass through a pinhole in the camera box. The transformer shown near the center of figures 1 and 2, is set for 6 volts on the secondary circuit. The light which passes through the pinhole, is reflected by an adjustable mirror, R, located in the camera box about 35 cm from the glass screen or photographic plate, transmitted through a 100 cm focal length lens, L, to the external stellite mirror, M (fig. 6) in contact with the fused-quartz plugs described previously, and then reflected through the lens in the camera box to the screen or photographic plate. The light reaching the glass screen is visible as a small bright spot. The distance from the screen or photographic plate to the external mirror, M, is equal to the distance from this mirror to the mirror inside the camera box plus the distance from the latter mirror to the pinhole, that is, the optical distances from the lens to the pinhole source and the screen were adjusted to equal the focal length of the lens. When the mirror, M, is moved by the expansion of the specimen or the temperature rod or both, the spot of light travels across the screen or photographic plate.

The back of the camera is provided with a hinged book form plate holder for 8 by 10 in. photographic plates or ground glass screen for photographic or visual observations, respectively.

III. CALIBRATION OF APPARATUS

After the apparatus was constructed and satisfactory temperature uniformity in the furnace was attained, 6 expansion tests were made with this apparatus on materials that had previously been tested with the Bureau's precision expansion apparatus, in order to calibrate the autographic expansion apparatus.

Figure 9 and table 1 show the observations obtained with the autographic apparatus on a 150 mm sample of copper alloy (1334 B). In fig. 9, OX represents the temperature axis and OY the expansion

axis. The temperature axis, OX, was located by turning the screw in contact with the fused-quartz plug to the right of the temperature rod, and indicating on a sheet of paper attached to the ground glass plate the path (OX) of the spot of light from right to left.[7] In a similar manner the expansion axis, OY, was located by turning the screw in contact with the fused-quartz plug to the right of the sample and indicating on this sheet of paper the path (OY) of the spot of light from bottom to top. This procedure may be simplified slightly

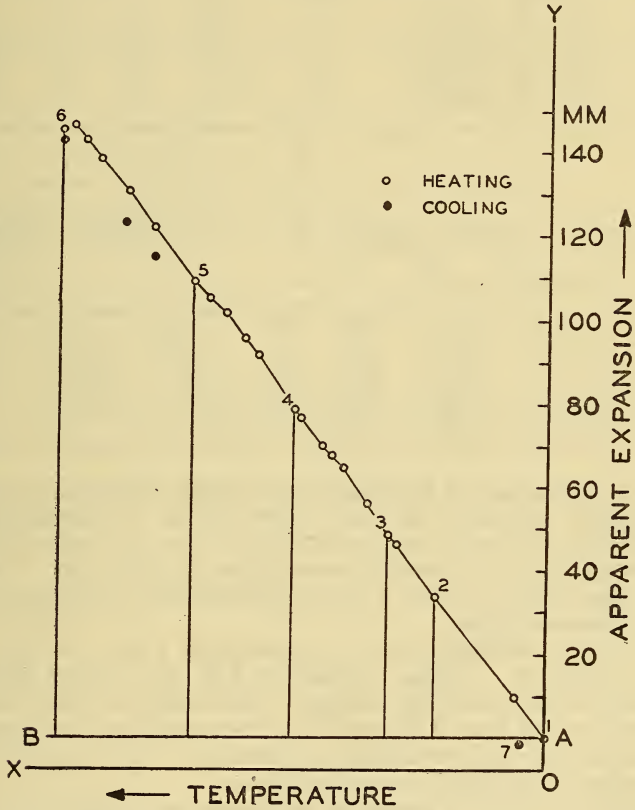

FIGURE 9.—*Observations on linear thermal expansion of copper alloy*

[The observer is located at the glass screen, G, of the camera box and is looking toward the furnace]

by indicating only points O, X, and Y before the test. Axes OX and OY may be drawn after the test has been completed.

The observations obtained on the sample of copper alloy (1334 B) are indicated in figure 10 and table 1. Observations 1 to 6 were obtained on heating and observation 7 was obtained after cooling to room temperature. At each of these observations the temperature was kept constant for a sufficiently long time to make certain that the sample had attained temperature equilibrium. The observations without numbers were taken without stopping to attain temperature equilibrium.

[7] The observer is located at the glass screen, G, of the camera box and is looking toward the furnace.

TABLE 1.—*Observations and computations on sample of copper alloy*

1	2	3	4	5				
Observation	Date	Time	Current	Thermocouple readings (millivolts)				
				Center	Left	Right	Center	Average
	1932		*Amperes*					
1	Oct. 13	3:34 p.m.	0.0	0.9	0.9	0.9	0.9	0.9
2	Oct. 14	8:42 a.m.	4.2	5.9	5.8	5.6	5.9	5.8
3	Oct. 14	11:32 a.m.	5.4	8.2	8.1	7.8	8.2	8.1
4	Oct. 14	1:35 p.m.	7.3	12.1	12.2	11.8	12.1	12.0
5	Oct. 14	2:43 p.m.	8.5	16.3	16.4	16.1	16.3	16.3
6	Oct. 14	3:35 p.m.	10.9	21.2	21.3	21.0	21.2	21.2
7	Oct. 15	9:05 a.m.	0.0	1.0	1.0	1.0	1.0	1.0

	6	7	8	9	10	11	12
Observation	Temperature	Apparent expansion	ΔT	$\Delta T \times 0.5$	Expansion in precision apparatus	Expansion in precision apparatus $-(\Delta T \times 0.5)$	M
	°C	*mm*	°C	*Millionths*	*Millionths*	*Millionths*	
1	22	0.0	0	0	0	0	--------
2	143	33.6	121	60	2,115	2,055	61.2
3	200	48.7	178	89	3,140	3,051	62.6
4	295	78.4	273	136	4,935	4,799	61.2
5	397	109.4	375	188	6,810	6,622	60.5
6	510	145.8	488	244	9,150	8,906	61.1
7	25	--------	--------	--------	--------	--------	--------

Column 4 of table 1 indicates the current required to maintain the temperature constant at each observation. The readings of the chromel-alumel thermocouples which are near the center,[8] the left end and the right end of the sample are given in column 5. The temperatures recorded in column 6 were obtained from the average readings of the thermocouples.

A line AB passing through observation 1 was drawn parallel to OX in figure 9. A line parallel to OY was drawn through each numbered observation on heating. The distance from each of these observations to line AB was then measured in mm (along a line parallel to OY) and recorded in column 7. This distance represents the apparent expansion of the sample.

Column 8 of table 1 gives the temperature change at each observation from the initial temperature 22° C at observation 1. Column 9 indicates the expansion of the central portion (150 mm) of the fused quartz "stationary" axis. This expansion is equal to $\Delta T \times 0.5 \times 10^{-6}$. Column 10 gives the linear expansion obtained with the Bureau's precision apparatus on a duplicate sample (1334) from 22° *C* to the temperatures indicated in column 6. Column 11 indicates the differential expansion between the sample and the "stationary" axis. Each value in column 11 is equal to the difference between the corresponding values in columns 10 and 9.

The values for *M* in the last column of table 1 were obtained by dividing the values in column 11 by the corresponding values in column 7. *M* represents the constant or factor for this apparatus.

[8] Readings were repeated at the center, in order to give the center proper weight.

Additional values for M were obtained from the other 5 tests in a similar manner. All of the values for M obtained in the 6 tests are shown in figure 10. From these results, the average value for M represented by the horizontal line in the figure was found to equal 59.90 for temperatures between room temperature and about 700° C. This average value will be regarded as the best or final factor for this individual apparatus.

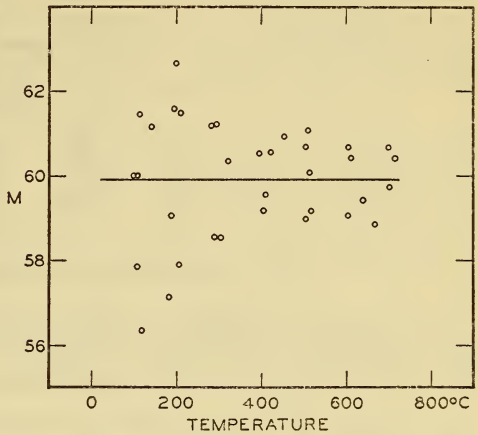

FIGURE 10.—*Values for M obtained in 6 tests*

Average value = 59.90

This factor (59.90) multiplied by the apparent expansion in mm (column 7 of table 1) plus the expansion of the central portion of the fused quartz "stationary" axis (column 9 of table 1), gives the linear expansion in millionths as determined by the autographic expansion apparatus on a 150 mm sample. Table 2 gives results obtained with this apparatus on the sample of copper alloy and also shows a comparison of these results with those obtained with the precision apparatus on a duplicate sample. Figure 11 shows a comparison of the expansion data plotted from the results given in table 2.

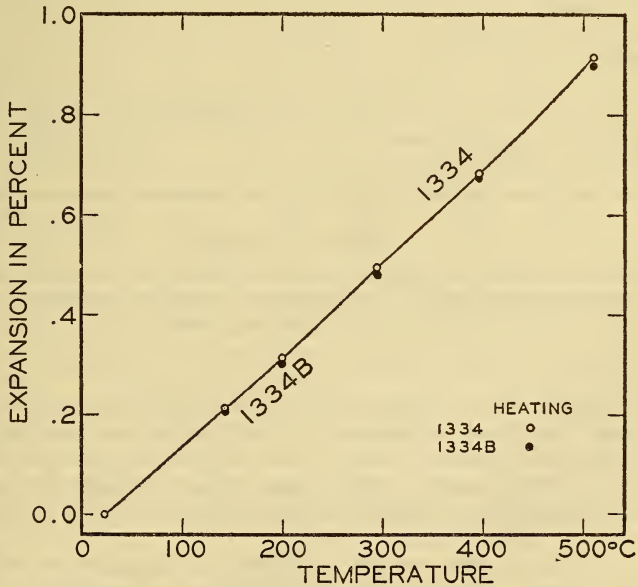

FIGURE 11.—*Comparison of expansion obtained on copper alloy with autographic apparatus and precision apparatus.*

1334—Precision apparatus; 1334B—Autographic apparatus.

TABLE 2.—*Comparison of expansion obtained on copper alloy with autographic apparatus and precision apparatus*

Observation	Temperature	Linear expansion		Deviation	Error
		Autographic apparatus	Precision apparatus		
	°C	*Millionths*	*Millionths*	*Millionths*	*Percent*
1	22	0	0		
2	143	2,072	2,115	43	2.0
3	200	3,006	3,140	134	4.3
4	295	4,832	4,935	103	2.1
5	397	6,741	6,810	69	1.0
6	510	8,977	9,150	173	1.9

IV. COMPARISON OF RESULTS

After the autographic expansion apparatus had been calibrated and a factor for equilibrium conditions had been derived, expansion tests were made on some low-, medium-, and high-expanding materials.

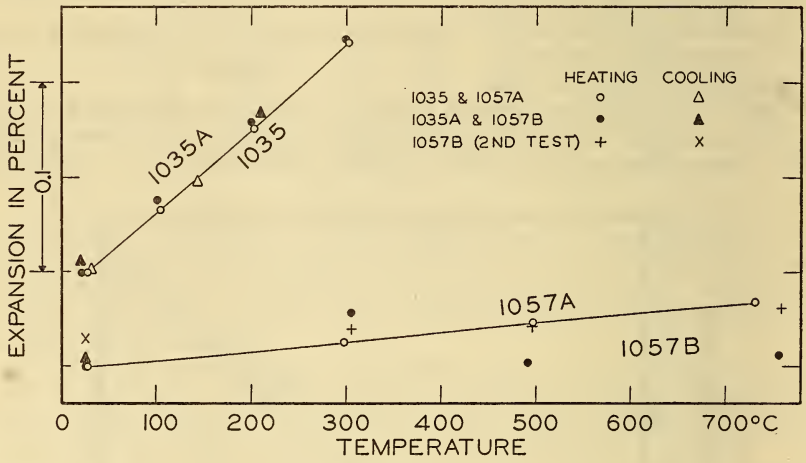

FIGURE 12.—*Comparison of linear expansion obtained on silica and borosilicate glass with autographic apparatus and precision apparatus.*

(All tests start from room temperature.)

1035 and 1057A—Precision apparatus; 1035A and 1057B—Autographic apparatus.

The observations were obtained in the same manner as illustrated in figure 9, and the linear expansion in millionths was computed from these observations by the method given in the preceding section. A comparison of the results with those obtained with the precision expansion apparatus on duplicate specimens is shown in figures 12 to 16.

Figure 12 shows the results obtained on samples of silica and borosilicate glass. The former material has a coefficient of linear expansion of 0.5×10^{-6} per degree C and the latter material approximately 4×10^{-6}. The agreement of the two types of apparatus is good for the glass, but it is not satisfactory for the fused silica. The

autographic expansion apparatus does not appear to be sufficiently sensitive for the most refined determinations of thermal expansion of materials having very low coefficients of expansion, such as silica and invar. In fact, for these materials, expansion apparatus having a high degree of accuracy is required. The actual changes in length for silica, invar, etc., as determined by the autographic method are just as accurate as those for any other material. When displayed on such a highly magnified scale as used in figure 12 they appear about four times greater than they would on figure 11.

The results obtained on the linear expansion of two thermometer glasses are shown in figure 13. The average coefficient of expansion of sample 1338 is 6.2×10^{-6} per degree C between 20 and 300° C, and for sample 1336 the coefficient is 8.2×10^{-6}. The critical regions located by the autographic apparatus are in good agreement with the critical regions located by the precision apparatus. Above the critical region, in the softening range, samples 1338B and 1336B tested by the autographic apparatus, indicated shrinkage. The shrinkage was caused by the pressure exerted on the samples in this method of test. The autographic apparatus appears to be well suited for locating critical regions of glasses and other materials that have transformations, but it is not satisfactory at temperatures where softening occurs.

Figure 14 shows the linear expansion of nickel-chromium-iron alloy and tempaloy. The average coefficient of expansion of the former alloy is 14.4×10^{-6} per degree C between 20 and 300° C and for the latter alloy the coefficient is 17.2×10^{-6}. The agreements in coefficients from the precision and autographic types are excellent.

Expansion data on an aluminum alloy and a bronze are given in figure 15. The average coefficients of expansion of these alloys between 20 and 300° C are 17.8×10^{-6} and 18.7×10^{-6}, respectively. For the aluminum alloy (samples 1206 and 1206A), the agreement between the results obtained with the autographic and the precision apparatus is excellent. Most of the observations obtained with the autographic apparatus on the bronze (sample 894A) are below the expansion curve obtained with the precision apparatus on the duplicate sample (894).

A comparison of the expansion curves obtained with the autographic and the precision apparatus on duplicate samples of a magnesium-aluminum alloy, is shown in figure 16. The broken or dashed curve representing the results obtained with the autographic apparatus is appreciably below the expansion curve obtained with the precision apparatus. The large deviations at the maximum temperature and on cooling to room temperature indicate that the sample bent [9] near the maximum temperature. It is well to point out here that the autographic apparatus should in many instances be employed with caution. It should not be used at high temperatures on magnesium alloys and other materials that deform at elevated temperatures. It should not be used for specimens which oxidize or fuse to fused quartz at high temperatures.[10]

[9] At high temperatures magnesium shows a tendency toward plastic flow. The tensile strength decreases rapidly with rising temperature.

[10] These temperatures may be determined by heating a small piece of the specimen, in contact with fused quartz, in a supplemental furnace.

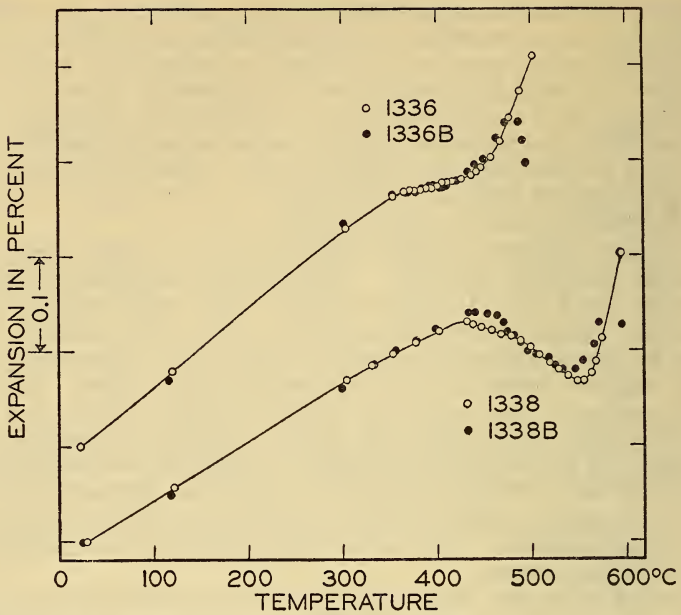

FIGURE 13.—*Comparison of linear expansion obtained on two thermometer glasses with autographic apparatus and precision apparatus.*

1336 and 1338—Precision apparatus; 1136B and 1338B—Autographic apparatus.

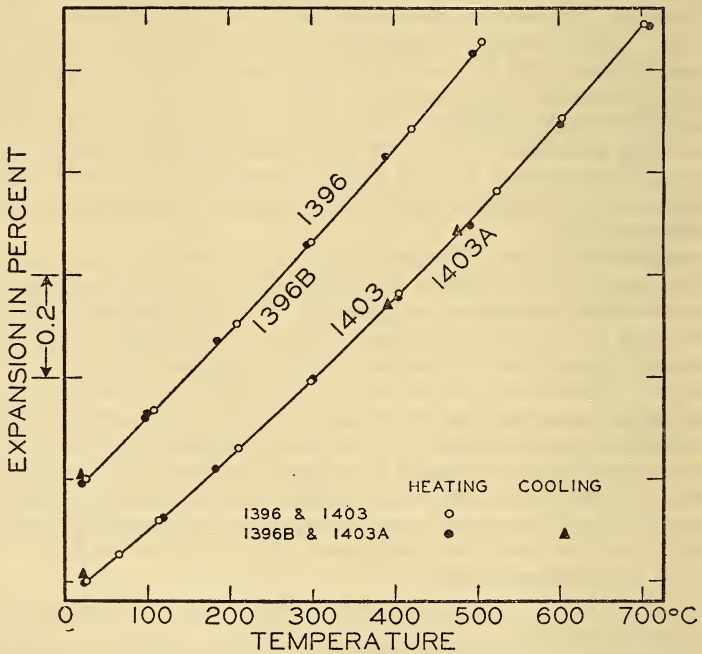

FIGURE 14.—*Comparison of linear expansion obtained on nickel-chromium-iron alloy (1403 and 1403A) and tempaloy (1396 and 1396B) with autographic apparatus and precision apparatus.*

1396 and 1403—Precision apparatus; 1396B and 1403A—Autographic apparatus.

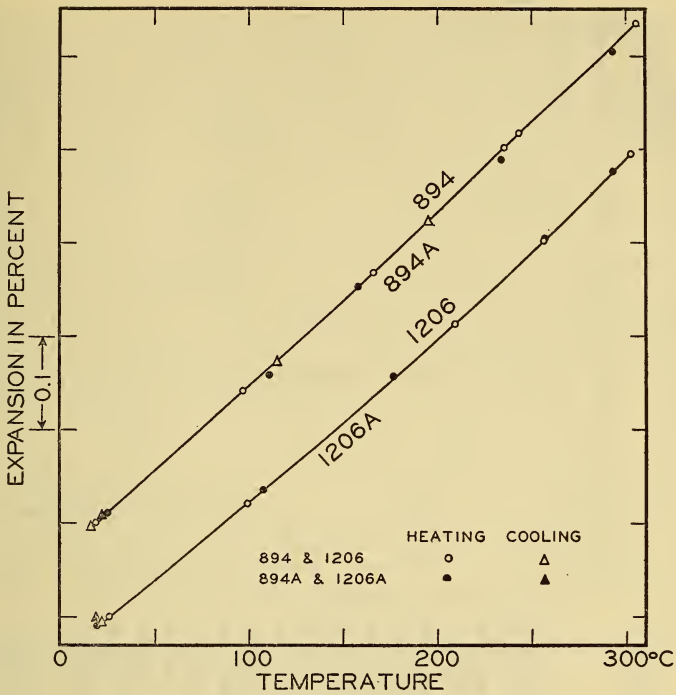

FIGURE 15.—*Comparison of linear expansion obtained on aluminum alloy (1206 and 1206A) and bronze (894 and 894A) with autographic apparatus and precision apparatus.*

894 and 1206—Precision apparatus; 894A and 1206A—Autographic apparatus.

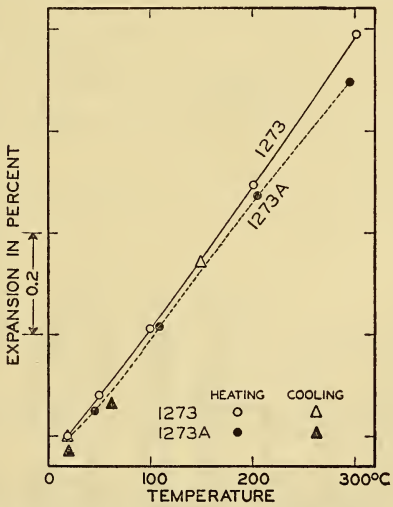

FIGURE 16.—*Comparison of linear expansion obtained on magnesium-aluminum alloy with autographic apparatus and precision apparatus.*

1273—Precision apparatus; 1273A—Autographic apparatus.

TABLE 3.—*Comparison of coefficients of expansion obtained with autographic and precision expansion apparatus*

Sample	Material	Chemical composition (per cent)						Expansion apparatus [1]	Average coefficients of expansion per degree centigrade									
		Iron	Silicon	Copper	Nickel	Manganese	Other elements		20 to 100° C	20 to 200° C	20 to 250° C	20 to 300° C	20 to 350° C	20 to 400° C	20 to 500° C	20 to 600° C	20 to 700° C	20 to 750° C
									$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$
1057B 1057A	Silica, annealed (1st test)							Autographic				1.0			0.0			+0.1
								Precision				0.5			+.5			+.5
								Deviation				+.5			−.5			−.4
1057B 1057A	Silica, annealed (2nd test)							Autographic				0.7			0.5			+0.4
								Precision				.5			.5			+.5
								Deviation				+.2			.0			−.1
1035A 1035	Borosilicate glass							Autographic	4.8	4.5		4.4						
								Precision	4.3	4.3		4.4						
								Deviation	+0.5	+0.2		0.0						
1338B 1338	Borosilicate thermometer glass,[2] not annealed							Autographic	5.2			5.9	6.0					
								Precision	6.2			6.2	6.1					
								Deviation	−1.0			−0.3	−0.1					
1336B 1336	Corning thermometer glass,[3] not annealed							Autographic	7.4			8.4	8.0					
								Precision	8.0			8.2	7.9					
								Deviation	−0.6			+0.2	+0.1					
1403A 1403	Nickel-chromium-iron alloy, hot-rolled	18.1	0.78		63.0	2.14	(4)	Autographic	13.4	14.3		14.5		14.7	15.0	15.6	15.9	
								Precision	13.4	14.0		14.4		14.8	15.2	15.7	16.0	
								Deviation	0.0	+0.3		+0.1		−0.1	−0.2	−0.1	−0.1	
1396B 1396	Tempaloy (soft), annealed at 850° C and quenched		.86	96.00	3.14			Autographic	16.8	17.0		17.1		17.4	17.7			
								Precision	16.6	16.7		17.2		17.3	17.8			
								Deviation	+0.2	+0.3		−0.1		+0.1	−0.1			
1206A 1206	Aluminum alloy, annealed at 400° C	0.84	19.30	3.14	4.18	1.08		Autographic	16.5	17.1	17.4	17.9						
								Precision	16.6	17.0	17.3	17.8						
								Deviation	−0.1	+0.1	+0.1	+0.1						
894A 894	Bronze, cast in green sand			85.5 to 87.5			(5)	Autographic	17.0	18.1		18.4						
								Precision	18.1	18.3		18.7						
								Deviation	−1.1	−0.2		−0.3						
1273A 1273	Magnesium-aluminum alloy, extruded at 330° C	.026	0.008	0.008		0.00	(6)	Autographic	24.2	25.6		25.3						
								Precision	26.2	27.1		27.9						
								Deviation	−2.0	−1.5		−2.6						

[1] The deviation is the coefficient of expansion obtained with the autographic expansion apparatus minus the corresponding coefficient obtained with the precision expansion apparatus.
[2] Similar to Jena glass 59 III.
[3] Developed for use with equivalent of Jena glass 16 III.
[4] Chromium 15.9, carbon 0.08, and phosphorus 0.013 percent.
[5] Tin 10.5 to 11.5, zinc 2.0 to 3.0, maximum impurities 0.2 percent.
[6] Magnesium 93.70 and aluminum 6.26 percent.

Table 3 gives coefficients of expansion of all the samples indicated in figures 12 to 16, inclusive. These coefficients were obtained with the autographic and the precision expansion apparatus. The table also shows the deviations or differences between the coefficients of expansion. These deviations vary from 0.0×10^{-6} to $\pm\ 2.6\times10^{-6}$.

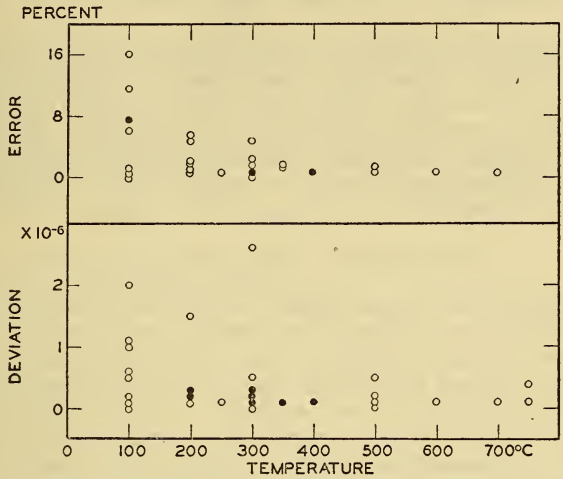

FIGURE 17.—*Deviations and errors for temperature ranges from 20° C to various temperatures indicated.*

Symbol: Black circle indicates more than one value.

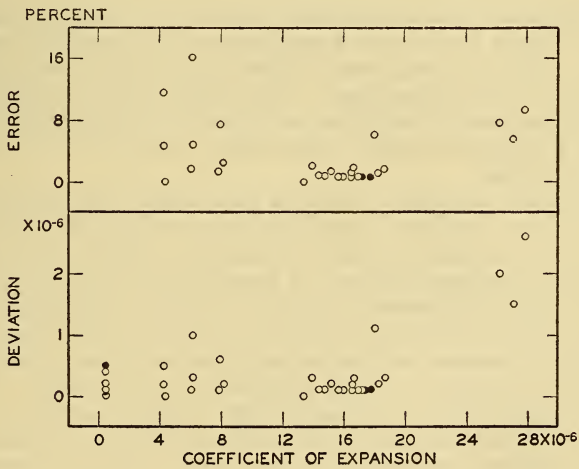

FIGURE 18.—*Deviations and errors against coefficients of expansion.*

Symbol: Black circle indicates more than one value.

The deviations indicated in table 3 are plotted in figure 17. The lower portion of the figure shows the deviations for temperature ranges from 20° to various temperatures between 100 and 750° C. The upper portion of the figure shows the errors [11] of the coefficients of

[11] The errors for sample 1057B (silica) were omitted.

expansion obtained with the autographic expansion apparatus for temperature ranges from 20° to various temperatures between 100 and 700° C. The errors were computed from the deviations on the assumption that the coefficients of expansion obtained with the precision expansion apparatus are correct. The deviations and the errors indicate a tendency to decrease with increase in the temperature range.

The deviations indicated in table 3 are also plotted in figure 18. The lower portion of the figure shows the deviations plotted against coefficients of expansion, and the upper portion of the figure shows the errors [12] plotted against coefficients of expansion. The deviations indicate a tendency to increase with increase of the coefficient of expansion, but the percentage errors appear to be independent of the coefficients of expansion.

V. SUMMARY AND CONCLUSIONS

An autographic expansion apparatus has been designed and built at the National Bureau of Standards, which is superior to a similar type used in European laboratories. This apparatus which employs the optical lever method is suitable for use in commercial laboratories where highest precision is not required. With this apparatus it is possible to obtain expansion curves photographically or to observe points on the expansion curves of materials during the progress of the test. The apparatus is useful for determinations of the linear expansion of various materials and also for locating transformation regions. A specimen 150 mm in length and from about 3 to 12 mm diameter is required.

A description of the autographic expansion apparatus is given, and the method used in obtaining satisfactory temperature uniformity is described. The apparatus was calibrated and a factor for this individual apparatus was determined. The factor 59.90, multiplied by the apparent expansion in millimeters, plus the expansion of the central portion of the fused-quartz "stationary" axis, gives the linear expansion in millionths.

A comparison has been made of the linear thermal expansion obtained on low-, medium-, and high-expanding materials with the autographic expansion apparatus and the precision expansion apparatus of the National Bureau of Standards. The deviations between the coefficients of expansion obtained with the autographic expansion apparatus and the precision expansion apparatus indicate a tendency to decrease with increase of the temperature range and they appear to increase with increase of the coefficient of expansion. The errors indicate a tendency to decrease with increase in the temperature range and they appear to be independent of the coefficients of expansion. For ordinary materials such as steel, it may be stated that the error of the autographic expansion apparatus is about 6 percent for the range from 20 to 100° C and about 3 percent for the range from 20 to 500° C.

The results show that the Bureau has accomplished the purpose indicated in the introduction of this paper. However, it should not be assumed that the autographic expansion apparatus is the best type for all laboratories. It does not give as accurate results as the fused-

[12] See footnote 11.

quartz expansion apparatus which was also designed for use in certain laboratories. Neither does the fused-quartz apparatus give results as accurate as the precision apparatus. Each type has its field of application.

The autographic expansion apparatus has its limitations and should be used with discretion. The apparatus is not sufficiently sensitive for tests on low-expanding materials. It is not satisfactory at temperatures where softening occurs in the specimen or for materials that bend at elevated temperatures. It is, however, a convenient, trustworthy, and efficient apparatus and fills a definite need.

Blueprints of both the fused-quartz expansion apparatus and the precision expansion apparatus are available and will be loaned to interested persons upon request. Detailed drawings for the construction of the autographic apparatus are not available at this date.

WASHINGTON, August 21, 1934.