The Thermal Expansion of Crystalline Sodium Between 80°K and 290°K*

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The observed linear thermal expansion of crystalline sodium is tabulated at ten degree intervals between 80°K and 290°K. The behavior of this material is in accord with the relation obtained by Gruneisen between thermal expansion and heat content, within the precision measure of the latter quantity. A description of the thermal expansion and cryostatic apparatus is given.

THE only data on the thermal expansion of sodium that the writers have been able to discover are the observations of Dewar,[1] who measured the density of sodium at the temperature of boiling liquid oxygen, and those of Richards and Brink,[2] who measured the density at 20°C. This circumstance blocked the completion of a research on the temperature variation of the principal elastic constants of crystalline sodium, in which the dynamical method of Balamuth[3] and Rose[4] was used. Accordingly the investigation here reported was undertaken.

APPARATUS AND METHOD

The specimen material is triply distilled Mallinckrodt sodium, the first and last quarters of the distillate having been rejected in the first distillation. The specimens are single crystals in the form of right circular cylinders 0.47 cm in diameter and 4 cm long.[5]

A cross-sectional elevation and two cross-sectional plans of the thermal dilatometer are shown in Fig. 1. The dilatometer proper, represented by the cross hatched portion of the figure, is constructed entirely of clear fused quartz. The envelope is Pyrex glass. The specimen is loosely encased in a thin-walled glass tube, which is held vertical against guides on a vertical support by a silk thread. This thread passes around the tube at its middle, over pulleys on opposite sides of the support, and down to a 15 gm weight, not shown, hanging below. The specimen rests on a hemispherical protuberance on a horizontal plate fused to the bottom of the support.

A bit of microscope cover glass is placed on top of the specimen, and on this rests a 2 mm quartz rod held vertical in guides. This rod can be raised or lowered into position by means of a silk thread attached near the top and wrapped around a spindle operated through a ground glass joint. The top of the rod is drawn out to a very fine, short, vertical fiber. Immediately adjacent to this fiber is another, attached to the support. The tips of both fibers are viewed simultaneously through a compound microscope equipped with a 32 mm objective and a filar micrometer eyepiece. The change in length of the specimen is measured by measuring the change in the distance between the fixed and moving fiber tips.

The temperature of the specimen is measured with a copper-constantan thermojunction located near its midpoint. The thermojunction leads are brought out of the envelope at the points labeled *T.C.* in the figure.

The dilatometer and microscope are mounted in common on a heavy metal fitting, which is firmly secured to an elevating table. The specimen is inserted in the cryostat described below, or in an appropriate constant temperature bath, by lowering this table. This procedure leaves the entire measuring equipment undisturbed.

Observations below 100°K are made with the lower part of the dilatometer immersed in a dewar of liquid nitrogen and liquid oxygen. Above 220°K the bath liquid is methanol containing a suitable amount of solid carbon dioxide. Thermal contact between the specimen

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[1] Dewar, Proc. Roy. Soc. **70**, 237 (1902).

[2] Richards and Brink, J. Am. Chem. Soc. **29**, 117 (1907).

[3] Balamuth, Phys. Rev. **45**, 715 (1934).

[4] Rose, Phys. Rev. **49**, 50 (1936).

[5] The experimental methods for growing and handling the crystals will be described in the paper dealing with the elastic constants, shortly to be submitted for publication in this journal.

and these constant temperature baths is secured by filling the dilatometer with helium at atmospheric pressure. Temperatures between 100°K and 220°K are obtained with the cryostat shown diagrammatically in Fig. 2.

C (Fig. 2) is a copper tube 10 inches long, $\frac{13}{16}$ inch internal diameter, and $\frac{3}{4}$ inch wall thickness, about which is wound a single layer of No. 22 copper wire. It hangs suspended by three Bakelite screws from a copper pan, *D*, and is surrounded by an unsilvered dewar, *B*, which can at will be evacuated or filled with helium. This dewar rests on a brass and Bakelite frame, not shown, in a large high vacuum silvered dewar, *A*, which is mounted in a wooden box. The top of this box supplies the support for the pan, *D*, and the suspended copper tube. The pan is filled with a slush of solid carbon dioxide and methanol, and the large dewar with liquid nitrogen.

The temperature of the cryostat is adjusted by manipulating the current in the coil and the

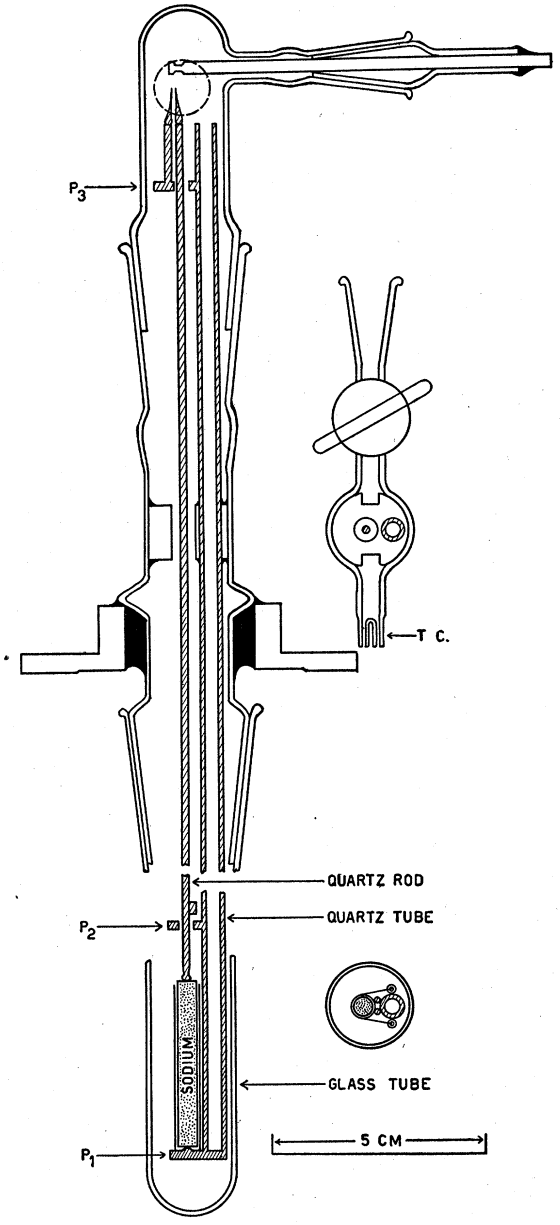

FIG. 1. Diagram of the thermal expansion apparatus.

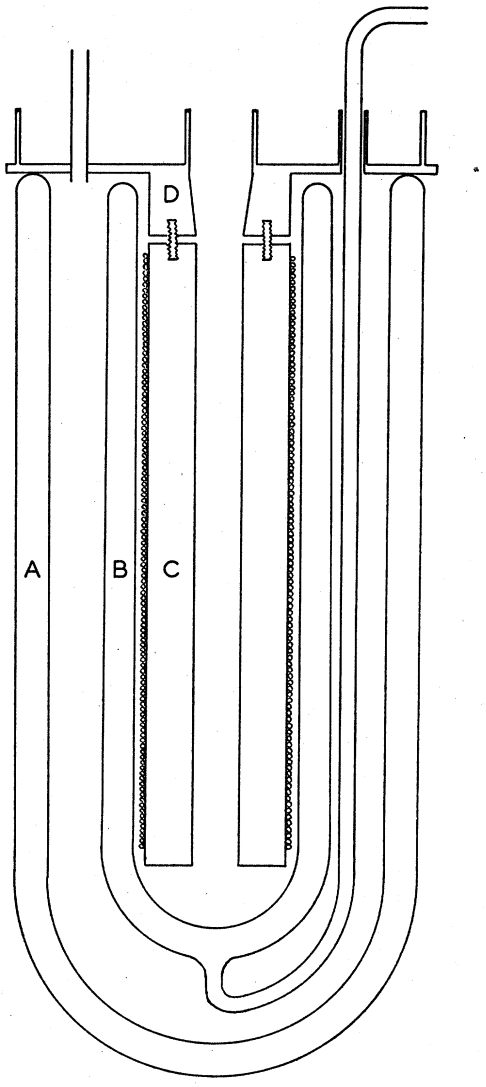

FIG. 2. The cryostat for obtaining temperatures between 100°K and 220°K.

vacuum in the dewar, B. The maximum temperature difference between the top and the bottom of the tube is about 1°K. The temperature of the specimen in the cryostat is easily stabilized to 0.1°K for several minutes. A single run from 220°K to 100°K, with observations every 10°K, takes about 8 hours and consumes about 15 lb. of liquid nitrogen.

Results

The data given in Table I represent the mean of observations on three single crystals of sodium. The data on one of these crystals is plotted in Fig. 3. None of the observations on any of the crystals departs from the mean by more than 0.3 percent of the total change in length between 80°K and 290°K.

The last column in Table I contains the ratio of the change in length per unit length here observed to the corresponding change in the heat content, ΔH, as calculated from the data given in the *International Critical Tables*.[6] In accordance with a simplified relation obtained by Gruneisen from the lattice theory of crystals[7] this ratio should be independent of the temperature. The agreement is well within the precision measure of ΔH.

TABLE I. *The thermal expansion of crystalline sodium. The last column gives the ratio of the thermal expansion to the corresponding change in the heat content.*

Temp. (°K)	Total Expansion in Percent of the Length at 273°K	$(\Delta L/L)/\Delta H$
80	−1.155	2.36
90	1.114	
100	1.071	2.41
110	1.022	
120	0.970	2.40
130	0.917	
140	0.860	2.42
150	0.801	
160	0.742	2.44
170	0.682	
180	0.621	2.46
190	0.557	
200	0.493	2.46
210	0.428	
220	0.361	2.47
230	0.294	
240	0.226	2.51
250	0.158	
260	0.090	2.50
270	0.022	
280	+0.047	
290	+0.116	2.31

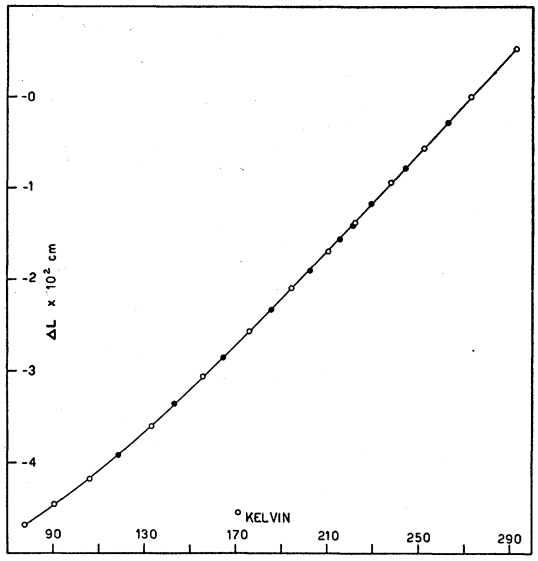

FIG. 3. The thermal expansion of a single crystal of sodium. The circles represent observations made with the temperature decreasing, and the dots observations made subsequently with the temperature increasing.

Accuracy

The filar micrometer screw was calibrated on a large Geneva Society comparator. The calibration constant of the microscope is 0.00145 mm per scale division of the screw head, and is uniform over the working range. Settings can be repeated within a single division. The correction for the thermal expansion of 4 cm of quartz amounts to only 1 percent. The thermocouple was temperature calibrated before and after the observations against a platinum resistance thermometer certificated by the National Bureau of Standards. The two calibrations agreed to 0.2°K. Accordingly it is estimated that the measurements of ΔL are accurate to 0.002 mm.

In conclusion, the writers acknowledge their indebtedness to the Ernest Kempton Adams Fellowship of Columbia University for the financial assistance which made this research possible.

[6] *International Critical Tables*, V, p. 88.

[7] Gruneisen, *Handbuch der Physik*, Vol. 10, p. 42. Durand (Physics **7**, 297 (1936)) has shown that single crystals of MgO obey Gruneisen's relation over the same temperature range.