

the sample in  $V_U$  is

$$\beta = -\frac{1}{V_U} \frac{dV_U}{dP_U} = \frac{S_L}{V_U} \left( \frac{dP_L}{dP_U} \frac{S_U + S_L}{S_L} \right). \quad (1)$$

Generally, the values of  $\Delta P$  are small enough to represent the differentials directly. With the cell characteristics  $V_U = 0.3380 \text{ cm}^3$ ,  $S_U = 1.31 \times 10^{-3} \text{ cm}^3 \text{ atm}^{-1}$ , and  $S_L = 1.09 \times 10^{-3} \text{ cm}^3 \text{ atm}^{-1}$ ,

$$\beta \approx 2.5 \times 10^{-3} (\Delta P_L / \Delta P_U - 2.2) \text{ atm}^{-1}. \quad (2)$$

### B. Apparatus

The  $P$ - $V$ - $T$  cell was made from Be-Cu (Berylco-25) disks, welded together by an electron beam, then heat-treated for favorable strength and elasticity. The cell was designed to measure a range of  $\Delta V/V$  values from  $5 \times 10^{-5}$  for thermal expansion to  $10^{-1}$  for melting, a much greater range than needed here for the liquid compressibility. At  $4^\circ\text{K}$ , the diaphragm displacement at the center was  $3 \times 10^{-4} \text{ cm atm}^{-1}$  up to the maximum working pressure of 68 atm. The upper diaphragm deflection was measured with a Sanborn 959 DT 005 differential transformer, whose output was put through a Sanborn 311 amplifier and read on a Weston dc voltmeter. The resolution of 0.01 V corresponded to  $10^{-3}$  atm. The sensitivity was frequently checked between compressibility measurements against a room-temperature gauge. The diaphragm behavior seemed to stay constant, but the over-all sensitivity varied slightly with bath height (an effect of lead resistance) and with axial position of the transformer core.

The volume of the upper (sample) chamber was calibrated against various pressures in the upper and lower chambers by metering withdrawn helium, gas at 296 and  $76^\circ\text{K}$ , liquid at  $4^\circ\text{K}$ . The molar volumes at  $4^\circ\text{K}$  were taken from Edeskuty and Sherman<sup>5</sup> after a  $-0.30\%$  correction. The observed values of the volume sensitivity increased with temperature, 5% for 4 to  $76^\circ\text{K}$  and 14% for 4 to  $296^\circ\text{K}$  but were constant with pressure to 68 atm.

A rigid requirement in the  $\Delta V$  measurements was the tightness of the valve sealing the sample in the cell. The valve tip was a  $55^\circ$  cone of Teflon; its seat was a 0.5-mm hole in the brass body. A leak test after each closing showed the valve to be tight in all cases.

The pressure standards were: (a) a Consolidated Electroynamics Corp. 6-201 gas piston gauge to 34 atm; and (b) an Ashcroft 1313A oil piston gauge to 68 atm. The first was calibrated against other standard gauges and the  $\text{CO}_2$  sublimation pressure at the ice point; accuracy was better than 0.01%. Both piston gauges had calibrated weights so that pressure changes

<sup>5</sup> F. J. Edeskuty and R. H. Sherman, in *Low Temperature Physics and Chemistry*, edited by J. R. Dillinger (University of Wisconsin Press, Madison, Wisconsin, 1958), p. 102.

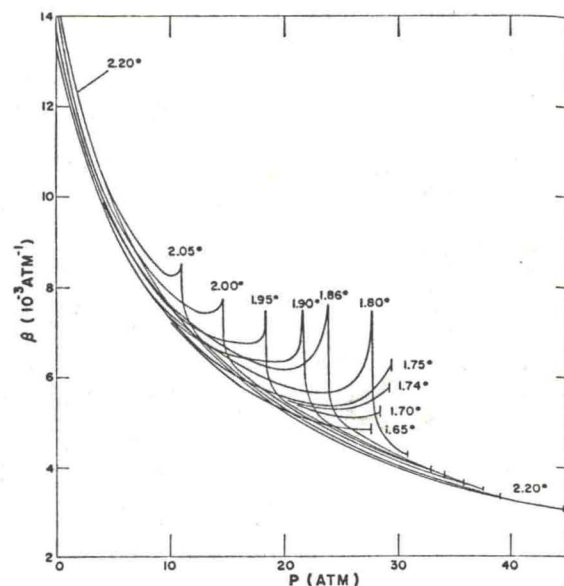


FIG. 2. Isothermal compressibility coefficient versus pressure for liquid  $\text{He}^4$  at several temperatures. The measurements show no deviation from the curves on this scale.

of 0.3 atm were known to 0.01%; this was useful in checking the consistency of the  $P$ - $V$ - $T$  cell diaphragm sensitivity. Routine pressure measurements were made with Heise and Seegers Bourdon-type and Consolidated diaphragm-type gauges.

Temperatures of the liquid  $\text{He}^4$  bath were determined from vapor pressures on the "1958 Scale".<sup>6</sup> The bath pressure was regulated to less than 0.5 mdeg equivalent.

### III. RESULTS

The isothermal compressibility coefficient  $\beta$  was measured directly over a wide pressure range, usually from about 1 atm to the melting pressure, for temperatures between 1.60 and  $2.50^\circ\text{K}$ . Typical results are shown in Fig. 2. The  $2.20^\circ\text{K}$  curve illustrates the monotonic decrease of  $\beta$  with increasing pressure for

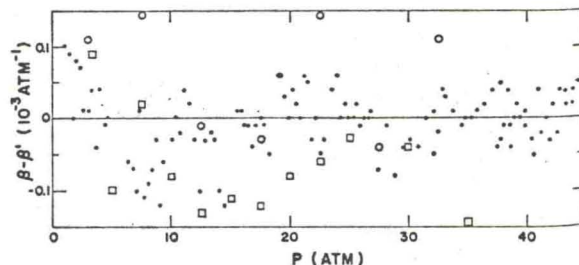


FIG. 3. Deviations of liquid  $\text{He}^4$  compressibility at  $2.200^\circ\text{K}$  from  $0.30 \times 10^{-3} + (72.0 \times 6.66P)^{-1}$ . ● present measurements; ○ derived from density data of Keesom and Keesom (Ref. 1); □ derived from density of Edeskuty and Sherman (Ref. 5).

<sup>6</sup> F. G. Brickwedde, H. van Dijk, M. Durieux, J. R. Clement, and J. K. Logan, *J. Res. Natl. Bur. Std. (U. S.)* 64A, No. 1 (1960).