



FIG. 10.  $(\partial P/\partial T)_V$  and  $(C_P - C_V)$  for fluid He<sup>3</sup> along the melting curve.

lowest accessible mean temperature for the present  $\alpha_f$  measurements. It is seen that the curve of Fig. 5 intersects the melting curve at 47 kg/cm<sup>2</sup> in good agreement with the extrapolations made in Figs. 4 and 10. Temperatures where  $\alpha_f = 0$ , derived from pressure-volume-temperature data by Brewer and Daunt (28) and Sherman and Edeskuty (29), are in general agreement with the measurements of Fig. 5.

The slopes,  $(\partial\alpha_f/\partial T)_P$  and  $(\partial\beta_f/\partial P)_T$ , decrease with increasing melting pressure as shown in Figs. 6 and 7, respectively. From the thermodynamic formulas,

$$(\partial C_P/\partial P)_T = -T(\partial^2 V/\partial T^2)_P = -TV[\alpha^2 + (\partial\alpha/\partial T)_P] \quad (7)$$

and the data given above for fluid He<sup>3</sup>, it can be seen that  $C_P$  decreases with increasing pressure in the vicinity of the melting curve. Gutsche (30) and Jones and Walker (31) reported a similar variation for H<sub>2</sub> and A, respectively.

Equation (5) combined with the thermodynamic relation,

$$\frac{dP_m}{dT_m} = \left[ \left( \frac{\partial P}{\partial V} \right)_T \right]_m \frac{dV_m}{dT_m} + \left[ \left( \frac{\partial P}{\partial T} \right)_V \right]_m, \quad (8)$$

leads to

$$\beta_f = \alpha_f \frac{dT_m}{dP_m} - \frac{1}{V_f} \frac{dV_f}{dP_m}. \quad (9)$$

For He<sup>3</sup> at low pressures, the values of  $\beta_f$  calculated from Eq. (9) compare reasonably well with those measured directly (Fig. 4), deviating by +27 percent at  $P_m = 50$  kg/cm<sup>2</sup> and by -2 percent at  $P_m = 225$  kg/cm<sup>2</sup>. At 3555 kg/cm<sup>2</sup>, the calculated  $\beta_f$  is  $7.4 \times 10^{-5}$  cm<sup>2</sup>/kg.

The theory of melting for metals that was advanced by Bonfiglioli *et al.* (32) predicts that  $\alpha_s T_m$  is constant for a given crystal type. Unfortunately, available data are restricted to melting pressures of  $\sim 1$  atmos but for face-centered-cubic, body-centered-cubic, and hexagonal-closest-packed metals of widely varying melting temperature,  $\alpha_s T_m$  appears to be  $\sim 0.06$ . Above the anomalous region where  $\alpha_f$  shows a maximum, the present results for fluid He<sup>3</sup> (and He<sup>4</sup>) indicate that values of  $\alpha_f T_m$  rise rapidly with  $P_m$  then approach constancy around 0.05–0.06 at high melting pressures. The empirical deduction from the present work that  $\alpha_s = 0.75\alpha_f$  indicates that the expansion of the solid along the melting curve follows closely that of the fluid and implies a constant value of 0.04–0.05 for  $\alpha_s T_m$  at high pressures. It is interesting to compare the ratio  $\alpha_s/\alpha_f = 0.75$  for He<sup>3</sup> and He<sup>4</sup> with the ratios 0.70 and 0.77 for Na and K, respectively, measured by Bridgman (33) at  $P_m = 1$  kg/cm<sup>2</sup>.

Values of  $V_s$  can be calculated from the present measurements of  $V_f$  and  $\Delta V_m$ . For He<sup>3</sup> the ratio  $V_f/V_s$  was found to be constant and equal to 1.044 with a maximum deviation of only 0.4 percent over the full pressure range studied.<sup>4</sup> Therefore  $(1/V_f)(dV_f/dP_m) = (1/V_s)(dV_s/dP_m)$  which, with Eq. (8) and the ratio  $\alpha_s/\alpha_f = 0.75$ , leads to the following equations for He<sup>3</sup>:

$$\beta_s = 0.75\alpha_f \frac{dT_m}{dP_m} - \frac{1}{V_f} \frac{dV_f}{dP_m}, \quad (10)$$

and

$$\Delta\beta = \beta_f - \beta_s = 0.25\alpha_f (dT_m/dP_m). \quad (11)$$

<sup>4</sup> For He<sup>4</sup> the ratio of  $V_f/V_s$  varied monotonically from 1.066 at  $P_m = 35$  kg/cm<sup>2</sup> to 1.044 at  $P_m = 3555$  kg/cm<sup>2</sup>.