$$\Gamma_v = \frac{C_g}{C_p}\Gamma_g + \frac{C_e}{C_p}\Gamma_e + \frac{C_m}{C_p}\Gamma_m \qquad (5)$$

where the subscripts g, e and m refer to the lattice, electronic and magnetic contributions respectively. In most metals Γ_g varies with temperature with values varying from 1.5 to 3. At low temperature, where C_e and C_m may be relatively large, a negative Γ_v and therefore a negative α_v may arise, as in the case of uranium below 45° K, from the Γ_e and/or Γ_m contributions. Because of the absence of compressibility values below 42° K we cannot at the present time evaluate Γ_v in this interesting temperature range. The other anomaly, α_2 above 350° K, can, however, be analyzed quantitatively using the tensor form of the Grüneisen relation to determine whether a negative Γ_v is necessarily involved in this situation [14]). The following relations are thus obtained:

$$\begin{aligned}
\frac{V}{C_p}\alpha_1 &= (s_{11}\Gamma_1 + s_{12}\Gamma_2 + s_{13}\Gamma_3) = \\
&= \frac{\Gamma_1}{E_1} - \frac{\sigma_{21}}{E_2}\Gamma_2 - \frac{\sigma_{31}}{E_3}\Gamma_3 \\
\frac{V}{C_p}\alpha_2 &= (s_{12}\Gamma_1 + s_{22}\Gamma_2 + s_{23}\Gamma_3) = \\
&= -\frac{\sigma_{12}}{E_1}\Gamma_1 + \frac{\Gamma_2}{E_2} - \frac{\sigma_{32}}{E_3}\Gamma_3 \\
\frac{V}{C_p}\alpha_3 &= (s_{13}\Gamma_1 + s_{23}\Gamma_2 + s_{33}\Gamma_3) = \\
&= -\frac{\sigma_{13}}{E_1}\Gamma_1 - \frac{\sigma_{23}}{E_2}\Gamma_2 + \frac{\Gamma_3}{E_3},
\end{aligned} \qquad (6)$$

which reduces to,

$$\alpha_v = \frac{C_p}{V}(\beta_{[100]}\Gamma_1 + \beta_{[010]}\Gamma_2 + \beta_{[001]}\Gamma_3). \qquad (7)$$

Γ_1, Γ_2 and Γ_3 are the Grüneisen coefficients which apply for uniaxial thermal strains in the [100], [010] and [001] directions respectively and the same subscript scheme applies to E_1, E_2 and E_3. The solutions for Γ_1, Γ_2, Γ_3 and Γ_v obtained from the simultaneous equations using the s_{ij} values from the present measurements, the α_i computed by Lloyd *et al.*[13]) and the total C_p[7]) are shown in the curves of fig. 9. All of the Γ_j rise quite sharply upon cooling below 100° K; Γ_v is relatively independent of temperature between 75° K and 700° K, with a value of 2.35 and decreases to 2.15 at 900° K. Γ_1 varies from 2.68 to 2.81 in this range and Γ_3 undergoes the greatest changes with limits of 2.45 and 2.97. Γ_2 is remarkably constant between 175° K and 300° K and decreases from 1.6 to 1.15 above 300° K. Although the decrease in Γ_2 may be a contributing factor, the negative α_2 arises, primarily, from the abnormally large Poisson's ratio σ_{32} and the large negative temperature dependence of E_3.

4.2. The anomalous specific heat

Fig. 10 shows the temperature dependence of various contributions to the total specific heat for alpha uranium. The C_p curve between 0° and 300° K is that given by Flotow and Lohr [15]) and the higher temperature part is due to Ginnings *et al.*[7]). The specific heat at constant volume, C_v, was derived using the thermodynamic relation

$$C_v = \left(\frac{\beta_v}{\alpha_v^2 VT + \beta_v C_p}\right) C_p^2, \qquad (8)$$

at temperature T. The lattice specific heat that was calculated from the Debye model using θ_D of 200° K [16]) is noted as the dashed line, C_D. The experimental lattice specific heat due to temperature change only, $C_v(V_0, T) - \gamma_0 T$, was computed from the C_v data by assuming a temperature independent electronic specific heat coefficient, $\gamma_0 = 26 \times 10^{-4}$ cal/mol·deg² [16]); and then correcting for the change in C_v with volume using the relation

$$\left(\frac{\partial C_v}{\partial V}\right)_T = T\frac{\{\beta_v(d\alpha_v/dT) - \alpha_v(d\beta_v/dT)\}}{V^2}\frac{C_v}{C_p}. \qquad (9)$$

The resulting curve approaches the C_D curve in the range of 100° to 120° K. Below 100° K the specific heat in excess of C_D increases with decreasing temperature; this reflects either a decreasing θ_D or an increasing contribution from the free electrons, or from a magnetic moment. Above 120° K the $C_v(V_0, T) - \gamma_0 T$ curve follows the Debye function reasonably well, allowing for experimental error, up to approximately 400° K where it has a significant positive curvature and increases above 3 R at higher temperatures.