$$\Gamma_{\mathrm{v}} = \frac{C_{\mathrm{g}}}{C_{\mathrm{p}}}\Gamma_{\mathrm{g}} + \frac{C_{\mathrm{e}}}{C_{\mathrm{p}}}\Gamma_{\mathrm{e}} + \frac{C_{\mathrm{m}}}{C_{\mathrm{p}}}\Gamma_{\mathrm{m}} \tag{5}$$

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:

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

which reduces to,

$$\alpha_{\mathrm{v}} = \frac{C_{\mathrm{p}}}{V}(\beta_{[100]}\Gamma_1 + \beta_{[010]}\Gamma_2 + \beta_{[001]}\Gamma_3). \tag{7}$$

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

$$C_{\mathrm{v}} = \left(\frac{\beta_{\mathrm{v}}}{\alpha_{\mathrm{v}}^2 VT + \beta_{\mathrm{v}}C_{\mathrm{p}}}\right)C_{\mathrm{p}}^2, \tag{8}$$

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, $C_{\mathrm{v}}(V_0, T) - \gamma_0 T$, was computed from the C_{v} data by assuming a temperature independent electronic specific heat coefficient, $\gamma_0 = 26\times10^{-4}$ cal/mol·deg² [16]); and then correcting for the change in C_{v} with volume using the relation

$$\left(\frac{\partial C_{\mathrm{v}}}{\partial V}\right)_T = T\frac{\{\beta_{\mathrm{v}}(\mathrm{d}\alpha_{\mathrm{v}}/\mathrm{d}T) - \alpha_{\mathrm{v}}(\mathrm{d}\beta_{\mathrm{v}}/\mathrm{d}T)\}}{V^2}\frac{C_{\mathrm{v}}}{C_{\mathrm{p}}}. \tag{9}$$

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 $C_{\mathrm{v}}(V_0, T) - \gamma_0 T$ 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.