

metals is shown in Fig. 19a. In general, most of the γ values lie quite close to 10 mj/g-at/deg², the value for lanthanum. The exceptions are the values for praseodymium, europium, holmium, thulium, ytterbium, and α -cerium (not shown in Fig. 19a, since its value is much larger than the range given in the figure). The values for europium (estimated) and ytterbium are low because these metals are divalent and have no d electrons.¹³ The high values for the other four materials are not as easily explained. Since the rare earths have essentially the same valence band composed of $6s^25d^1$ electrons and since the $4f$ level is buried radially and shielded by the $5s^25p^6$ electrons from external forces, one would expect that the density of states (and thus the γ value) would be governed by the $6s^25d^1$ configuration; i.e., one would expect a constant value for the density of states for this series of elements. Since very large values are observed for the four elements, one might be tempted to suggest that there exists an f band which overlaps the $6s^25d^1$ bands and for a few elements the density of states is governed by the $4f$ band rather than by the $5d$ band, which leads to the very large γ values. This appears to be the situation for α -cerium,⁶⁰ but it is unclear for the other rare-earth exceptions (praseodymium, holmium, and thulium). The problem with these and also many of the other rare earths is that besides the normal lattice and electronic contributions to the specific heat (Eq. (13.1)) there are also magnetic and nuclear contributions which make it difficult to evaluate γ and θ_D . Of these last two contributions the magnetic portion is by far the most uncertain from a theoretical standpoint, especially in view of the complex magnetic ordering which takes place in the rare-earth metals.⁶¹⁻⁶⁴ Much further research will be required before one can definitely conclude whether or not the $4f$ level is involved in determining the density of states of these metals.

Furthermore, if one attempts to calculate the lattice contribution to the heat capacity at constant volume, C_v , (see Section 15) he finds that C_v is anomalously low for praseodymium, holmium, and thulium. This is due to the fact that the γ values for these metals are too large. Indeed,

- ⁶⁰ K. A. Gschneidner, Jr., *Proc. 4th Rare Earth Conf., Phoenix, Arizona, 1964*. Gordon & Breach, New York (to be published ca. 1965).
- ⁶¹ W. C. Koehler, E. O. Wollan, M. K. Wilkinson, and J. W. Cable, in "Rare Earth Research" (E. V. Kleber, ed.), p. 149. Macmillan, New York, 1961.
- ⁶² W. C. Koehler, J. W. Cable, E. O. Wollan, and M. K. Wilkinson, *J. Phys. Soc. Japan* **17**, Suppl. B-III, 32 (1962).
- ⁶³ M. K. Wilkinson, H. R. Child, W. C. Koehler, J. W. Cable, and E. O. Wollan, *J. Phys. Soc. Japan* **17**, Suppl. B-III, 27 (1962).
- ⁶⁴ J. W. Cable, H. R. Child, W. C. Koehler, M. K. Wilkinson, and E. O. Wollan, in "Pile Neutron Research in Physics," p. 379. Intern. Atomic Energy Agency, Vienna, 1962.

if one chooses a value of $\gamma = 10$ mj/g-at/deg² he obtains much more reasonable values for C_v (also see the relevant discussion in Section 15). This also suggests that the high γ values for these three metals are suspect.

The electronic specific heat constant for α -plutonium is only less high than that of α -cerium. It is quite likely that the $5f$ band is involved in determining the density of states in plutonium.

Boron. Kaufman and Clougherty⁶⁵ estimated the electronic specific heat constant from the low-temperature data (20° to 300°K) of Johnston *et al.*,⁶⁶ assuming γ to be linear and the lattice contribution to be given by the Debye model over this temperature range.

Sodium. The value given by Parkinson and Quarrington⁶⁷ is not included in the average value given in Table XIII, since it is significantly larger than any of the other values, i.e., 1.8 as compared with the mean of 1.38 ± 0.05 mj/g-at/deg².

Aluminum. The value reported by Kok and Keesom⁶⁸ (1.46) is not included in the average (1.36 ± 0.01) since it was higher than the other reported values.

Chromium. Edwards *et al.*⁶⁹ reviewed the literature up to 1958 and gave a best value for γ . This value was averaged with values which have been reported since then.

γ -Manganese. The mean value for γ -manganese was taken from the value calculated by Weiss and Tauer⁷⁰ from high-temperature specific heat data, and from the value obtained at low temperatures from γ -stabilized copper-manganese alloys (extrapolated to 100% Mn) reported by Zimmerman and Sato.⁷¹ In view of the more recent data ($\gamma = 8.4$) published by Shinozaki *et al.*⁷² the low given in Table XIII (4.6 ± 0.1) may be incorrect. Since full details are presently not available, one can only point out this large difference.

Cobalt. The high value (5.02) reported by Duyckaerts⁷³ was omitted in calculating the average value (4.73) for cobalt.

Nickel. Recently Gupta *et al.*⁷⁴ obtained a value of 7.20 for nickel which

- ⁶⁵ L. Kaufman and E. V. Clougherty, "Investigation of Boride Compounds for Very High Temperature Applications," Semi-Annual Rept. No. 2. Man Labs, Inc., April, 1963.
- ⁶⁶ H. L. Johnston, H. N. Hersh, and E. C. Kerr, *J. Am. Chem. Soc.* **73**, 1112 (1951).
- ⁶⁷ D. H. Parkinson and J. E. Quarrington, *Proc. Phys. Soc. (London)* **A68**, 762 (1955).
- ⁶⁸ J. A. Kok and W. H. Keesom, *Physica* **4**, 835 (1937).
- ⁶⁹ A. R. Edwards, J. I. Nish, and H. L. Wain, *Metal. Rev.* **4**, 403 (1959).
- ⁷⁰ R. J. Weiss and K. J. Tauer, *Phys. Chem. Solids* **4**, 135 (1958).
- ⁷¹ J. E. Zimmerman and H. Sato, *Phys. Chem. Solids* **21**, 71 (1961).
- ⁷² S. Shinozaki, A. Arrott, H. Sato, and J. E. Zimmerman, *Bull. Am. Phys. Soc.* **8**, 66 (1963).
- ⁷³ G. Duyckaerts, *Physica* **6**, S17 (1939).
- ⁷⁴ K. P. Gupta, C. H. Cheng, and P. A. Beck, *Phys. Chem. Solids* **25**, 73 (1964).