

is reduced to  $\pm 26$ . Thus Eq. (25.1) is a fair approximation for these metals. The product  $\alpha T$  was found to be  $0.0049 \pm 0.0018$  for those elements which crystallize in a diamond-type lattice;  $0.0073 \pm 0.0026$  for the group VB elements (arsenic, antimony, and bismuth);  $0.0123 \pm 0.0046$  for those metals which do not crystallize in any of the above structures and which have four or less atoms per unit cell (gallium, indium, white tin, mercury, and uranium); and  $0.0365 \pm 0.0137$  for those metals which do not crystallize in any of the above structures and which have more than four atoms per unit cell (manganese, neptunium, and plutonium). The semimetals—sulfur, selenium, tellurium, and polonium—showed a wide variation in their  $\alpha T$  values, but it was noted that  $\alpha T$  decreased in a nonlinear manner with increasing atomic number for these four elements. The elements boron, graphite, and white phosphorus could not be placed in any of the above categories.

The product of  $\alpha T$  varies from a minimum value of 0.0027 for gray tin to a maximum value of 0.0502 for plutonium. The relationship between  $\alpha$  and  $T$  has been used to estimate the coefficient of thermal expansion for a number of elements from the known or estimated melting points (see Part III).

## 26. LEIBFRIED, MODIFIED LEIBFRIED, AND BRAGG NUMBERS

In Leibfried's study of melting<sup>114</sup> he observed that for a number of metals (specifically aluminum, copper, palladium, silver, gold, and lead) the quantity  $RT_m/\mu V = L \approx 0.042$ , where  $R$  is the gas constant,  $T_m$  is the melting point (Table IX),  $\mu$  is the shear modulus (Table II), and  $V$  is the atomic volume (Table VII). The term  $RT_m$  is an approximation of the heat of fusion, which follows from Richard's rule (see Section 27). Bragg,<sup>115</sup> on the other hand, noted that  $\Delta H_f/\mu V = \mathcal{B} \approx 0.034$  for a few metals (specifically aluminum, iron, cobalt, nickel, copper, silver, gold, and lead), where  $\Delta H_f$  is the heat of fusion (Table X). Since  $\Delta H_f \approx RT_m$  (Richard's rule) it is difficult to understand why such a large discrepancy exists between  $L$  (which will be referred to hereafter as the Leibfried number) and  $\mathcal{B}$  (referred to hereafter as the Bragg number). Furthermore, since these approximations were based on only a very limited number of metals, it would be desirable to know if they are generally valid for all metals and semimetals. In order to investigate these two points, and since the Bragg and/or Leibfried numbers are necessary to calculate the size factor, these numbers were calculated for all the elements from the appropriate data given in the earlier tables. The results are shown in Table XXII.

<sup>114</sup> G. Leibfried, *Z. Physik* 127, 344 (1950).

<sup>115</sup> L. Bragg, in "Symposium on Internal Stresses," p. 221. Inst. Metals, London, 1948.

TABLE XXII. LEIBFRIED, MODIFIED LEIBFRIED, AND BRAGG NUMBERS

Element	L	L'	$\mathcal{B}$
3 Li	0.0686	0.0611	0.0512
4 Be	0.0185	0.0165	0.0197
5 B	0.0233	0.0233	(0.0252) <sup>a</sup>
6 C(g)	1.99	1.99	5.72
6 C(d)	0.0222	0.0728	0.0640
11 Na	0.0378	0.0336	0.0299
12 Mg	0.0316	0.0369	0.0345
13 Al	0.0292	0.0341	0.0378
14 Si	0.0292	0.0956	0.0983
15 P(w)	(0.1070) <sup>a</sup>	(0.1070) <sup>a</sup>	(0.0239) <sup>a</sup>
15 P(r)	(0.0765) <sup>a</sup>	(0.0765) <sup>a</sup>	—
16 S(r)	0.0293	0.0293	0.0118
19 K	0.0481	0.0429	0.0375
20 Ca	0.0480	0.0428	0.0421
21 Sc	(0.0320) <sup>a</sup>	(0.0285) <sup>a</sup>	(0.0308) <sup>a</sup>
22 Ti	0.0342	0.0304	(0.0284) <sup>a</sup>
23 V	0.0466	0.0415	(0.0386) <sup>a</sup>
24 Cr	0.0212	0.0188	0.0161
25 Mn	0.0224	0.0200	0.0244
26 Fe	0.0260	0.0232	0.0249
27 Co	0.0287	0.0335	0.0284
28 Ni	0.0290	0.0339	0.0334
29 Cu	0.0351	0.0410	0.0381
30 Zn	0.0169	0.0197	0.0203
31 Ga	0.0057	0.0057	0.0118
32 Ge	0.0188	0.0614	0.0557
33 As	(0.0479) <sup>a</sup>	(0.1290) <sup>a</sup>	(0.1370) <sup>a</sup>
34 Se	(0.0114) <sup>a</sup>	(0.0309) <sup>a</sup>	(0.0143) <sup>a</sup>
37 Rb	(0.0462) <sup>a</sup>	(0.0412) <sup>a</sup>	(0.0391) <sup>a</sup>
38 Sr	(0.0490) <sup>a</sup>	(0.0436) <sup>a</sup>	(0.0484) <sup>a</sup>
39 Y	0.0288	0.0256	0.0209
40 Zr	0.0369	0.0329	(0.0306) <sup>a</sup>
41 Nb	0.0562	0.0500	(0.0466) <sup>a</sup>
42 Mo	0.0221	0.0197	0.0240
43 Tc	(0.0165) <sup>a</sup>	(0.0193) <sup>a</sup>	(0.0173) <sup>a</sup>
44 Ru	0.0162	0.0190	(0.0170) <sup>a</sup>
45 Rh	0.0152	0.0178	(0.0159) <sup>a</sup>
46 Pd	0.0334	0.0390	0.0354
47 Ag	0.0349	0.0407	0.0370
48 Cd	0.0158	0.0184	0.0185
49 In	0.0610	0.0712	0.0522
50 Sn(g)	0.0111	0.0362	0.0177
50 Sn(w)	0.0126	0.0126	0.0202
51 Sb	0.0206	0.0556	0.0510
52 Te	0.0191	0.0515	0.0520
55 Cs	(0.0560) <sup>a</sup>	(0.0499) <sup>a</sup>	(0.0443) <sup>a</sup>