is reduced to ±26. Thus Eq. (25.1) is a fair approximation for these metals. The product $\alpha T$ was found to be 0.0049 ±0.0018 for those elements which crystallize in a diamond-type lattice; 0.0073 ±0.0026 for the group VB elements (arsenic, antimony, and bismuth); 0.0123 ±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 ±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 they 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[114] he observed that for a number of metals (specifically aluminum, copper, palladium, silver, gold, and lead) the quantity $RT_m/\mu V = L \simeq 0.042$, 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,[115] on the other hand, noted that $\Delta H_f/\mu V = \mathfrak{B} \simeq 0.034$ 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 $\Delta H_f \simeq RT_m$ (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 $\mathfrak{B}$ (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.

[114] G. Leibfried, *Z. Physik* **127**, 344 (1950).

[115] L. Bragg, *in* "Symposium on Internal Stresses," p. 221. Inst. Metals, London, 1948.



Table XXII. Leibfried, Modified Leibfried, and Bragg Numbers

| Element | L | L′ | $\mathfrak{B}$ |
|---|---|---|---|
| 3 Li | 0.0686 | 0.0611 | 0.0512 |
| 4 Be | 0.0185 | 0.0165 | 0.0197 |
| 5 B | 0.0233 | 0.0233 | (0.0252)[a] |
| 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)[a] | (0.1070)[a] | (0.0239)[a] |
| 15 P(r) | (0.0765)[a] | (0.0765)[a] | — |
| 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)[a] | (0.0285)[a] | (0.0308)[a] |
| 22 Ti | 0.0342 | 0.0304 | (0.0284)[a] |
| 23 V | 0.0466 | 0.0415 | (0.0386)[a] |
| 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)[a] | (0.1290)[a] | (0.1370)[a] |
| 34 Se | (0.0114)[a] | (0.0309)[a] | (0.0143)[a] |
| 37 Rb | (0.0462)[a] | (0.0412)[a] | (0.0391)[a] |
| 38 Sr | (0.0490)[a] | (0.0436)[a] | (0.0484)[a] |
| 39 Y | 0.0288 | 0.0256 | 0.0209 |
| 40 Zr | 0.0369 | 0.0329 | (0.0306)[a] |
| 41 Nb | 0.0562 | 0.0500 | (0.0466)[a] |
| 42 Mo | 0.0221 | 0.0197 | 0.0240 |
| 43 Tc | (0.0165)[a] | (0.0193)[a] | (0.0173)[a] |
| 44 Ru | 0.0162 | 0.0190 | (0.0170)[a] |
| 45 Rh | 0.0152 | 0.0178 | (0.0159)[a] |
| 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)[a] | (0.0499)[a] | (0.0443)[a] |