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One of the fundamental properties needed in the description of a solid is the coefficient of thermal expansion. Unfortunately, such data at the temperatures of interest are often lacking. The purpose of this note is to present a generalized correlation, which expresses the reduced coefficient of thermal expansion as a function of the reduced Debye temperature for metallic solids. From this correlation, one can predict the coefficient of thermal expansion of a metallic solid at any temperature if the coefficient of thermal expansion is known at one temperature.

According to the Gruneisen relationship,[1] the coefficient of thermal expansion of a solid is proportional to its specific heat and one thus expects that the temperature dependence of the coefficient of thermal expansion should be similar to that of the specific heat. This indeed is the case. The coefficient of thermal expansion goes to zero at absolute zero temperature and approaches a nearly constant value at high temperatures. However, this value differs for different metallic solids, depending on the melting points. It is hoped that plots of the reduced linear coefficient of thermal expansion, β_T/β_θ versus the reduced Debye

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temperature, T/θ may produce a universal curve common to all metallic solids. The term β_T is the linear coefficient of thermal expansion of a solid at any temperature, β_θ is the linear coefficient of thermal expansion at the Debye temperature, T is the absolute temperature and θ is the Debye temperature, characteristic of a solid.

A plot of the reduced coefficient of thermal expansion versus the reduced Debye temperature is made for twenty-one metallic elements and one alpha-brass with 34 atomic percent zinc. As shown in Fig. 1, all these data fall close to the same curve except at temperatures higher than two-thirds of the absolute melting points. The deviation of the reduced coefficients of thermal expansion at high temperatures is perhaps due to the greater anhormonicity of lattice vibrations and the generation of vacancies in the lattice. It is noteworthy to point out that the linear coefficient of thermal expansion of beryllium with a Debye temperature of 1200°K and a melting point of 1556°K and lead with values of 88°K and 601°K, respectively, agree rather well in this generalized correlation.

The Debye temperatures, the coefficients of thermal expansion at the respective Debye temperatures and the references where thermal expansion data were obtained for these twenty-two metallic solids are summarized in Table 1. For cubic solids, the linear coefficient of thermal expansion is the same in every direction; and for non-cubic solids the average coefficients of thermal expansion obtained in the usual manner are used to obtain the curve in Fig. 1.

Consequently, the values of the coefficient of thermal expansion of any metallic solid at any temperature may be obtained from Fig. 1, when the Debye temperature and the coefficient of thermal expansion at one

Table 1. Thermal Properties of Metallic Solids

Metallic Solid	θ, °K	$\beta_\theta X10^6$, $°K^{-1}$	Reference
Ag	215	18.2	2,3,4,5,6
Al	400	25.0	2,3,5,7
Au	194	13.4	3,5,7
Be	1200	222.9	8,9
Ca	220	20.8	10
Cd	165	29.3	11
Cu	325	16.9	2,4,7,13,22
In	120	27.5	14,15
Li	500	53.0	16
Mg	406	27.2	3,4
Mo	350	5.3	5
Na	240	66.5	17
Nb	250	7.1	10
Pb	88	24.9	3,5,18
Pd	300	11.7	5
Pt	230	8.70	4,5
Ta	252	6.40	5
Th	200	10.3	10
V	450	9.5	10
W	310	4.6	19
Zn	180	28.1	11,20
$Cu_{66}Zn_{34}$	290	18.9	21,22

temperature are known. Values of the Debye temperature can be obtained either from the specific heat data or from the Lindemann relationship which relates the Debye temperature of a solid as a function of its melting point, atomic volume and atomic weight.[1] Recently, Gschneidner[23] has calculated the Debye temperature of many elements using the Lindemann

relationship. The values of the Debye temperature calculated are in good agreement with those used in the present correlation.

The room-temperature coefficient of thermal expansion of a metallic solid may be obtained from the relationship that the product of β and T_m, where β is the linear coefficient of thermal expansion at room temperature and T_m is the absolute melting point, is a constant. Gschneidner[23] has made an extensive compilation of the coefficients of thermal expansion at room temperature and the melting points of all the elements where data were available. He found the product βT_m to be 0.0186 ± 0.0080 for all the elements. However, when he considered only those elements crystallized either with a face-centered cubic, body-centered cubic or hexagonal close-packed structure, the product was found to be 0.0197 ± 0.0051. The uncertainty of ± 0.0051 corresponded to a percentage error of only 26% instead of 43% when all the elements were considered.

In short, the correlation shown in Fig. 1 with the well-known relationship that the product βT_m is a constant may be used to estimate the thermal expansion coefficient of any metallic solid, elements as well as alloys at any temperature, when experimental data are not available. Moreover, from the findings for metallic solids, it is anticipated that similar correlations also exist for non-metallic solids.

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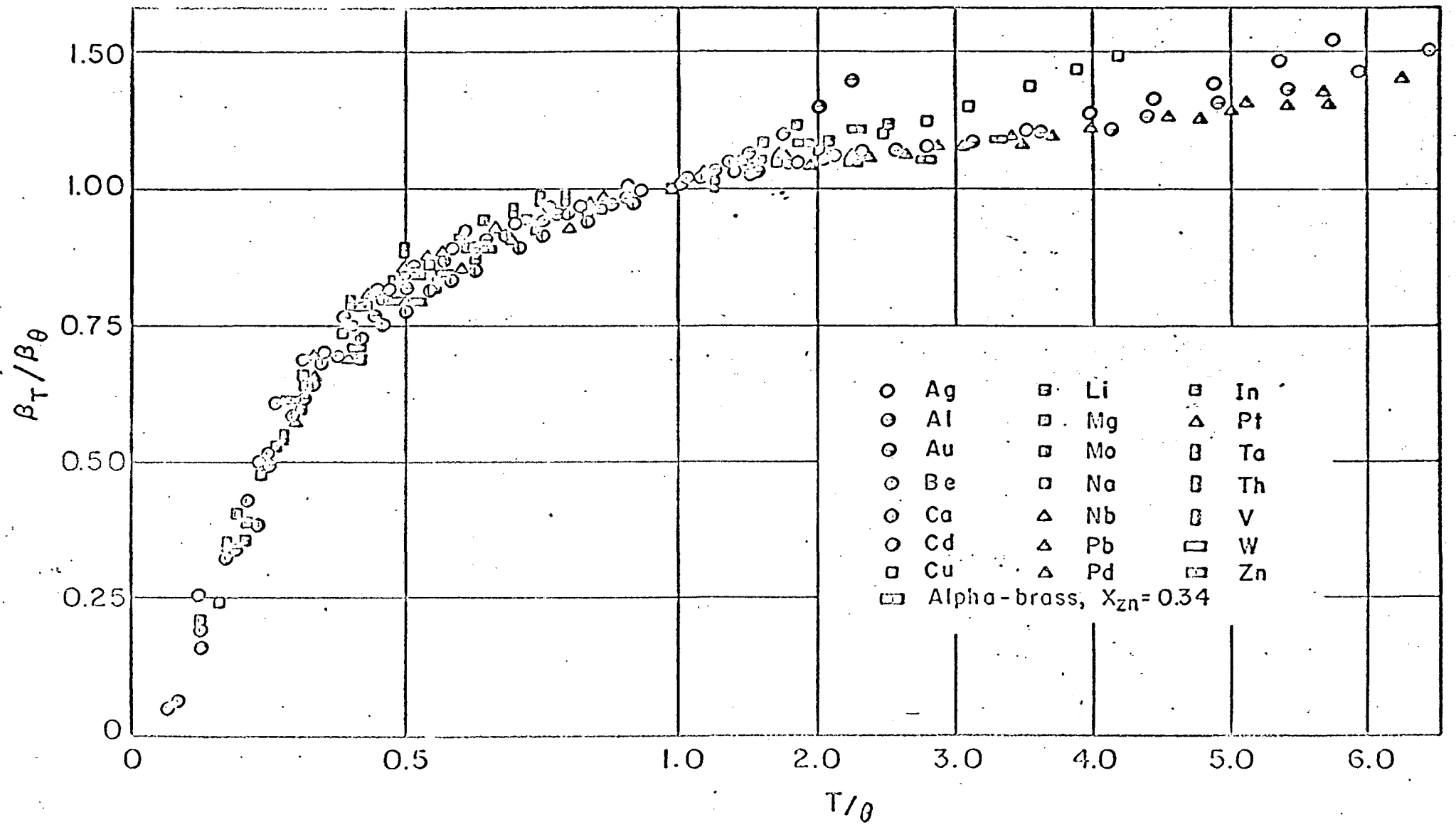
FIGURE CAPTION

Fig. 1 Reduced Coefficient of Thermal Expansion of Metallic Solids (The scales of both the ordinate and the abscissa are compressed at temperatures higher than $T/\theta = 1.0$.)


1.50
1.00
0.75
0.50
0.25
0
β_T/β_θ
0
0.5
1.0
2.0
3.0
4.0
5.0
6.0
T/θ
Ag
Al
Au
Be
Ca
Cd
Cu
Li
Mg
Mo
Na
Nb
Pb
Pd
In
Pt
Ta
Th
V
W
Zn
Alpha-brass, X_{Zn}= 0.34