RELATION OF THE ELECTRICAL RESISTIVITY AND THE EXPANSION COEFFICIENT OF METALS

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UDC 537.331.33

A simple formula is presented that establishes an unambiguous relation between the electrical resistivity and the thermal expansion coefficient of metals from roughly 0°K to the phase-transition temperature.

It is known [1-3] that for a description of the electrical resistivity of liquid metals, it is much more precise to consider the electrical resistivity to be a function of volume rather than of temperature. In this case, according to [1, 2], function $\rho = f(V)$ is continuous during the transition from solid to liquid. Considerations of a physical nature, in particular those introduced in [2], support the proposition that the volume dependence of the potential field which scatters conduction electrons indicates a dependence upon the free or accessible volume $\Delta V = V - V_0$, where V_0 and V are the volumes for 0°K and T°K, respectively. The variation of the quantity ΔV with temperature is determined by the product $\bar{\alpha}_V T$, where α_V is the average volume coefficient of expansion in the temperature interval 0 to T°K.

An empirical material analysis by electrical resistivity of solid metals leads to the conclusion that the dependence $\rho = f(\alpha_V T)$ has no less regular a character, where $\alpha_V = dV/dTV$.

TABLE 1. Reference Data and the Results of Calculations

Metal	T, K	$\rho \cdot 10^8$, $\Omega \cdot$m [4—8]	$\alpha_V \cdot 10^6$, 1/K [9]	$\frac{\rho}{\alpha_V T}$, $\Omega \cdot$m
Sodium	80	0,79	115,5	$82 \cdot 10^{-8}$
	100	1,15	137,1	81
	200	2,89	194,1	73
	300	4,93	214,5	77
	350	6,23	223,8	80
Gold	50	0,199	22,9	$171 \cdot 10^{-8}$
	200	1,44	39,9	179
	500	3,95	45,0	176
	1000	8,96	53,1	174
	1300	12,83	59,7	172
Magnesium	40	0,068	9,18	$182 \cdot 10^{-8}$
	100	0,902	46,1	192
	200	3,74	68,4	198
	400	6,18	81,9	189
	600	9,51	93,0	174
Indium	70	1,60	68,2	$33 \cdot 10^{-7}$
	100	2,45	76,5	32
	200	5,45	82,5	33
	300	9,00	90,9	33
	400	13,5	116,4	29
Lead	113	7,43	77,1	$84 \cdot 10^{-7}$
	303	22,0	85,5	85
	400	30,4	88,9	86
	500	39,7	95,2	84
	600	49,8	103,5	82
Tungsten	40	0,0664	1,2	$138 \cdot 10^{-7}$
	100	1,027	6,9	149
	600	13,14	14,1	155
	1400	37,26	15,9	169
	2200	63,80	20,1	148

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 41, No. 4, pp. 717-719, October, 1981. Original article submitted August 25, 1980.

0022-0841/81/4104-1153$07.50

By this it is possible to determine a simple relation for the temperature interval from ~0°K to the phase-transition temperature:

$$\rho/\alpha_V T = \rho^* = \text{const}, \tag{1}$$

where ρ is the difference between the measured and residual electrical resistance value ρ_0 and ρ^* is a constant characteristic of each metal. The scatter in the data obtained with formula (1) from their mean value is generally determined by the inaccuracy in the quantity α_V (5-10%). Data corresponding to metals representing different groups are shown in Table 1.

A rule analogous to (1) is valid for liquid metals also.

A definite correlation was observed between the quantity ρ^*, which has the dimensions of electrical resistivity, and the resistivity at the melting point ρ_m:

$$\rho^* = A\rho_m, \tag{2}$$

where A is a constant for practically all metals.

Possible practical applications of the given laws include: first, the determination of α by formula (1) based upon electrical resistivity data, i.e., upon a quantity more easily and precisely measured in the region inaccessible for investigating α; and second, the determination of α and ρ when one of these quantities is known and the determination of ρ_m from formula (2). Moreover, the deviation from formula (1) at low temperatures may serve as an indication of the purity of the metals.

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