SURFACE ENERGY AND SURFACE TENSION OF SOLID AND LIQUID METALS. RECOMMENDED VALUES

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ABSTRACT

In this work the experimental surface energy (SE) and surface tension (ST) values and their temperature coefficients for twenty three pure solid and forty eight pure liquid metals are presented. Error in the measuring SE and ST for solids was less than 2 %, and that for liquids and the temperature coefficients was about 0.5 %. and 8 %, respectively. High purity metals (99.999 % of the basic elements) have been used. The measurements have been carried out either under high vacuum conditions or in inert gas atmosphere when the thermodynamic equilibrium was achieved.
An analysis of data for SE and ST obtained during the last thirty years has been made. The recommended values of ST of metals are presented in a Table.

INTRODUCTION

The specific free surface energy f_ω and the surface tension σ are the basic characteristics of a transition layer between phases. The surface tension σ is the isochoric - isothermal work of formation of unit area of a new surface. The relation between the ST and SE is

$$\sigma = f_\omega + \omega\left(\frac{\partial f_\omega}{\partial \omega}\right)_{T,V} + \sum_j \mu_j \Gamma_j, \qquad (1)$$

where μ_j is the chemical potential, Γ_j is the adsorption of the j-th component, ω is the area of surface. As the formed new surface is identical to the original one for liquids and polycrystals, then $\partial f_\omega / \partial \omega = 0$ and

$$\sigma = f_\omega + \sum_j \mu_j \Gamma_j \qquad (2)$$

For one - component system when Γ_j=0, equation (2) takes the form $\sigma = f_\omega$, i.e. only in this case the ST is numerically equal to f_ω.
At present several reliable experimental methods have been developed for accurate measurement of SE and ST in the liquid state. There are many methods of investigation of the ST and SE for the solid state [1], however, truly reliable

values of the ST of metals may be obtained by various versions of the "zero-creep" method in the temperature range $(0.8 \div 0.9) T_m$, where T_m is the melting point.

In this work the experimental results of the ST and their temperature coefficients for twenty three pure solid metals by the compensation version of the "zero-creep" method [1-3] and forty eight liquid metals by the sessile-drop profile method [4,5] are presented.

THE COMPENSATED "ZERO-CREEP" METHOD

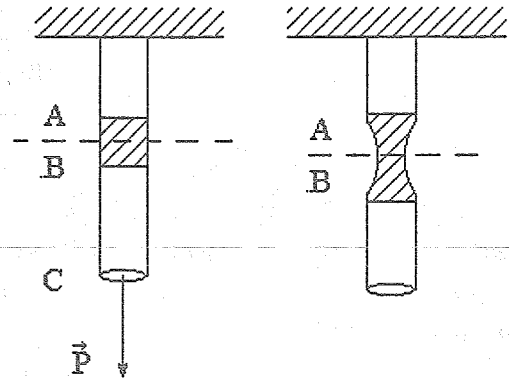

Fig. The compensated "zero-creep" method

The principle of the compensation version of the "zero-creep" method is the following. The sample of the metal in the form of a thin wire was suspended by one of its ends (Fig.). A small part of the sample AB was heated up to 0.95 T_m in a cylindrical gradient furnace. At 0.95 T_m a creep of the metal with an appreciable rate was observed. Then, the surface tension forces compresses this part of the sample, transforming the cylindrical shape of the last into the spherical shape with a minimum surface area at constant volume. The latter was compressed (shortened) when $P<P_0$, and was stretched (lengthened) when $P>P_0$, where P_0 is the external force, which compensates for the surface tension force. At $P=P_0$ the creep rate becomes equal to zero, then, the surface tension $\sigma = P_0/\pi r$, where r is the radius of the sample.

If in the experiment $P<P_0$ is obtained, then, it is necessary to add a force f to the stretching force P, which enables to compensate the surface tension force, i.e. $P+f= P_0$. The value of P was measured by weighing the lower part of the sample, which was cut off at 0.98 T_m in the above mentioned small part of the sample (AB), resulting in forming a narrow neck (Fig., b). To measure f a few methods were proposed. The most reliable way is by using a beam scales together with a moving light spot fixing the coming of the zero-creep on the screen.

In Table 1 the experimental results on the Sn wires are presented. It is shown, that the reproducibility of the results is good, the errors are less than 2 %.

Table 1

№ of the experiences	1	2	3	4	5	6	Average
$r \cdot 10^3$, m	0.34	0.25	0.18	0.20	0.29	0.32	-
P, mN	0.2489	0.1637	0.1196	0.1392	0.3440	03626	-
f, mN	0.4779	0.3589	0.2576	0.2818	0.2752	0.3186	-
σ, mN/m	680.8	665.7	667.4	670.4	680.0	678.0	672.1±7.7

RESULTS

A careful analysis of SE and ST values obtained by other authors has been made, taking into account the reliability of the used method, the purity of metals and the achievement of the thermodynamic equilibrium condition, reproductibility and reliability of the results and comparision of the experimental data with the results of the theoretical calculations.

This analysis showed that, the most reliable data for ST of solids have been obtained mainly by the compensated "zero-creep" method, elaborated in Kabardino-Balkarian State University [2,3].

The Recommended values of surface tension σ and its temperature coefficients β for solid (σ_s, β_s) and liquid (σ_l, β_l) metals at the melting point are given in Table 2.

Table2

№	Me	σ_ℓ, $\frac{mN}{m}$	$-\beta_\ell$, $\frac{mN}{m \cdot K}$	Ref.	σ_s, $\frac{mN}{m}$	$-\beta_s$, $\frac{mN}{m \cdot K}$	Ref.	$\frac{\sigma_s}{\sigma_\ell}$
1.	Ag	920	0.125	11	1155	0.4	7	1.26
2.	Al	914	0.142	11	1140	-	9	1.26
3.	Au	1170	0.10	10	1363	0.5	7	1.20
4.	Bi	390	0.077	10	500	0.05	7	1.33
5.	Ce	707	0.08	10	-	-		-
6.	Cs	75	0.050	13	-	-		-
7.	Cd	627	0.080	11	672	0.10	1	1.07
8.	β-Co	1830	0.34	10	2404	0.17	7	1.31
9.	Cr	1640	-	10	2066	0.14	7	1.25
10.	Cu	1350	0.24	11	1473	0.5	7	1.09
11.	Dy	648	0.13	10	-	-		-
12.	Er	637	0.12	10	-	-		-
13.	Eu	264	0.05	10	-	-		-

№	Me	σ_ℓ, $\frac{mN}{m}$	$-\beta_\ell$, $\frac{mN}{m \cdot K}$	Ref.	σ_s, $\frac{mN}{m}$	$-\beta_s$, $\frac{mN}{m \cdot K}$	Ref.	$\frac{\sigma_s}{\sigma_\ell}$
14.	δ-Fe	1856	0.23	10	2040	-	12	1.10
15.	γ-Fe	1856	0.23	10	2170	-	14	1.11
16.	Ga	714	0.088	11	766	0.08	1	1.07
17.	Gd	664	0.06	10	-	-		-
18.	Ge	605	0.105	10	-	-		-
19.	Hg	497	0.28	11	-	-		-
20.	Ho	650	0.12	10	-	-		-
21.	In	565	0.09	11	631	0.12	6	1.12
22.	K	116	0.06	13	-	-		-
23.	La	729	0.10	10	-	-		-
24.	Li	419	0.15	13	-	-		-
25.	Lu	940	0.07	10	-	-		-
26.	Mg	588	0.18	10	-	-		-
27.	Mo	2225	-	10	2582	0.18	7	1.16
28.	Na	205	0.09	13	-	-		-
29.	Nb	2010	-	10	2150	0.17	7	1.07
30.	Nd	685	0.09	10	-	-		-
31.	Ni	1770	0.39	10	1920	0.5	7	1.08
32.	Pb	470	0.08	10	557	0.21	6	1.22
33.	Pd	1475	0.28	11	-	-		-
34.	Pr	690	0.07	10	-	-		-
35.	Pt	1746	0.37	11	1940	0.13	7	1.11
36.	Rb	96	0.05	13	-	-		-
37.	Sb	380	0.07	10	-	-		-
38.	Sc	939	0.12	10	-	-		-
39.	Si	746	0.15	11	-	-		-
40.	Sn	544	0.08	11	671	0.13	6	1.23
41.	Ta	2140	0.25	10	2414	0.17	7	1.13
42.	Tb	669	0.06	10	-	-		-
43.	Ti	1650	0.30	15	1938	-	16	1.17
44.	Tl	458	0.11	11	555	0.22	6	1.21
45.	V	1857	-	11	1925	0.12	7	1.04
46.	W	2316	-	11	2653	0.17	7	1.15
47.	Y	872	0.09	10	-	-		-
48.	Yb	319	0.10	10	-	-		-
49.	Zn	821	0.26	11	863	0.21	1	1.05

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