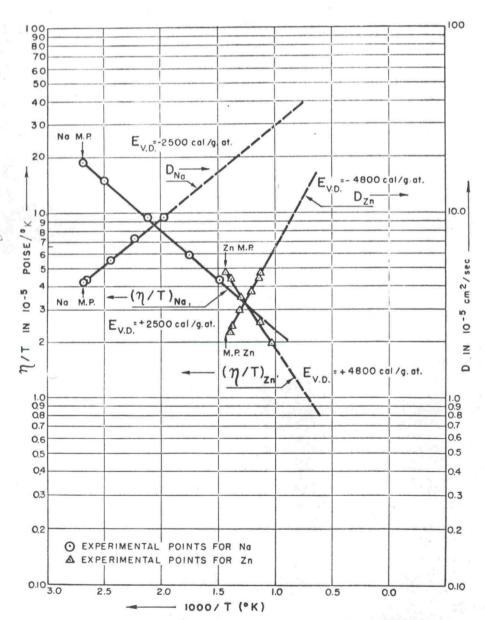
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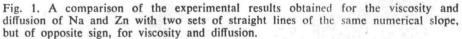
Viscosity and Self-Diffusion of Liquid Metals

Abstract. It is demonstrated that the empirical relationship between activation energy of viscosity and the melting point of a metal is also true for the energy of self-diffusion, in view of the Stokes-Einstein relation. The provision is that viscosity and self-diffusion be expressed in a self-consistent manner, as provided, for example, by the J. Frenkel's theory of liquids. Thus, one can now estimate either the viscosity or the self-diffusion of any metal over a substantial temperature range from its known melting point.

A few years ago (1, 2) we drew attention to the empirical fact that the activation energy of viscosity, H_{η} , of metals is a straight line function of their melting points, T_{mp} , when plotted on a log-log graph (see 1, p. 788, Fig. 9).

Self-diffusion, D, is directly related to viscosity, η , by means of the Stokes-





Einstein relation (in its Eyring version):

$$\eta D = \frac{kT}{6\delta} \tag{1}$$

where T is the temperature in deg K, k is the Boltzman constant, and $\delta = (V_{\rm at}/N_{\rm avog})^{1/3}$, $V_{\rm at}$ being the atomic volume and $N_{\rm avog}$, Avogadro's number. It therefore follows that the above empirical relationship should also hold between the activation energy for selfdiffusion (2) and the T_{mp} of the metal, since the two energies are equal except in sign, and provided both η and D are expressed in a self-consistent manner.

If the simplest form of theory of liquids is used, namely, Frenkel's kinetic theory (3)

$$\eta = B T e^{-\gamma} e^{+R_{\rm VD}/RT}$$
 (2)

and

and

$$D = D_0 e^{\gamma} e^{-R_{\rm VD}/RT} \tag{3}$$

where B, D_0 and γ are constants, E_{VV} is the activation energy for both viscosity and diffusion (in cal/g-atom) and R is the gas constant; η is the viscosity (in poises), D in cm²/sec. It follows further from Frenkel's theory that the constants B and D_0 can be calculated for any metal from the expressions

$$B = h N_{\rm avog} / \theta_{\rm D} V_{\rm at} \tag{4}$$

$$D_0 = (k/6 h N_{\text{avog}^{2/3}}) \theta_D V_{\text{at}^{2/3}}$$
(5)

where h is Plank's constant, $\theta_{\rm D}$ and $V_{\rm at}$ are the Debye temperature in deg K and the liquid atomic volume of the metal (at the melting point), respectively. Thus defined, it is evident that the product ηD gives the Stokes-Einstein relation. The Frenkel factor $e^{-\gamma}$ (or its reciprocal e^{γ}) is close to unity and for the moment may be considered as an adjustment of $B_{\rm exptl}/B_{\rm theor}$ (or $e^{\gamma} = D_{\rm o}^{\rm exptl}/D_{\rm o}^{\rm theor}$) for each metal; it can be considered as the entropy of $E_{\rm VD}$.

The activation energy for viscosity or self-diffusion—that is, $E_{\rm VD}$ (in cal/ g-atom) is, like H_{η} (1, 2), a straight line function of the melting point of the metal, $T_{\rm mp}$, (in deg K) on a log-log graph and may be expressed as

$$E_{\rm VD} = 3.53 \ T_{\rm mp}^{1.10} \tag{6}$$

The E_{vD} here differs from our original H_{η} (1, 2) and is equal to:

$$E_{\rm VD} = H\eta \left[\frac{\ln \left(\frac{\eta_1/T_1}{\eta_2/T_2} \right)}{\ln \left(\eta_1/\eta_2 \right)} \right],\tag{7}$$

if η_1 and η_2 are the viscosities at temperatures T_1 and T_2 .

The above formulas obviously are not exact for an infinite temperature range. They are functions of T only, whereas actually the volume of the liquid metal is also a variable, since it expands—or the number of atoms per cubic centimeter decreases—although slowly, with temperature. Thus, they cover practically a range of about 500°K from the melting point upward,