

where the thermodynamic potential  $\zeta$  is seen to increase with pressure and decrease with tension at the stressed face. The melting point at the free face is depressed for both compression and tension. Here  $(\psi_0)_{FF} = (\zeta)_{FF}$  always increases. The ratio of lowering at the two faces is the same as that found for (9a) and (9b).

The number of atoms with Maxwellian energies in excess of that needed to break the lattice bonds, i.e., the number of free migrating atoms, increases with increase in temperature. At the melting point this fraction of the total number becomes unity. The factor

$$\theta = T/T_m, \quad (13)$$

where  $T$  denotes the constant experimental and  $T_m$  the melting temperature, has been used in correlating temperature *versus* creep data for different metals. The behavior of a low melting point metal is thus considered as equivalent in behavior to a high melting point metal at a correspondingly higher temperature to give the same  $\theta$ , other factors remaining unchanged. The argument should be carried out in terms of energy but, as compensation is here effected through the  $h$  term this expression is a sufficiently satisfactory approximation.

On combining (12a) and (13) and integrating we have

$$\pi - \pi_0 = \rho h \ln(\theta/\theta_0), \quad (14)$$

where  $\rho$  and  $h$  are here the mean values over the range of integration.

For a sufficiently large load, i.e., for relatively large creep rates, we may in the same manner as before write

$$\pi - \pi_0 = K' \ln(\dot{\epsilon}_s/\dot{\epsilon}_0), \quad (15)$$

where  $K'$  is a physical constant and  $\dot{\epsilon}_s$  the steady state or minimum creep rate. This is the expression that has been used for about thirty years to express the empirical relation between yield stress and minimum creep rate  $\dot{\epsilon}_s$  in metal mosaics.

The expressions (12) and (15) were derived for relatively large creep rates and thus for compressive loads large enough to iron out the initial inequalities over a short period of time. Let us assume now that we are operating with either very small stresses or with a substance that does

not "migrate" readily. For these conditions the number of migrating units will be relatively few and their paths much shorter. Thus, instead of being able to picture a statistical streaming action, we are slowed down to a hop-skip process and can no longer set up a steady mean flow. The crystallization process must be explicitly considered here and for these cases we have for mobility along the stressed surfaces.

$$K(\theta/\theta_0) = K e^{(\pi - \pi_0) / \rho h} \quad (16a)$$

and for crystallization along the same surfaces

$$K(\theta_0/\theta) = K e^{-(\pi - \pi_0) / \rho h}. \quad (16b)$$

The creep rate will be given by the difference between these two quantities or

$$(\dot{\epsilon}/\dot{\epsilon}_0) = K \sinh \frac{\pi - \pi_0}{\rho h}. \quad (17)$$

The same reasoning and therefore a similar sinh expression also replaces (12) for very small creep rates.

An expression of this type was obtained empirically<sup>14</sup> by combining analytically the empirical logarithmic relation for high creep rates (see Eq. (15)) with the linear relation between stress and creep rate observed for very low creep rates.

So far we have considered only the relation between steady creep rate and stress. When compressive load is first applied the irregularities in the structure of the polycrystalline material set up an initial localization of stress at the raised points and thus, for large enough loads, in an initially high creep rate. This rate gradually diminishes toward a steady state as the original inhomogeneities of texture become ironed out and the stress redistributes itself over larger and larger surface areas. The effective stress, for constant load, thus decreases with time. Finally the pore spaces in the texture become filled and the grains more or less reoriented into their most stable crystallographic configuration for an axial load distribution. If now a series of such creep-time tests is made for varying compressive loads on initially identical specimens this last state should be reached at

<sup>14</sup> For example see H. Mussmann, Ann. d. Physik 31, 130 (1938).