In certain electrochemical problems, for example, the illustrative example of the first communication[1], the consideration of individual barrier potential differences and of the chemical potentials of individual ions may be required. Since these cannot be measured, it is general practice to adopt conventional values. These are based upon the 'hydrogen scale', which takes the potential of the standard hydrogen electrode as zero, ignores metal–metal contact potentials, and attempts when necessary to eliminate liquid-junction potentials by means of salt bridges. So far as these conventional values are precise, they must be thermodynamically consistent, and in particular they must satisfy the conditions of equilibrium described above. The individual potential differences mentioned in my first communication[1] are to be understood as conventional values of this kind, since the metal–metal contact potential difference was not mentioned.

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[1] *Nature*, **165**, 934 (1950).
[2] *Nature*, [**166**, 962 (1950).]

Transient Creep in Pure Metals

WHEN an annealed pure metal is loaded beyond the yield point, the deformation continues after the load is applied. The strain/time graph is called the creep curve. At constant stress Andrade[1] has shown it consists of the strain on loading, followed by decelerating or transient creep and finally steady-rate creep. Meissner, Polanyi and Schmid[2] have observed transient creep at the lowest temperatures; steady-rate creep occurs only at high temperatures.

Andrade[1,3] and others[4,5] have found the transient creep curve to fit

$$\varepsilon = \beta t^{1/3} + c_1. \tag{1}$$

But Phillips[6] and others[7,8] have used

$$\varepsilon = \alpha \log t + c_2. \tag{2}$$

I have measured creep curves at constant stress using a new machine with pneumatic loading and continuous strain recording. The load could be applied rapidly and readings taken within a second of loading. A high sensitivity to strain (2×10^{-5}) combined with a large strain range (10 per cent) permitted measurements over a wide range of stresses and temperatures ($-196°$ C. to $170°$ C.). I have tested polycrystalline copper, aluminium and cadmium; and also aluminium with only a few grains per specimen.

I find for each metal that at low temperatures the creep curve is given by equation 2 and at higher temperatures by equation 1. In an intermediate range of temperature, which is lower for higher stress, the creep curve fits

$$\varepsilon = \alpha \log t + \beta t^{1/3} + c_3. \tag{3}$$

The transition from equation 1 to equation 3 with copper is shown in Fig. 1. At the lower temperatures, the strain/log(time) curve is approximately linear. At higher temperatures it becomes concave upwards, especially at later times. If the α-component given by a tangent to the first part of the curve is subtracted from the total strain, the difference is linear with $(t)^{1/3}$, as shown in Fig. 2.
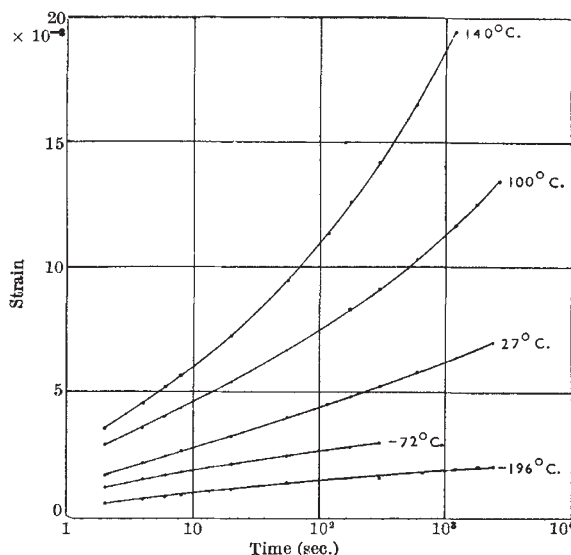

Fig. 1. Creep of copper at 18 kgm./mm.^{2} at various temperatures. The total strain at 2 sec., from the top curve to the bottom, is : 116, 99, 86, 72 and 60

Theories have been given by Orowan[9] and Smith[10] which give equations 1 and 2 respectively. Orowan[9] and Los showed experimentally that pure metals do not obey a mechanical equation of state, that is $F(\sigma, \varepsilon, \dot{\varepsilon}, T) = 0$, and Orowan claimed his theory avoided one.

I have altered the stress by small amounts at various times during a creep curve and also changed the temperature between tests on one specimen at increasing stresses. I find that when α-flow alone is present, an equation of state is obeyed; but this fails when β-flow occurs.
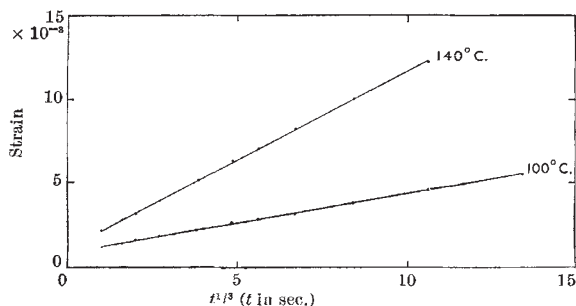

Fig. 2. β-Component of creep curves in Fig. 1

This has led to a theory of α transient creep in which Smith's exhaustion theory is applied to a strain-hardening material; an equation of state is implicit. β-flow is not yet fully understood, but it seems to be connected with recovery rather than strain hardening as suggested by Orowan.

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[1] Andrade, E. N. da C., *Proc. Roy. Soc.*, A, **84**, 1 (1910).
[2] Meissner, W., Polanyi, M., and Schmid, E., *Z. Phys.*, **66**, 477 (1930).
[3] Andrade, E. N. da C., *Proc. Roy. Soc.*, A, **90**, 329 (1914).
[4] Andrade, E. N. da C., and Chalmers, B., *Proc. Roy. Soc.*, A, **138**, 348 (1932).
[5] Cottrell, A. H., and Aytekin, V., *J. Inst. Metals*, **77**, 389 (1950).
[6] Phillips, F., *Phil. Mag.*, **9**, 513 (1905).
[7] Chevenard, P., *Rev. de Metall.*, **31**, 473 (1934).
[8] Laurent, P., and Eudier, M., *Rev. de Metall.*, **47**, 39 (1950).
[9] Orowan, E., *West of Scotland Iron and Steel Inst.* (1947).
[10] Smith, C. L., *Proc. Phys. Soc.*, **61**, 201 (1948).