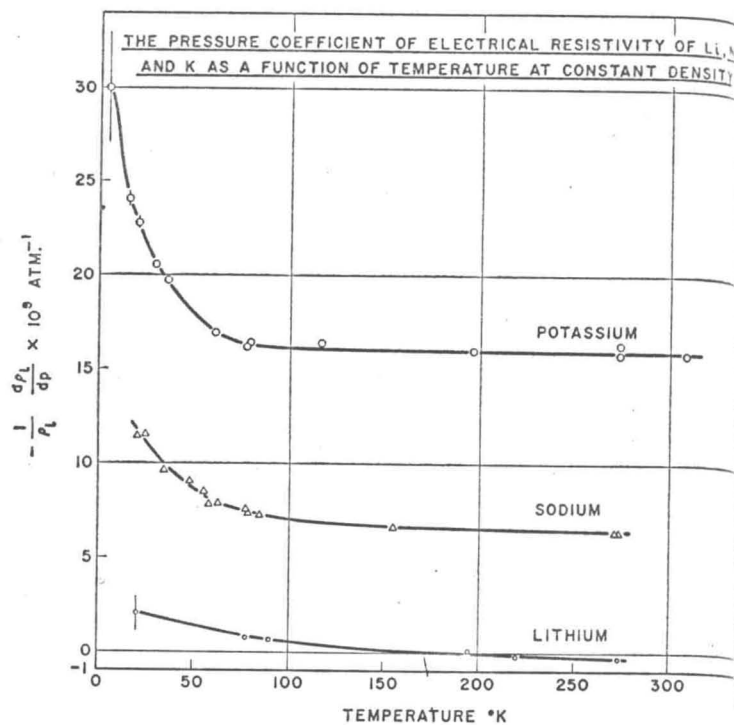


Fig. 1 (left). The electrical resistivity of potassium as a function of temperature. The solid line shows the resistivity at a fixed volume (that at 0°K under zero pressure); this is the quantity which is most convenient for direct comparison with theory. Fig. 1 (right). The pressure coefficient of electrical resistivity of lithium, sodium, and potassium as a function of temperature at constant density (13).



volume) in terms of readily observable quantities.

Considerations of this kind can also be applied to the discussion of the pressure dependence of the electrical resistivity of metals, but first I must describe briefly how this resistivity depends on the temperature (5). It is convenient to distinguish between two sources of electrical resistivity: (i) a temperature-dependent part  $\rho_i$  (the ideal resistivity), due to the thermal vibrations of the lattice, which vanishes as the temperature approaches zero, and (ii) a temperature-independent part  $\rho_0$  (the residual resistivity), which is due to chemical and physical imperfections in the lattice.

In a perfectly periodic lattice the conduction electrons can move without hindrance; that is to say, the electrical resistance of the metal is then zero. If physical imperfections or chemical impurities are introduced into the lattice, these will then upset the perfect periodicity and cause electrical resistance by scattering the electrons when they are accelerated by an electric field. If, in addition, the lattice temperature is raised so that thermal vibrations of the ions begin, these vibrations also contribute to the electrical resistance. The part of the resistance caused by the lattice vibrations may be thought of as approximately proportional to the mean square amplitude of vibration of the

ions. If the mass of the ions is  $M$ , their characteristic vibrational frequency is  $\omega$ , and their amplitude of vibration is  $x$ , then at a high temperature  $T$

$$M\omega^2 \bar{x}^2 = kT$$

by the classical theorem of the equipartition of energy. Therefore, by introducing a characteristic temperature  $\theta$  such that  $\hbar\omega = k\theta$ ,

$$\bar{x}^2 = \frac{\hbar^2}{k} \frac{T}{M\theta^2}$$

and the resistivity due to thermal vibrations,  $\rho_i$ , is proportional to  $T/M\theta^2$ . At the lowest temperatures  $\rho_i$  is no longer proportional to the mean square amplitude of the lattice vibrations because at these temperatures the lattice waves are less efficient in scattering electrons; in fact,  $\rho_i \propto T^5/\theta^6$  in this temperature region. In quantum language, it is usual to discuss the scattering of electrons by lattice waves in terms of "phonons." A phonon is a quantum of lattice energy analogous to the photon in electromagnetic radiation. The total number of phonons in the lattice varies as  $T$  at high temperatures and as  $T^3$  at low temperatures. The temperature dependence of the number of phonons largely determines the temperature dependence of the ideal resistivity. At low temperatures, however, the "momen-

tum" of the phonons falls off and the resistivity, as indicated above, falls off as  $T^5$ —that is, more rapidly than the number of phonons. Figure 1 illustrates the temperature dependence of the electrical resistivity of a typical monovalent metal, potassium:

If the effect of pressure on the ideal electrical resistivity arises solely from the change produced in  $\theta$ , we should expect that at high temperatures

$$\frac{d \ln \rho_i}{dp} = - \frac{2d \ln \theta}{dp}$$

and at low temperatures

$$\frac{d \ln \rho_i}{dp} = - \frac{6d \ln \theta}{dp}$$

Since  $\theta$  increases with pressure, we expect that at once that as far as the lattice contribution is concerned the effect of pressure is to diminish the electrical resistivity (6). Moreover we see that the pressure coefficient of ideal resistivity at low temperatures should be three times that at high temperatures. Figure 2 shows how the pressure coefficient of resistivity of lithium, sodium, potassium, and copper varies with temperature. The temperature dependence is of the general form to be expected. Note, however, that in lithium the pressure coefficient at high temperatures is anomalous, being positive.