In more general terms, there are theoretical grounds for believing that

$$\rho_i = \frac{K}{T} f(T/\theta_R)$$

where K measures the interaction between the conduction electrons and the lattice vibrations and θ_R is a temperature characteristic of the resistive properties of the lattice [1]. (The results I have already quoted are simply special cases of this, indicating that at high temperatures $f(T/\theta_R)$ approaches T^2/θ_R^2, and at low temperatures, T^6/θ_R^6.) This relationship means that the product $\rho_i T$ is a function of a reduced temperature τ equal to T/θ_R, and we may expect, by analogy with the behavior of the thermodynamic properties of the lattice, to relate the pressure coefficient of electrical resistivity at a given temperature with the temperature coefficient of electrical resistivity at that temperature. In theoretical considerations it is more logical to work in terms of volume coefficients; in these terms the relationship is as follows [6]:

$$\frac{d \ln \rho_i}{d \ln V} = \frac{d \ln K}{d \ln V} - \frac{d \ln \theta_R}{d \ln V}\left(1 + \frac{d \ln \rho_i}{d \ln T}\right) \quad (6)$$

The term $d \ln K/d \ln V$, which depends on the properties of the conduction electrons and on the static lattice, should be effectively independent of temperature at normal and low temperatures, as is also the term $d \ln \theta_R/d \ln V$. This relationship, therefore, tells us that the volume coefficient and the temperature coefficient of the ideal resistivity are linearly related; this in turn means that $d \ln \rho_i/d \ln V$ will change with temperature only at temperatures at which $d \ln \rho_i/d \ln T$ itself changes. This conclusion explains why we must make measurements at low temperatures if we wish to find any temperature variation of the pressure dependence of electrical resistivity, since a glance at Fig. 1 shows that only at low temperatures does the temperature coefficient of resistance change significantly.

Equation 6 means that if we measure the pressure and temperature coefficients over a suitable temperature range we can determine $d \ln \theta_R/d \ln V$ and $d \ln K/d \ln V$ separately, in this way distinguishing the lattice contribution to the pressure coefficient from the contribution of the electron properties. Before comparing the experimental results with these theoretical predictions I should like to say something about the experimental methods.

Hydrostatic Pressure at Low Temperatures

The application of hydrostatic pressure at low temperatures [7] presents a problem because all substances become solid under pressure at these temperatures; at pressures above about 30 atmospheres there are no true fluids at the lowest temperatures. The substance which retains its fluid properties at a given pressure to the lowest temperature is helium (the He³ isotope is very slightly, though for our purposes not significantly, better than the He⁴ isotope in this respect). For that reason, and also because solid helium can be used to produce an effectively hydrostatic pressure, we have used this substance as our pressure transmitting medium [8, 9]. Other solids can of course be used for this purpose [Hatton [10] used solid hydrogen], and for some purposes the solid to be studied can act as its own pressure medium; that is to say, the metal is directly compressed in a cylinder by a piston without any intervening substance (see [11]).

In Fig. 3 is shown part of the melting curve of He⁴ [12]. Points to the right of and below this curve correspond to the fluid phase, and as long as we are using this phase the application of pressure is quite straightforward. To understand how pressures and temperatures corresponding to the solid phase are produced, we must know something of the equation of state of the solid. This information is also indicated in Fig. 3, in which it is shown how the pressure in the solid varies with temperature at various fixed volumes [12]. It may be seen that at constant volume the pressure in the solid is not very dependent on the temperature; this is because in solid helium most of the pressure arises from the vigorous zero-point motion of the helium atoms and is thus independent of the temperature (incidentally, it is this strong zero-point motion which makes liquid helium the stable phase at 0°K at normal pressures).

Our technique of applying high pressures in the solid state can be described as a constant-volume method. The pressure is first applied at such a temperature that the helium is still just fluid—that is, at a temperature close to, but to the right of, the melting curve shown in Fig. 3. The high-pressure bomb is then closed off so that the helium is kept effectively at constant volume, and it is then cooled to the required low temperature. In this process, in which the helium becomes solid, about one-quarter of the applied pressure is lost. However, the pressure existing in the bomb in the final state can be deduced from a knowledge of the initial density (which is also of course the final density) and the final temperature. Our measurements have
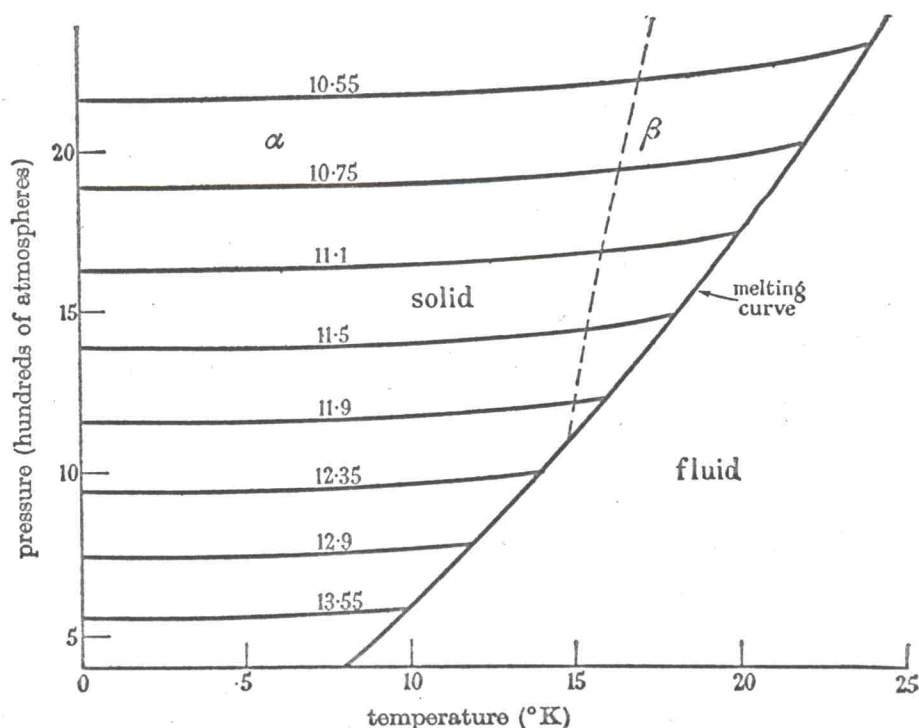

Fig. 3. Part of the melting curve of He⁴ and the lines of constant volume in the solid. The figures give the corresponding molar volume in cubic centimeters. [After Dugdale and Simon (12)]