the net effect of the potential is to cause the electrons to drift through the lattice at a speed, u_{el}, that is governed by the field intensity, $|\bar{E}|$, and the collision frequency, $\tau_{c,F}$. As described by Newton's third law, the relationship is $|\bar{F}_{el}| = e|\bar{E}| = m_e^* |\bar{a}_{el}| = m_e^* u_{el}/\tau_{c,F}$, where the electron acceleration is expressed as a ratio of the drift velocity and the mean free time. The current density can also be described in terms of the drift velocity (as well as the free electron number density and the electron charge) $i'' = n_{v,el} e u_{el}$. This permits one to eliminate the drift velocity between these two expressions. The result is an expression in the form of *Ohm's Law* that allows the *electrical conductivity*, σ_{el}, to be determined.

$$i'' = \sigma_{el}|\bar{E}| = \left(\frac{n_{v,el} e^2 \tau_{c,F}}{m_e^*}\right)|\bar{E}| \quad \text{or} \quad \sigma_{el} = \frac{n_e N_A \rho e^2 \tau_{c,F}}{m_e^* M V_F} \qquad \text{(IIIE-24a, 24b)}$$

We have expressed the electrical conductivity in terms of the free electron mean free path. This is the only variable in eqn. IIIE-24b. Thus the temperature dependence of σ_{el} can be deduced from our earlier discussion of free electron collision processes as they related to K_{el}, Fig. IIIE-6.

<u>The temperature dependence of</u> σ_{el} is governed by $\lambda_{c,F}$. In the <u>*high temperature region*</u>, $T > \theta_D$, free electron collisions are dominated by electron-phonon interactions, $\lambda_{c,F} \simeq \lambda_{c,el-phn} \propto 1/n_{v,phn} \propto 1/T$. Thus,

$$\sigma_{el}(T > \theta_D) \propto \frac{1}{T}$$

In the <u>*low temperature region*</u>, $T << \theta_D$, the phonon density is sufficiently reduced that $\lambda_{c,el-phn} \simeq \lambda_{c,el-def} = \delta L$. Thus at low temperatures metallic electrical resistance becomes constant

$$\sigma_{el} \Rightarrow \sigma_{el,o} \propto T^o$$

The temperature level at which the transition from phonon to defect scattering occurs is heavily dependent on the purity and condition (annealing, cold working, etc.) of the conductor.

The analogy between electrical conductivity and the *free electron component* of thermal conductivity in metals can be expressed in an analytic form.

<u>Ans. 19</u>. (a) Aluminum transmission cables will be at temperatures slightly above those of environment. Thus, $\theta_{D,Al} = 396$ K $> T_o$. In this excellent conductor, the thermal conductivity will have a slight negative slope. Constant K analysis should be satisfactory. (b) $\theta_{D,Cu} = 315$ K. The copper wire's temperature varies from low to intermediate. The slope of K(T) will be negative throughout. Variable K(T) analysis is essential to achieve a reasonable solution in this situation. (c) Silicon rectifiers ($\theta_D = 658$ K) are at temperatures slightly above their environment. Assuming an environment near 300 K, K(T) is significantly variable with negative slope. Over the narrow temperature span within the material constant K analysis should be satisfactory. (d) Iron, Chrome, and Nickel are the principal components in stainless steel. Thus, $\theta_D \sim 450$ K. At the elevated temperatures of operation, K should be constant. (e) Diamond has a high Debye temperature, 1860 K. Even at high cutting temperatures, $T < \theta_D$. K(T) will have a negative slope.