Free electron theory successfully accounts for a wide range of metallic properties. In the form originally put forth by Drude the most striking deficiencies of the model were due to the use of classical statistical mechanics in describing the conduction electrons. As a result, predicted thermoelectric fields and heat capacities were hundreds of times too large, even at room temperature. The difficulty was obscured by the fact that classical statistics fortuitously gave a form for the Wiedemann-Franz law that was not in such gross error. Sommerfeld's application of Fermi-Dirac statistics to the conduction electrons eliminated this class of difficulties while retaining all of the other basic assumptions of the free electron model.

However, the Sommerfeld free electron model still makes many quantitative predictions that are quite unambiguously contradicted by observation, and leaves many fundamental questions of principle unresolved. We list below those inadequacies of the free electron model that have emerged from the applications made in the preceding two chapters.[1]

DIFFICULTIES WITH THE FREE ELECTRON MODEL

1. Inadequacies in the Free Electron Transport Coefficients

(a) ***The Hall Coefficient*** Free electron theory predicts a Hall coefficient which at metallic densities of electrons has the constant value $R_H = -1/nec$, independent of the temperature, the relaxation time, or the strength of the magnetic field. Although observed Hall coefficients have this order of magnitude, generally speaking they depend on both the magnetic field strength and the temperature (and presumably on the relaxation time, which is rather harder to control experimentally). Often this dependence is quite dramatic. In aluminum, for example, R_H (see Figure 1.4) never gets within a factor of three of the free electron value, depends strongly on the strength of the field, and at high fields does not even have the sign predicted by free electron theory. Such cases are not atypical. Only the Hall coefficients of the alkali metals come even close to behaving in accordance with the predictions of free electron theory.

(b) ***The Magnetoresistance*** Free electron theory predicts that the resistance of a wire perpendicular to a uniform magnetic field should not depend on the strength of the field. In almost all cases it does. In some cases (notably the noble metals, copper, silver, and gold) it can be made to increase apparently without limit as the field increases. In most metals the behavior of the resistance in a field depends quite drastically on the manner in which the metallic specimen is prepared and, for suitable specimens, on the orientation of the specimen with respect to the field.

---

[1] These examples and the remarks making up the rest of this brief chapter are not intended to give a detailed picture of the limitations of the free electron model. That will emerge in the chapters that follow, together with the solutions to the difficulties posed by the model. Our purpose in this chapter is only to emphasize how varied and extensive the shortcomings are, thereby indicating why one must resort to a considerably more elaborate analysis.