than that of phonons, $V_F >> c_s$, that K_{el} dominates the conductivity of good electrical conductors by one and a half to two orders of magnitude. In alloyed materials and poor conductors the ratio is much less and the two contributions may be comparable.

Exercise 19. The following are illustrations of material applications in which the consideration of heat conduction is an essential element in design: (a) aluminum wire for long distance electrical transmission; (b) copper lead wires to a superconducting magnet (these span the temperature range from the $\sim$10 K magnet to the 300 K supply); (c) silicon rectifier; (d) the stainless steel tubes of steam boiler; (e) synthetic diamonds used as the cutting edge on a high-speed cutting tool. We are to make a decision based on engineering judgement whether their respective thermal conductivities could be considered constant or must they be treated as a variable for accurate engineering design. If variable conductivity analysis is necessary, will K(T) have a positive or negative slope?

The second transport process that is of great significance in solids is charge transport. To be a conductor a crystal must contain electrons that are not bound to specific points within the crystal-free electrons. Whether a specific solid is an insulator, conductor, or semiconductor can be discussed in terms of the *band theory* for the electrons of a solid.

Consider the formation of an atomic lattice point solid. The Bohr model for the atom specifies that the states accessible to the electrons are located on spheres of increasing radii (the successively higher energy shells, levels, have 2, 8, 18, etc., states). As these atoms are packed into a crystal, their electron interactions cause a slight shift in the magnitude of the states giving rise to an almost continuous *"band"* of accessible states clustered around the still discrete Bohr levels, see Fig. IIIE-5. We will examine this model to distinguish the electrical properties of solids.

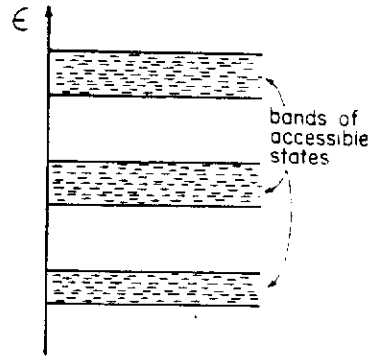

Fig. IIIE-5. Bands Formed by the Splitting of Levels

Insulators. Noble gas atoms have a full outer electron shell. In their crystalline form the band corresponding to the outer shell is full and the next higher band is empty. The Fermi level in such solids is in the *forbidden gap* between the bands. As a result there are no empty states accessible to the electrons; these solids are nonconducting. Molecules are formed by ionic or covalent electron bonding. In that sense they achieve a stable outer electron configuration similar to the rate gases. Molecular crystals are generally elecrical insulators. (See Fig. IIIE-6a.)

Conductors. Metals have a relatively small number of electrons in their outer shell. As a result they form atomic crystals in which the outer shell band is only partly full. The Fermi level is within this conduction band. Since there are many empty state accessible to these free electrons, metals are electrical conductors. (See Fig. IIIE-6b.)

Semiconductors. Transition elements like carbon, silicon, and germanium, form atomic crystals in which the valence electrons are shared among the nearest