

phosphor made by dissolving  $Tl^+$  ion in alkali halides is an example. Since in both the ground state and excited state the electron is highly localized, one obtains no electrical conductivity in such systems.

As the wave function becomes a little more delocalized it is no longer practical to think of slightly perturbed atomic levels. The solution of the Schroedinger equation in the periodic potential of the lattice is known as a Bloch function. It is of the form

$$\psi = u(r) \exp (i \vec{k} \cdot \vec{r})$$

where  $u(r)$  has the symmetry of the lattice and the exponential represents a wave motion.  $\vec{k}$  is a reciprocal lattice vector which is called the crystal momentum since  $\hbar \vec{k}$  represents the momentum of the wave. This solution of the wave equation gives rise to bands of closely spaced allowed states separated by relatively large energy gaps where, in a perfect crystal, there are no allowed states. Each of the states in the band can accommodate two electrons of opposite spin.

If one now considers a crystal made of atoms or ions having filled electronic shells (e.g.  $Na^+$  and  $Cl^-$  or  $I_2$ ), each state in the band is filled. Since the next available level is far out of reach, when an electrical potential is applied there are no available empty states and therefore there can be no net displacement of electrons. Thus one has an electrical insulator. One can get significant conductivity by supplying energy to excite electrons to the next empty (conduction) band, or by adding impurities which will supply conduction electrons or trap electrons from the valence band, leaving it a partially filled band. In the absence of these effects the only conducting electrons will be those which can escape by fluctuations in thermal energy. It can be shown that the number of these is proportional to  $\exp \left( \frac{\Delta E}{2kT} \right)$  where