Lecture 3b

Bonding Model and Dopants

Reading:

(Cont'd) Notes and Anderson[2] sections 2.3-2.7

The need for more control over carrier concentration

Without “help” the total number of “carriers” (electrons and holes) is limited to $2n_i$.

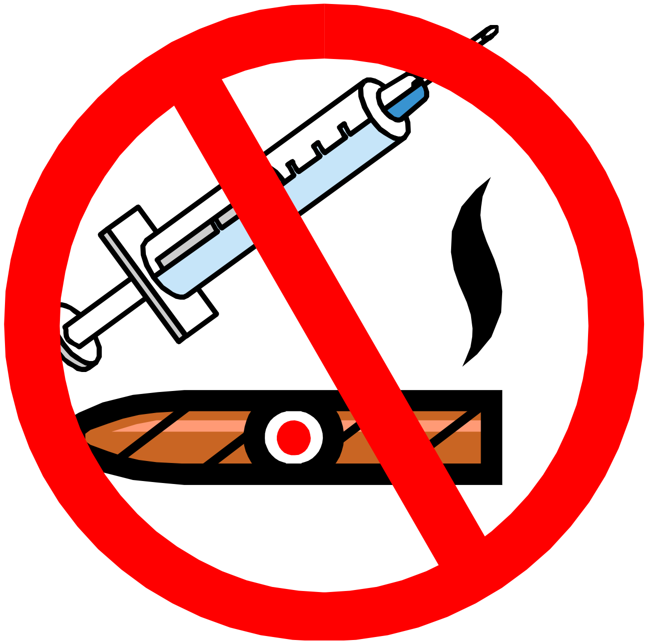
For most materials, this is not that much, and leads to very high resistance and few useful applications.

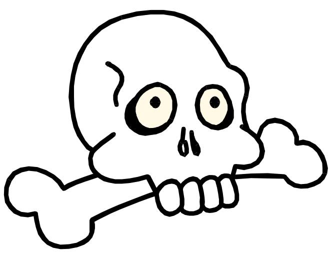
We need to add carriers by modifying the crystal.

This process is known as “doping the crystal”.

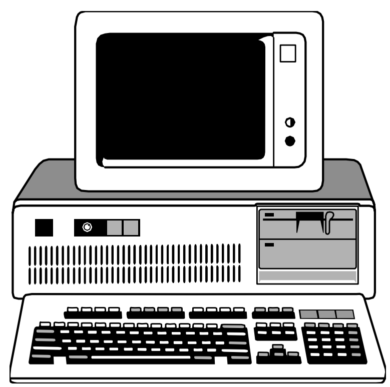
Regarding Doping, ...

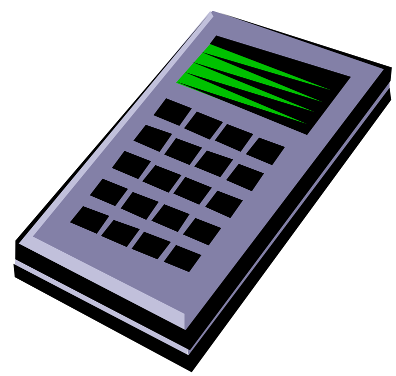
Just Say No!



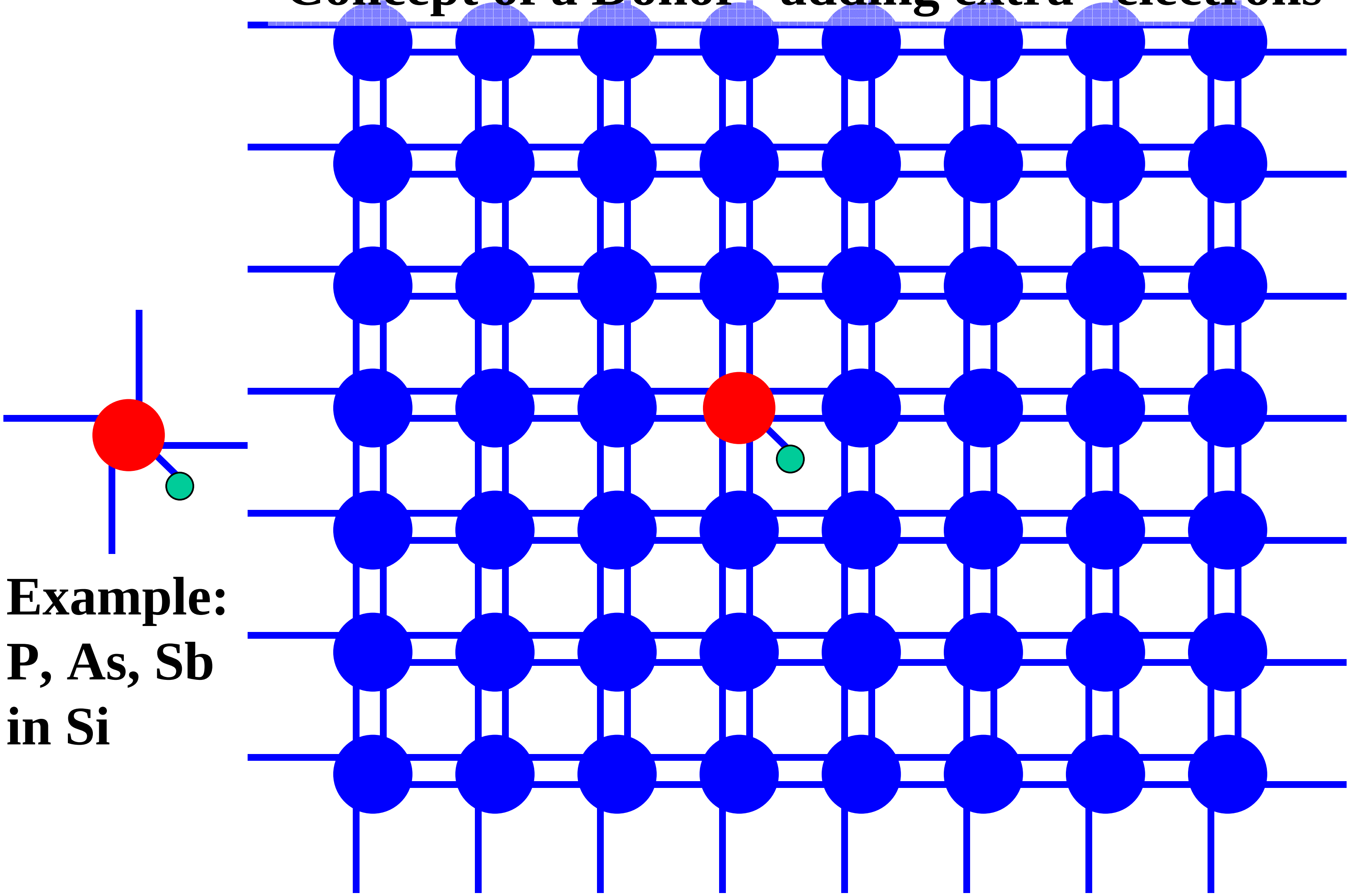


Just Say Yes to Crystal Doping!





Extrinsic, (or doped material):
Concept of a Donor "adding extra" electrons



Example:
P, As, Sb
in Si

Concept of a Donor "adding extra" electrons

Use the Hydrogen Atomic Energy levels to approximate the energy required to free an electron on a donor.

•Replace dielectric constant with that of the semiconductor

•Replace mass with that of the semiconductor

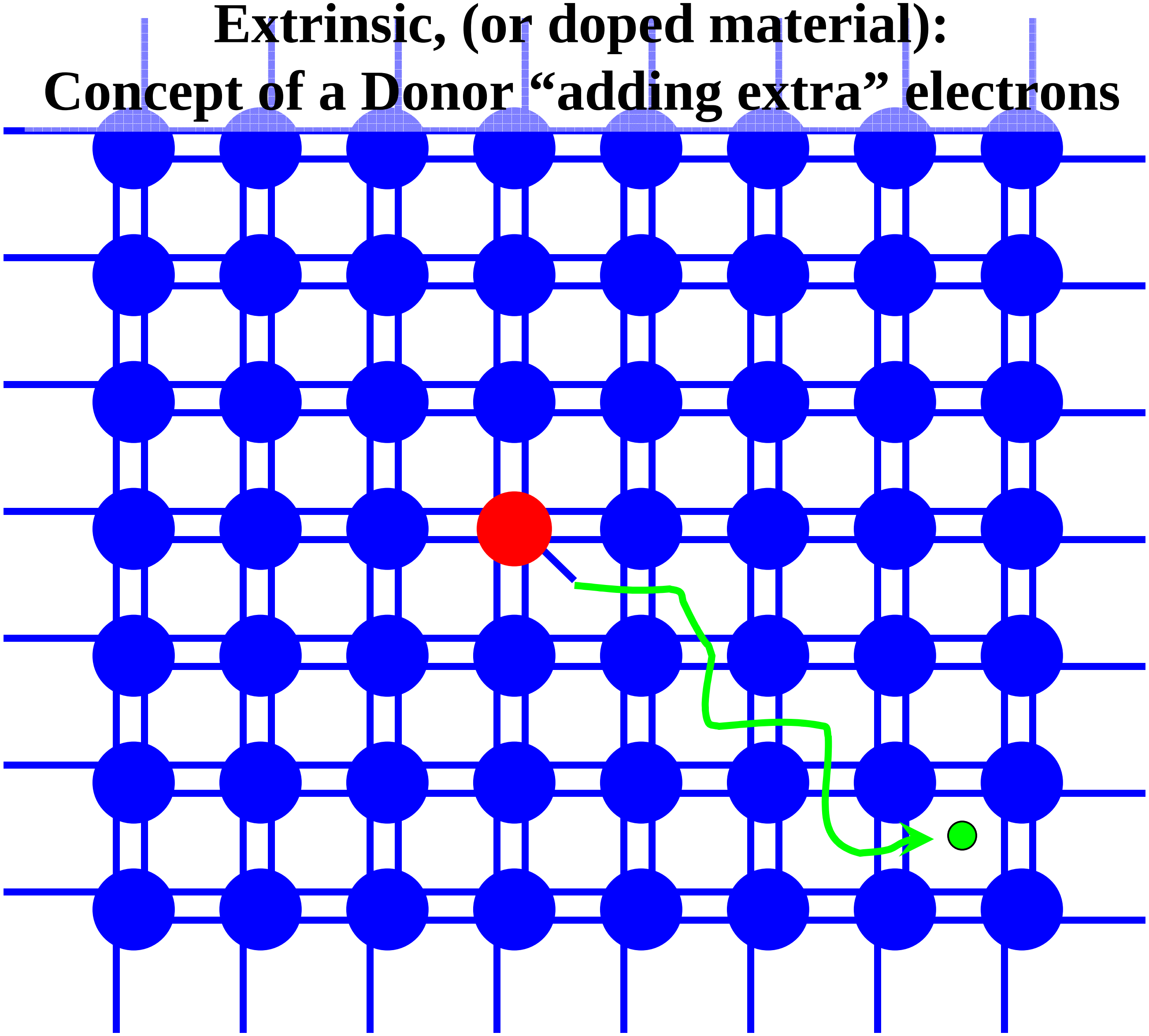
$$Energy_{Hydrogen\ electron} = E_H = -\frac{m_o q^4}{2(4\pi\varepsilon_o \hbar n)^2} = -\frac{13.6\ eV}{n^2}$$

$$where\ m_o = electron\ mass,\ \hbar = planks\ constant/2\pi = h/2\pi$$

$$q = electron\ charge,\ and\ n = 1,2,3...$$

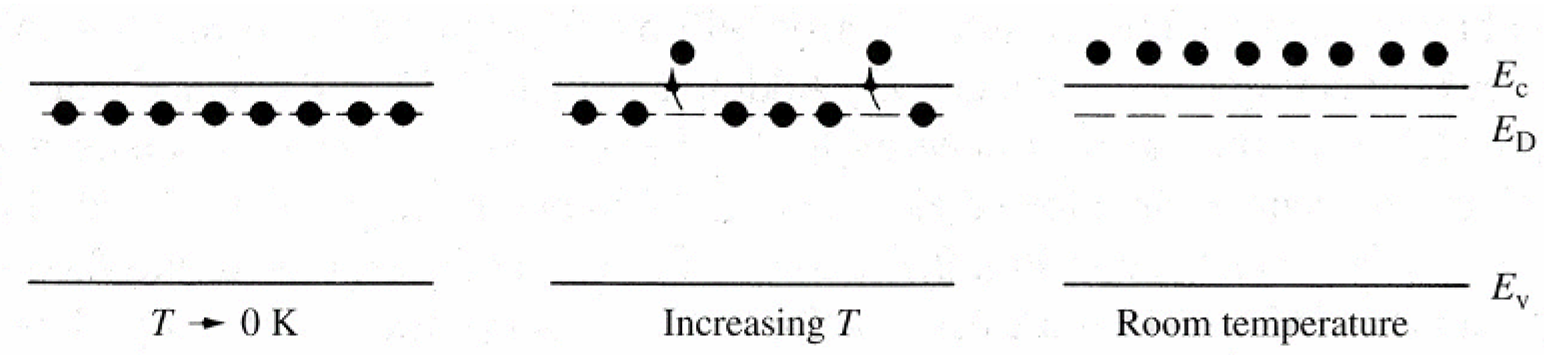
$$E_{Binding\ \ for\ electron} \approx -\frac{m_n^* q^4}{2(4\pi\varepsilon_R\varepsilon_o\hbar n)^2} = \frac{m_n^*}{m_o}\frac{1}{\varepsilon_R^2}E_H \cong -0.1\,eV\ \ for\ n = 1$$

Extrinsic, (or doped material):
Concept of a Donor "adding extra" electrons

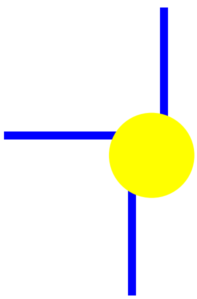


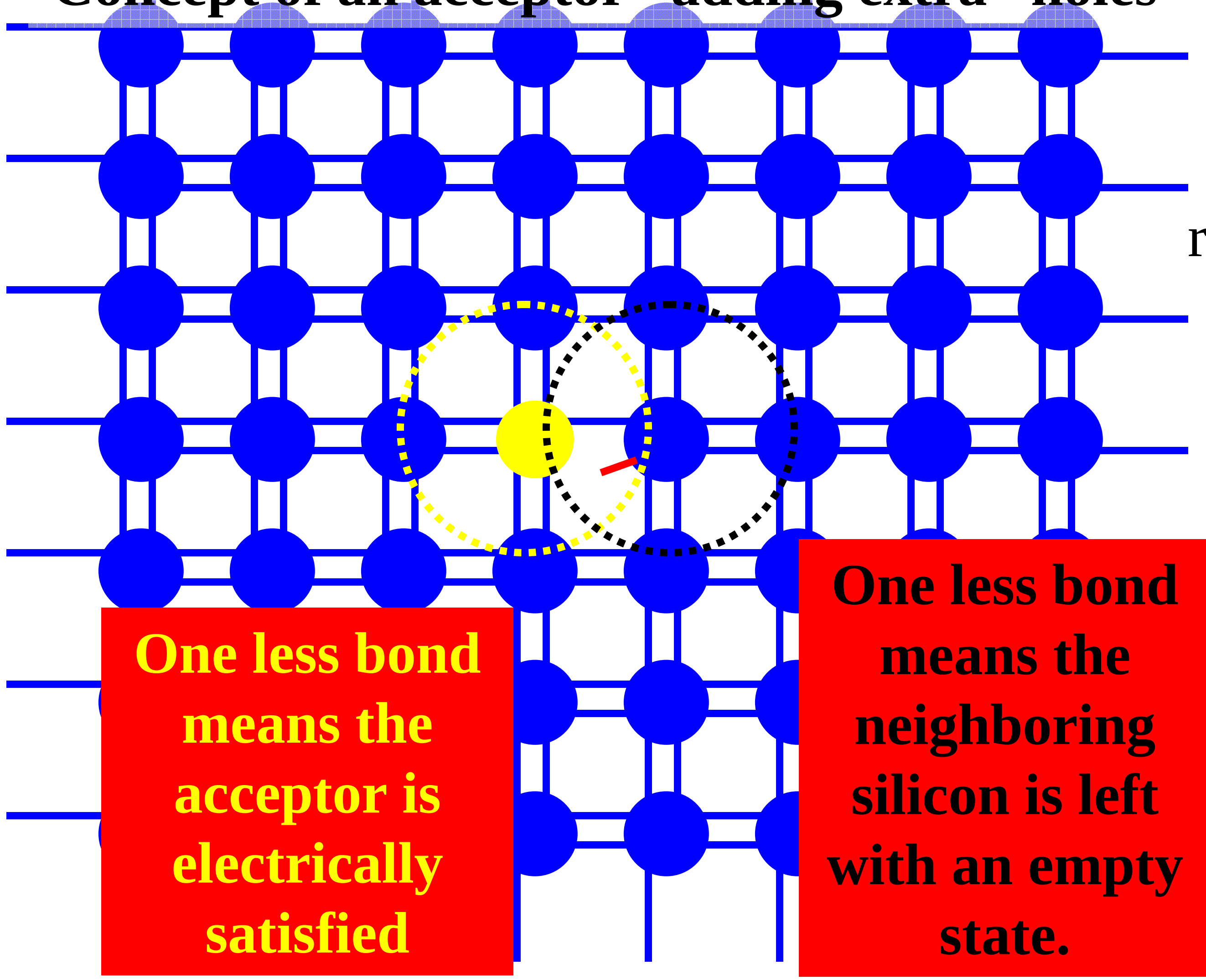
Concept of a Donor "adding extra" electrons:

Band diagram equivalent view



Extrinsic, (or doped material):
Concept of an acceptor "adding extra" holes



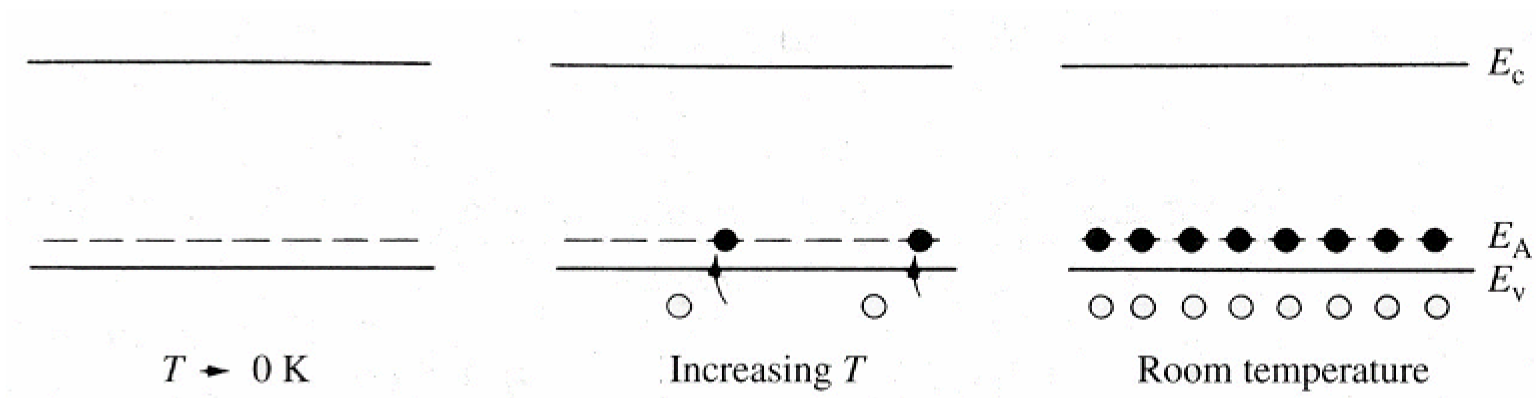


Example: B, Al, In in Si

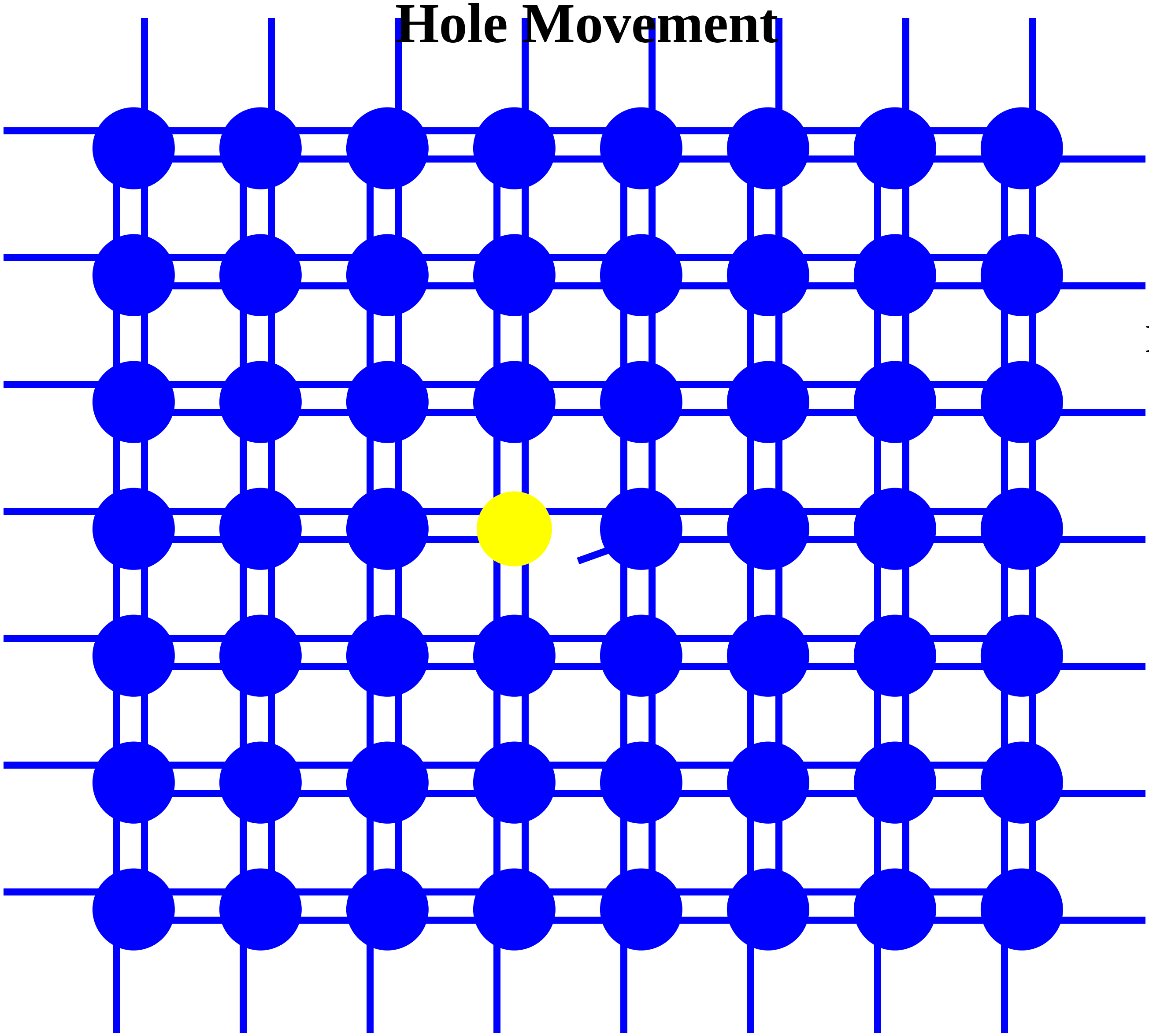
All regions of material are neutrally charged.

Concept of an Acceptor"adding extra hole":

Band diagram equivalent view



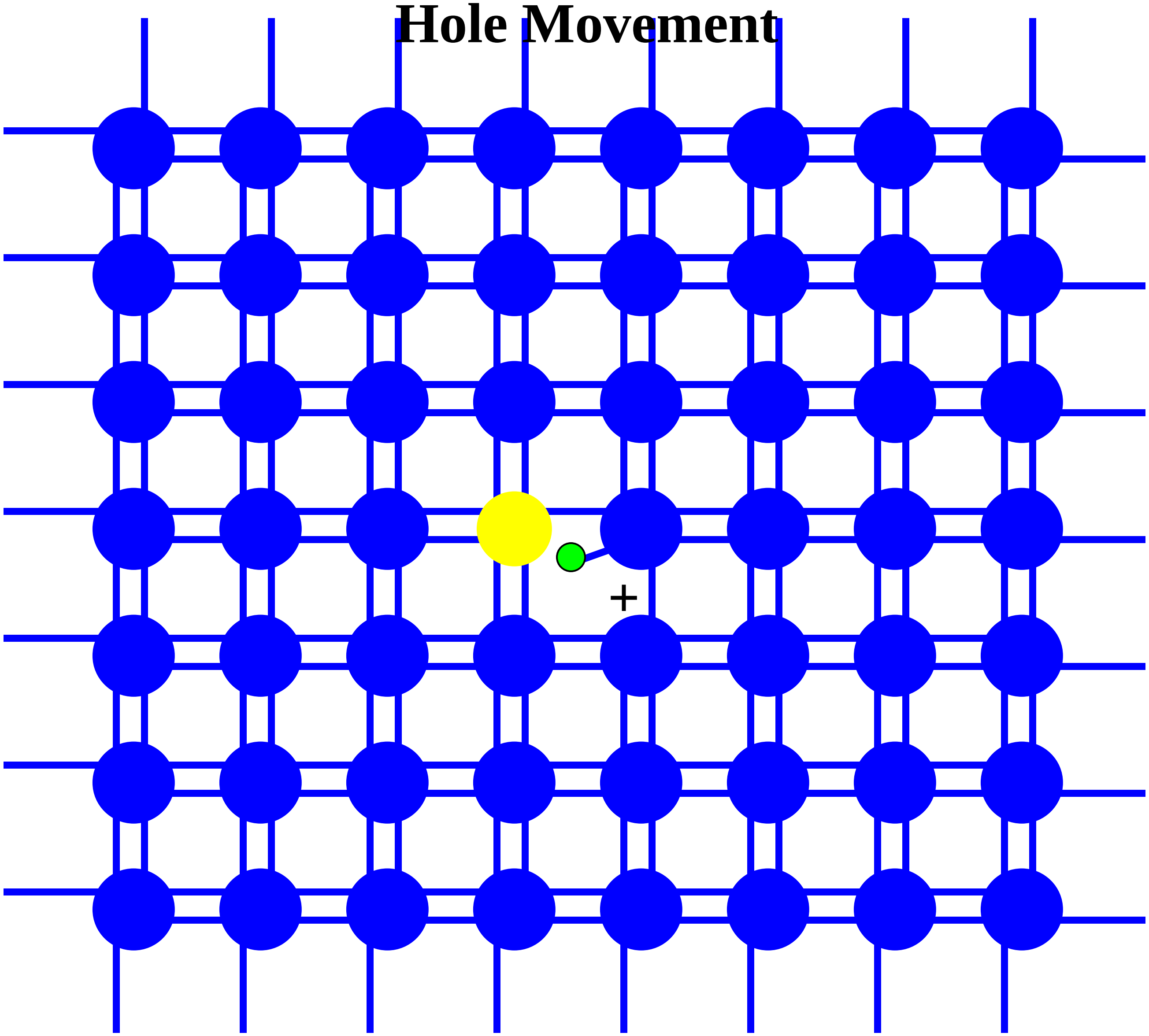
Hole Movement



All regions of material are neutrally charged.

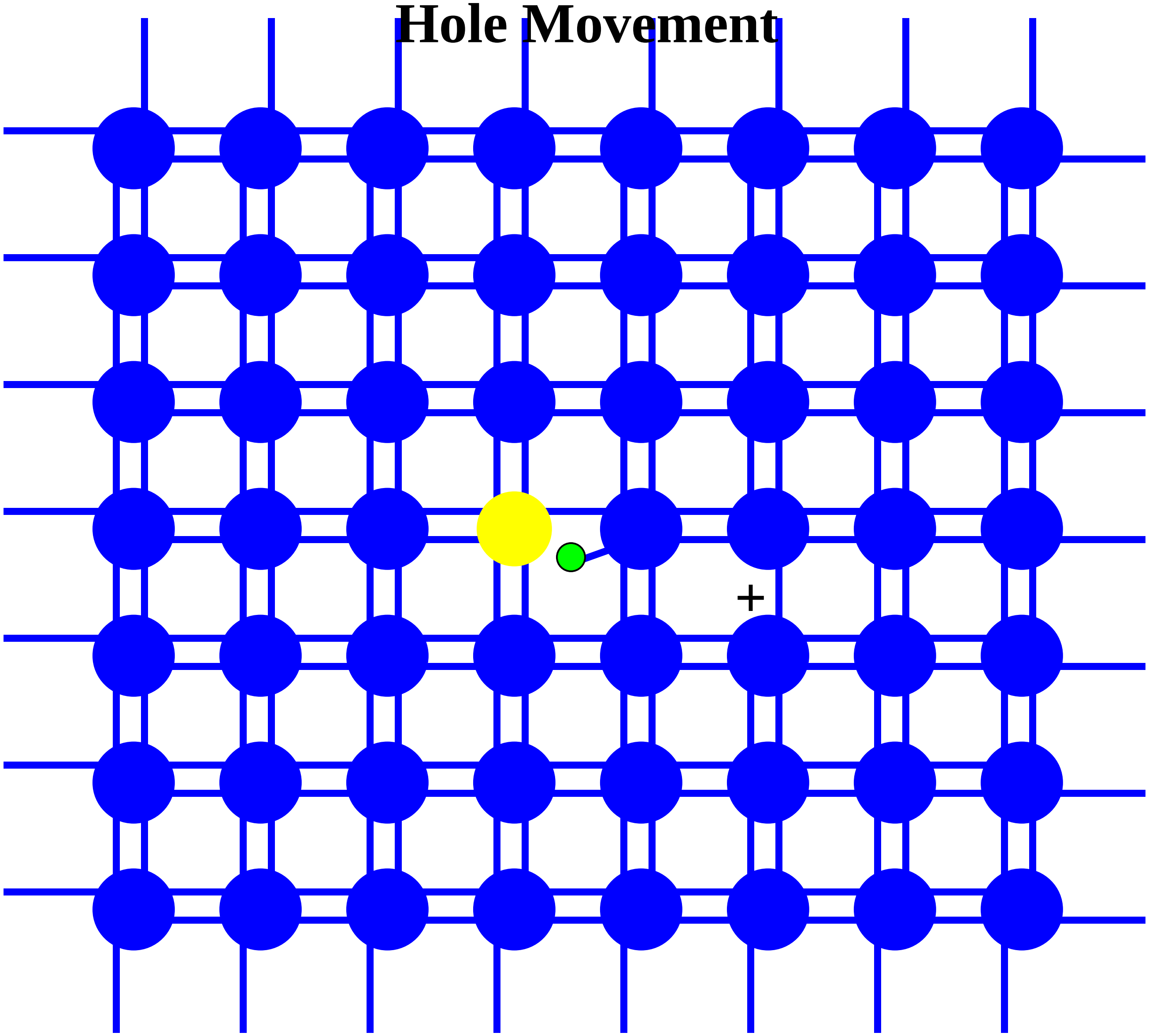
Empty state is located next to the Acceptor

Hole Movement



Another valence electron can fill the empty state located next to the Acceptor leaving behind a positively charged “hole”.

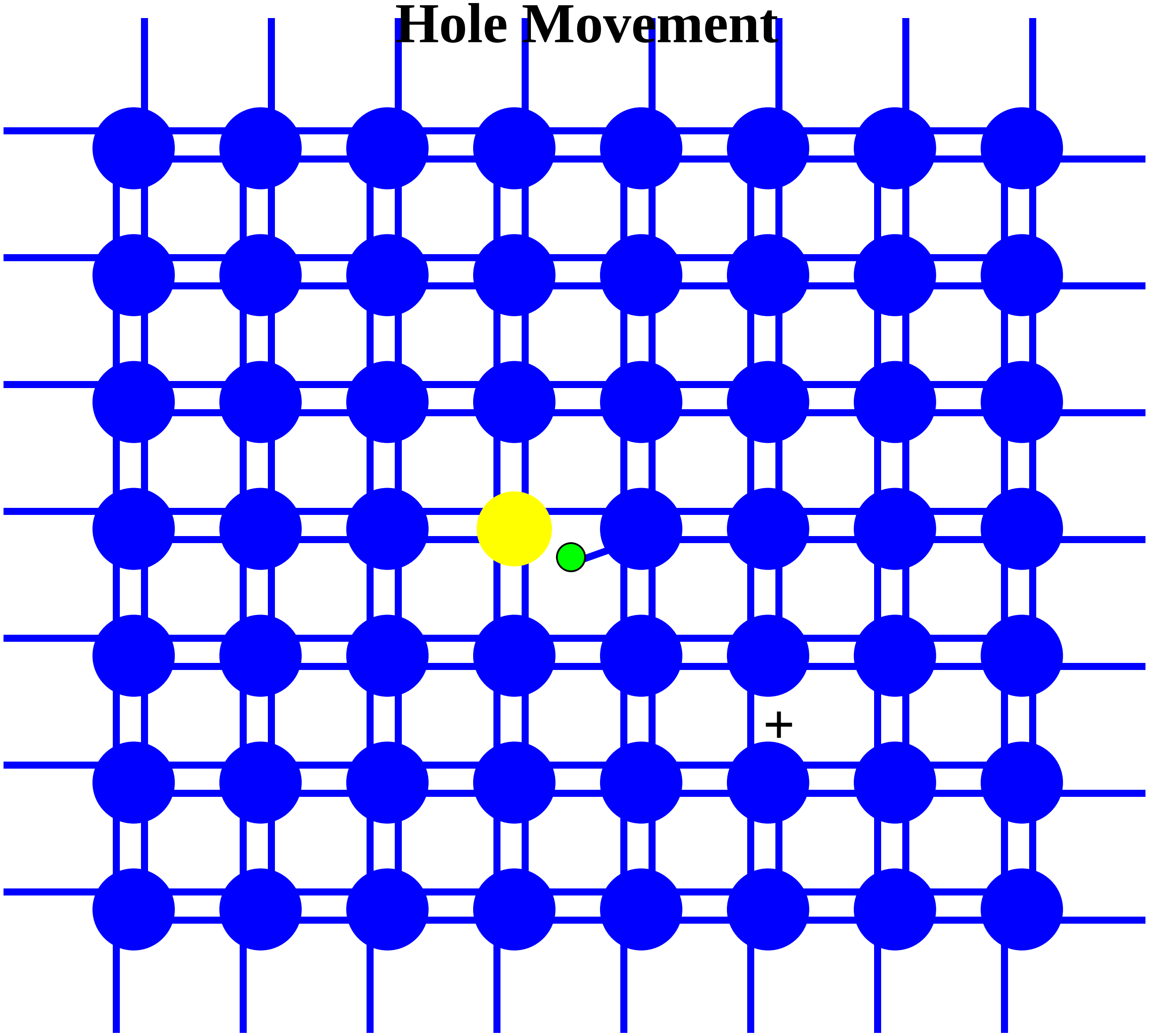
Hole Movement



The positively charged "hole" can move throughout the crystal

(really it is the valance electrons jumping from atom to atom that creates the hole motion).

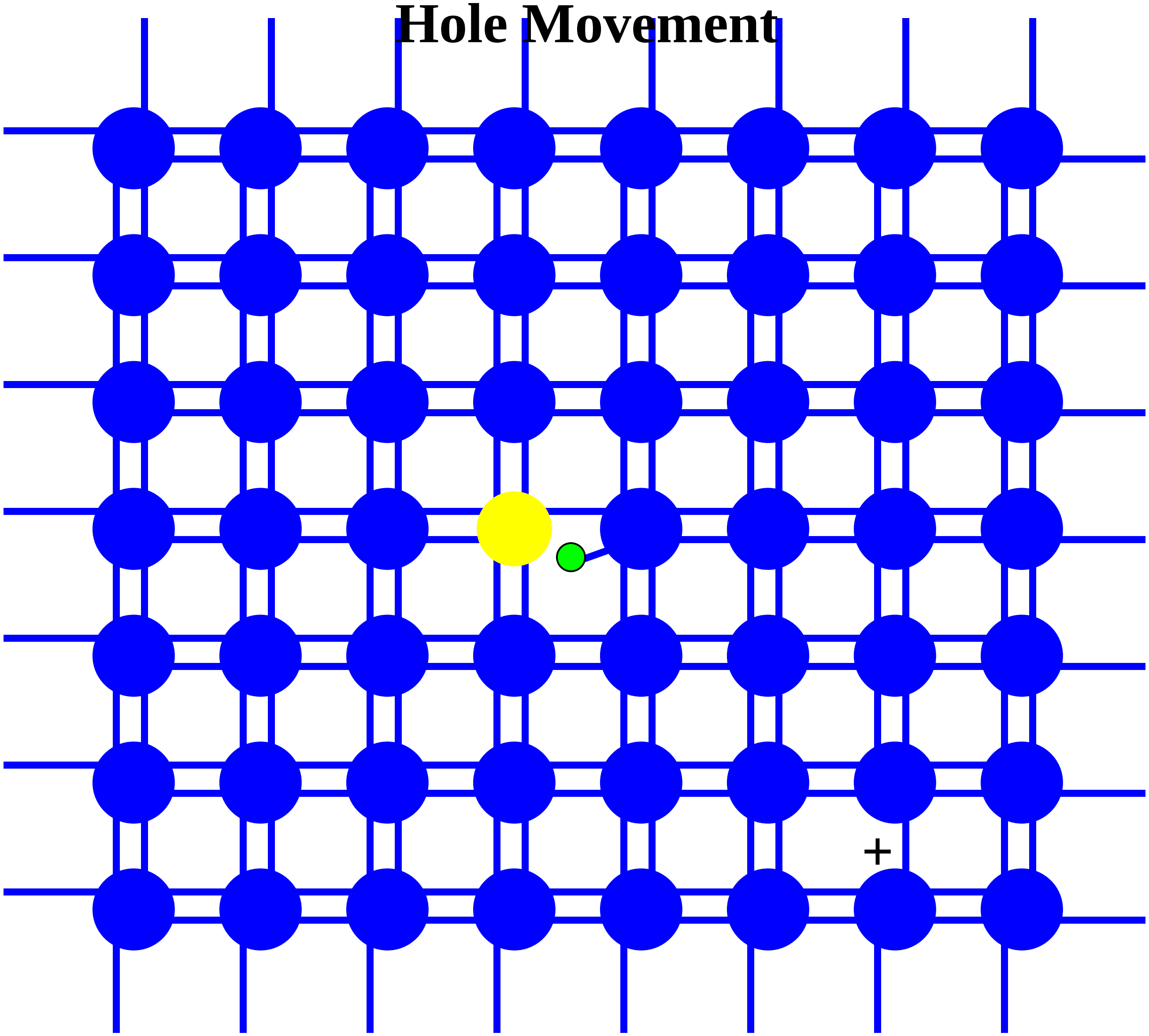
Hole Movement



The positively charged “hole” can move throughout the crystal

(really it is the valance electrons jumping from atom to atom that creates the hole motion).

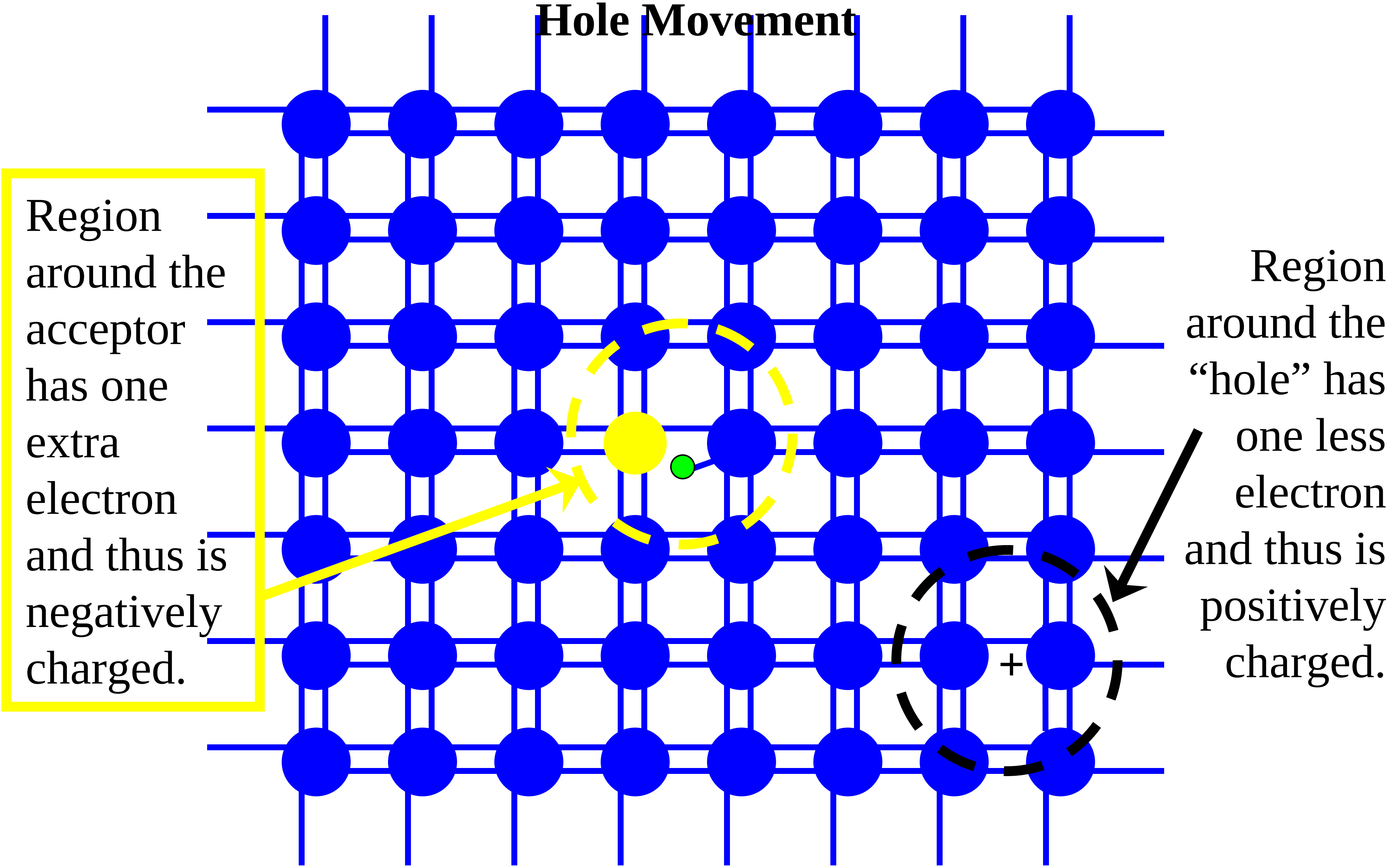
Hole Movement



The positively charged "hole" can move throughout the crystal

(really it is the valance electrons jumping from atom to atom that creates the hole motion).

Hole Movement



The positively charged "hole" can move throughout the crystal

(really it is the valance electrons jumping from atom to atom that creates the hole motion).

Summary of Important terms and symbols

Bandgap Energy: Energy required to remove a valence electron and allow it to freely conduct.
Intrinsic Semiconductor: A "native semiconductor" with no dopants. Electrons in the conduction band equal holes in the valence band. The concentration of electrons (=holes) is the intrinsic concentration, $\mathbf{n_i}$.
Extrinsic Semiconductor: A doped semiconductor. Many electrical properties controlled by the dopants, not the intrinsic semiconductor.
Donor: An impurity added to a semiconductor that adds an additional electron not found in the native semiconductor.
Acceptor: An impurity added to a semiconductor that adds an additional hole not found in the native semiconductor.
Dopant: Either an acceptor or donor.
N-type material: When electron concentrations (**n=number of electrons/cm^3**) exceed the hole concentration (normally through doping with donors).
P-type material: When hole concentrations (**p=number of holes/cm^3**) exceed the electron concentration (normally through doping with acceptors).
Majority carrier: The carrier that exists in higher population (ie n if n>p, p if p>n)
Minority carrier: The carrier that exists in lower population (ie n if n<p, p if p<n)
Other important terms (among others): Insulator, semiconductor, metal, amorphous, polycrystalline, crystalline (or single crystal), lattice, unit cell, primitive unit cell, zincblende, lattice constant, elemental semiconductor, compound semiconductor, binary, ternary, quaternary, atomic density, Miller indices, various notations, etc...