Lecture 6:Semiconductors

Valence bonds, conduction band and valence band, doping, N-type and P-type materials, examples

Atomic Structure

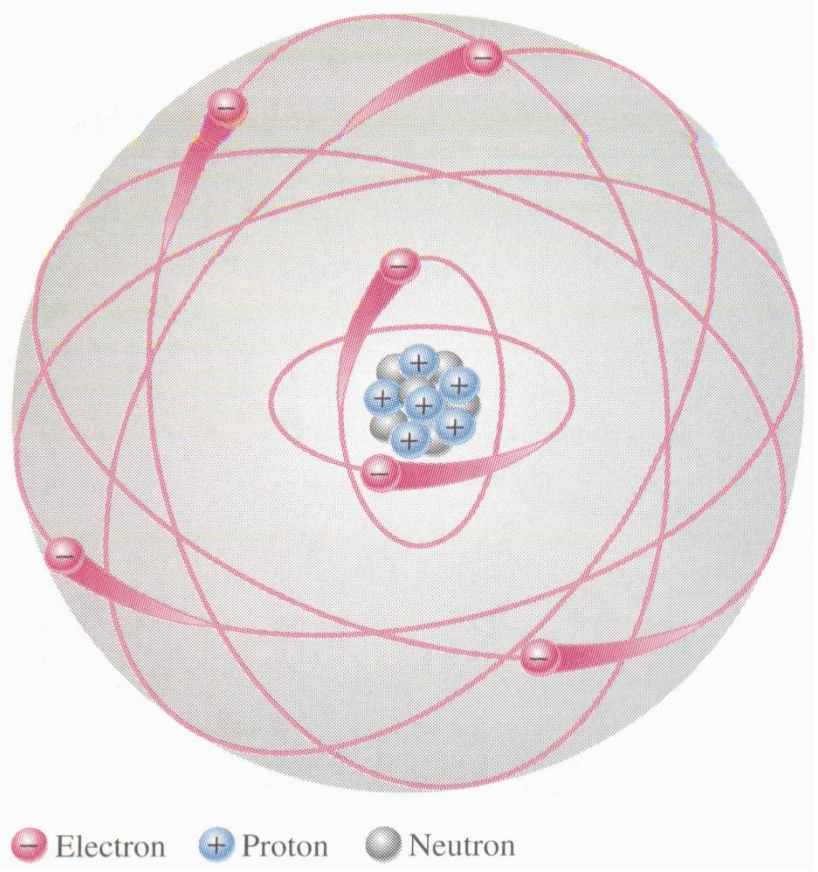
The atom is the smallest particle of an element that retains its characteristics

It consists of a central nucleus surrounded by orbiting electrons (-)

The nucleus consists of protons (+) and neutrons (neutral)

The atom is electrically neutral, i.e. number of electrons = number of protons = *atomic number*

Electrons orbits the nucleus at discrete shells, each shell has a specific energy level



Atomic Structure (Cont’d)

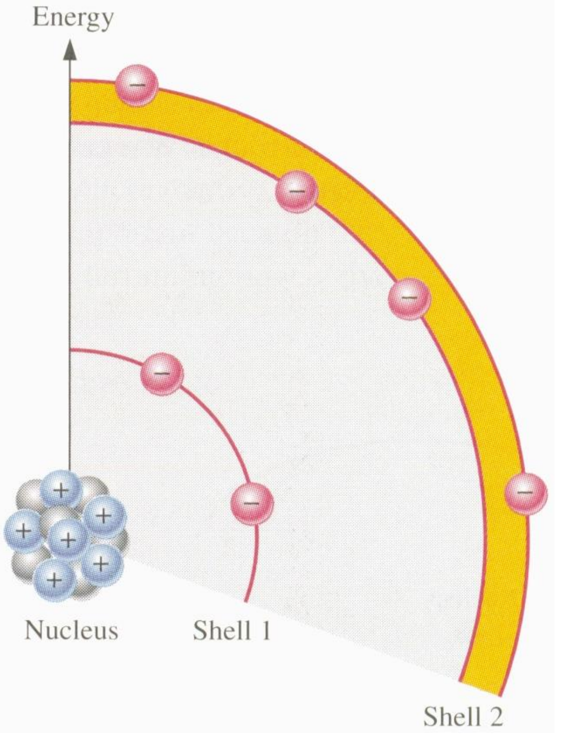
A shell can possess a number of sub-shells whose energies are approximately the same.

The maximum allowable number of electrons in the nth shell is $2n^2$.

The outer-most shell is referred to as the *valence shell*, whose electrons are referred to as the *valence electrons*.

Valence electrons are the highest in energy and the less bound to the nucleus.

A valence electrons can acquire external energy, and escape from the atom. The escaped electron is referred to as *free electron* and the residual atom becomes a +ve *ion*.

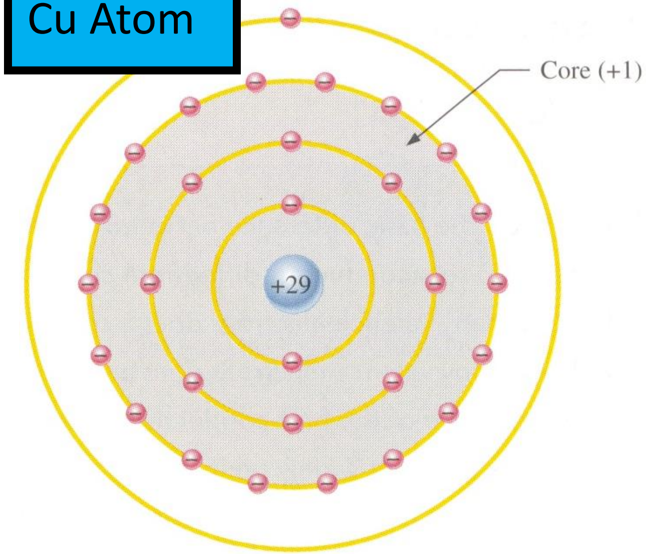


Conductors, Semiconductors, and Insulators

The *core* of the atom can be defined as the atom without the valence shell and its valence electrons.

Conductors

Cu Atom

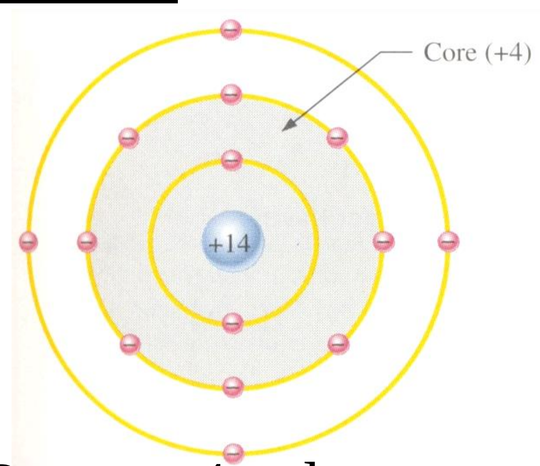


Possess single valence electron and (+1) core

Single-element materials

Semiconductors

Si Atom



Possess 4 valence electrons and (+4) core. Single-element or compounds.

Insulators

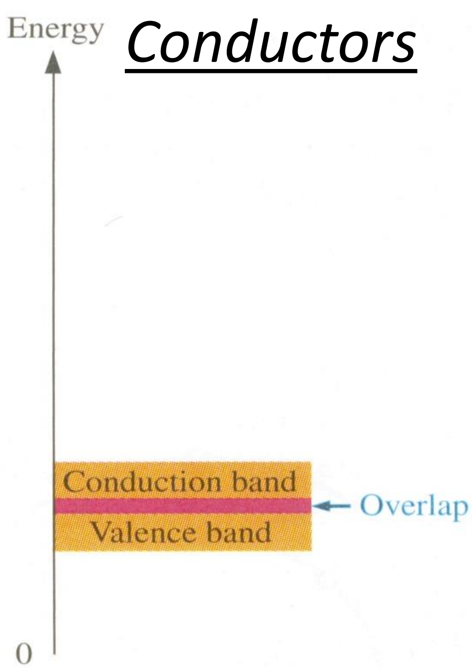
Their valence electrons are tightly bound to the atoms.

Compounds of more than one element.

Semiconductors (Cont'd)

The *energy gap* is defined as the required energy for a valence electron to escape from the atom and become a *free electron*.

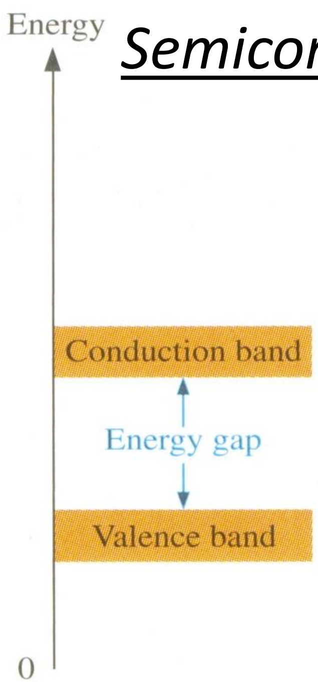
Conductors



Zero energy gap.

Easy transition of electrons.

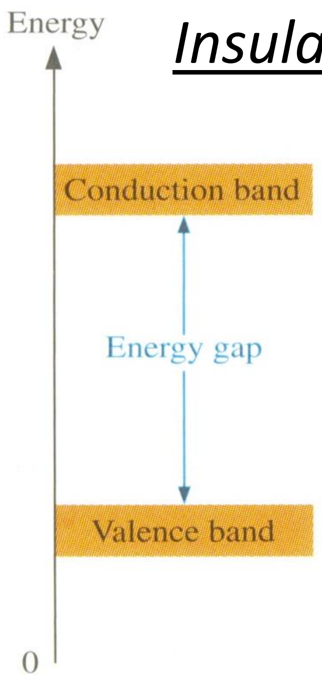
Semiconductors



Moderate energy gap.

Possible transitions.

Insulators



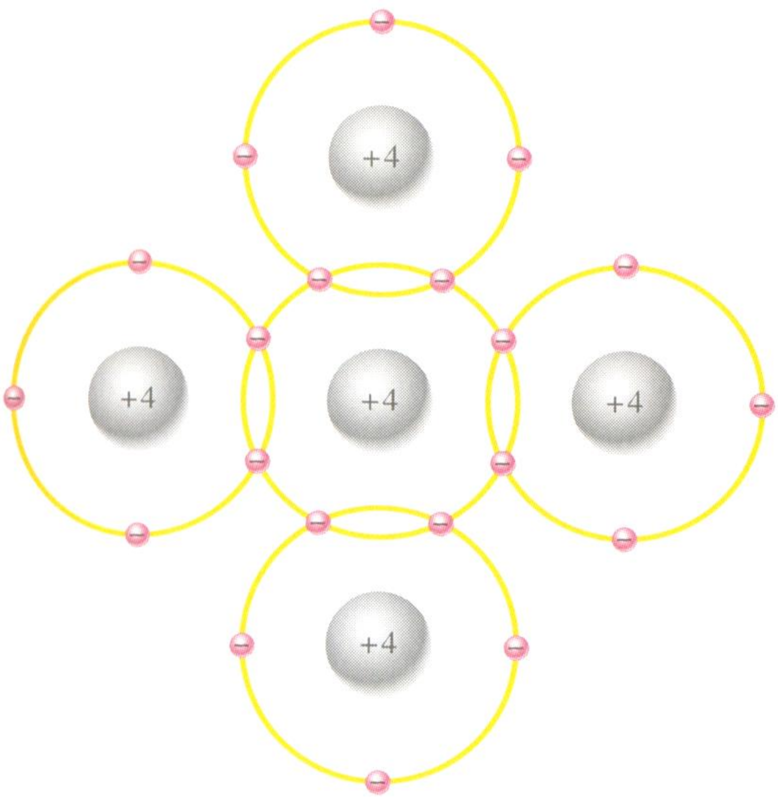
Large energy gap.

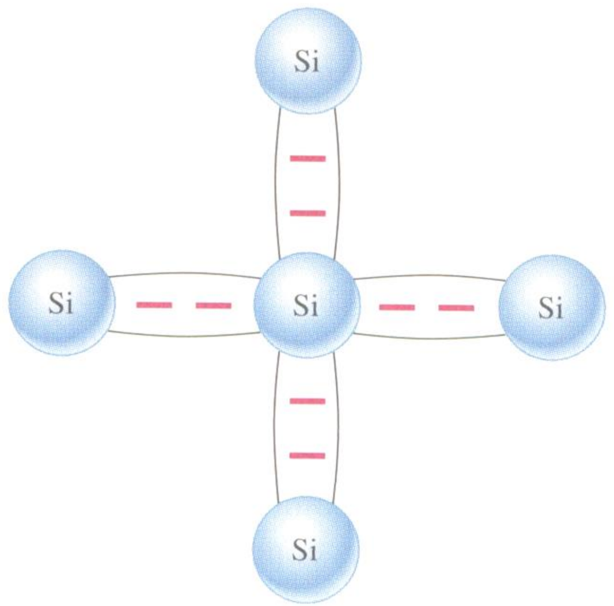
Impossible transitions

Covalent Bonds

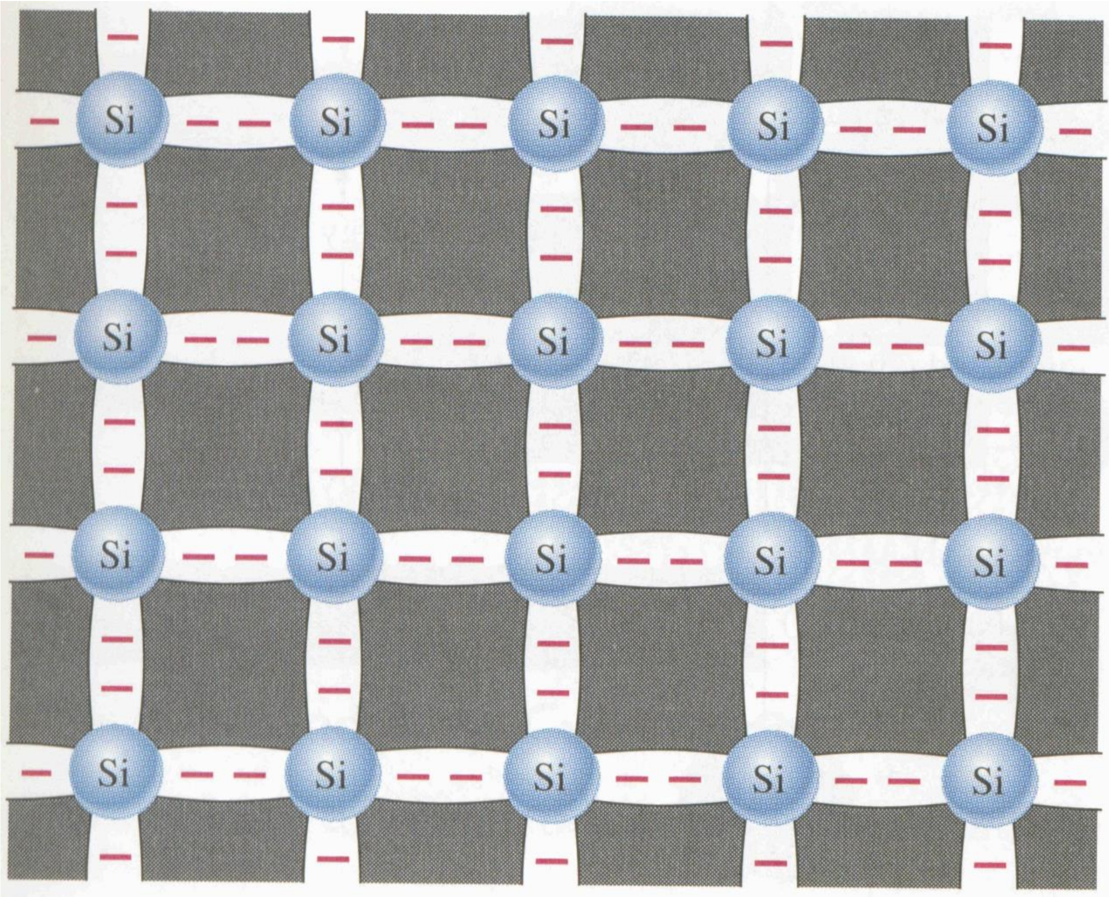
Eight electrons are required to reach the state of *chemical stability*.

This way of sharing electrons is referred to as *covalent bonds*, that hold the atoms together.





Covalent Bonds (Cont'd)

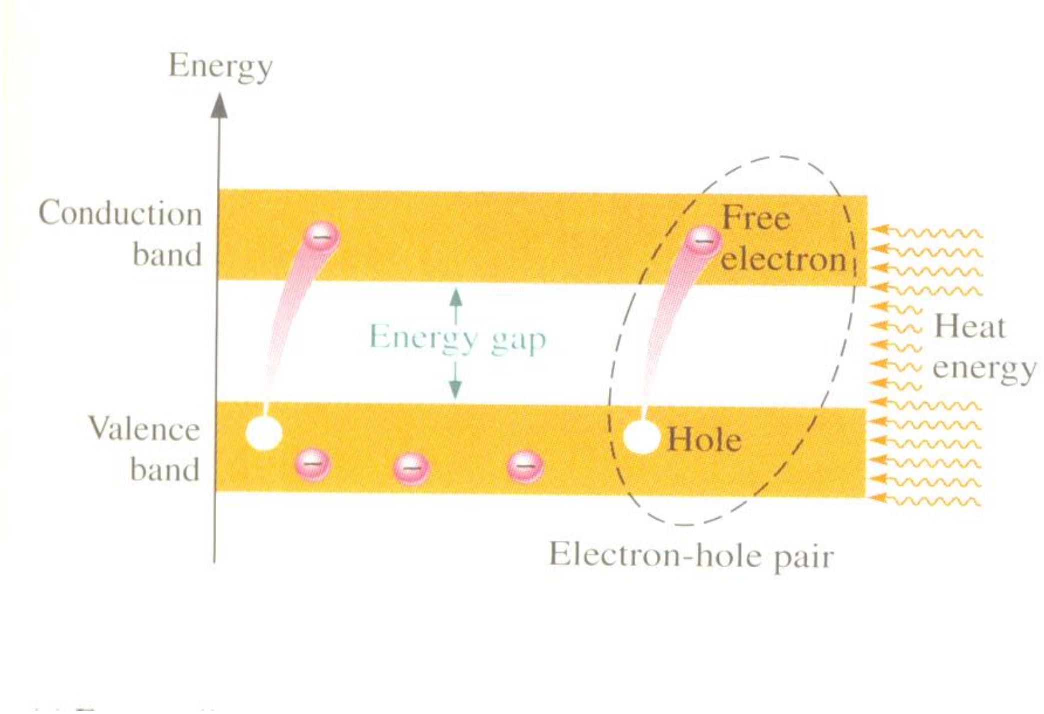


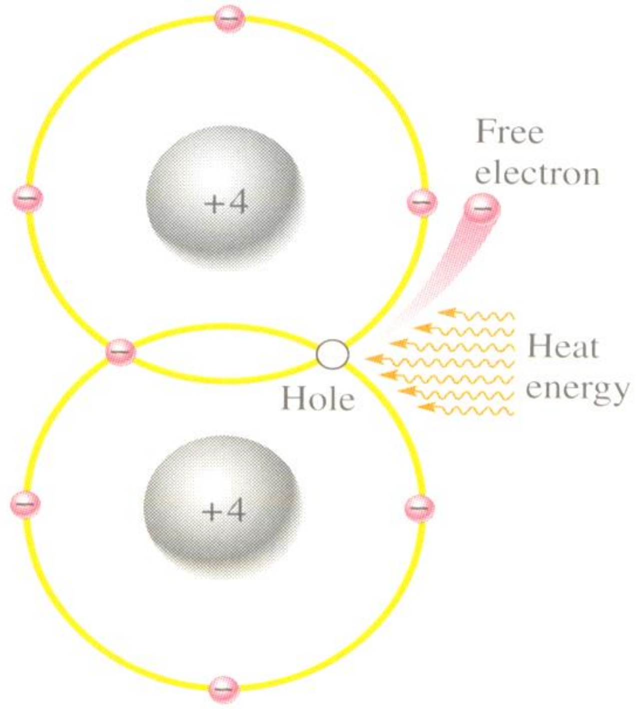
Covalent bonding of silicon atoms creates an *intrinsic* silicon crystal

Conduction in Semiconductors

Generation of an electron-hole pair occurs when a valence electron acquires external energy, escapes from the atom, and becomes a *free electron*, leaving a *hole* in the valence shell.

The thermal energy at room temperature is sufficient for this process to take place.

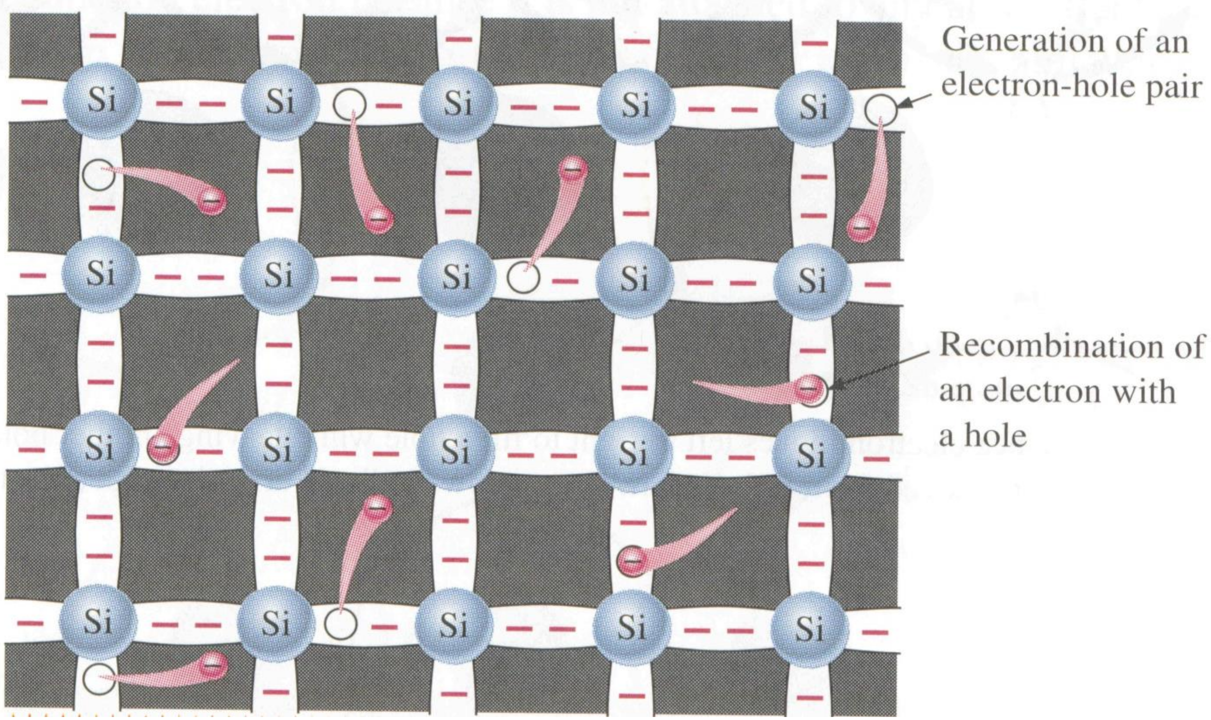




Conduction in Semiconductors (Cont'd)

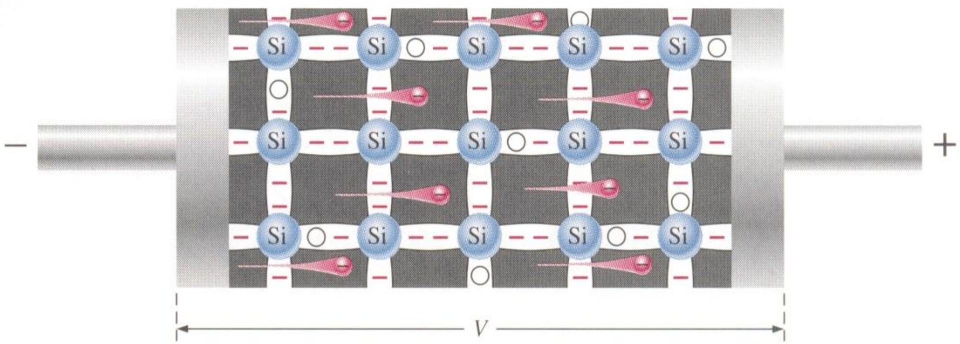
Recombination of electron-hole pair occurs when a conduction (free) electron loses energy and falls back into a hole in the valence shell.

This energy loss is released in the form of *photon emission*, whose energy (frequency or color) depends on the energy gap.



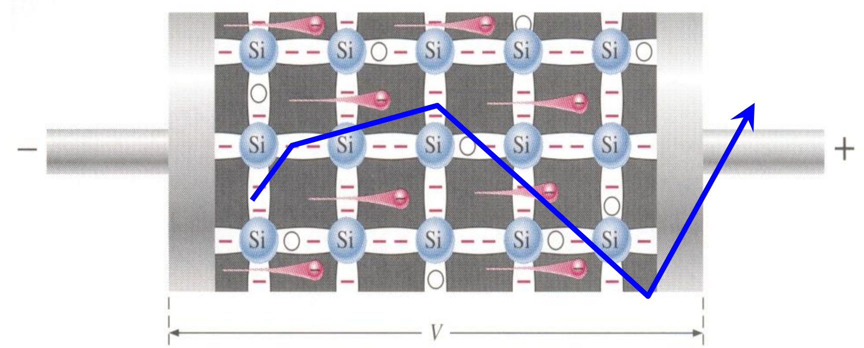
Conduction in Semiconductors (Cont'd)

Conduction Band Current



Due to motion of *free electrons* in the *conduction band* along the *opposite* direction of the applied electric field.

Valence Band Current



Due to motion of *valence electrons* in the *valence band* along the *opposite* direction of the applied electric field.

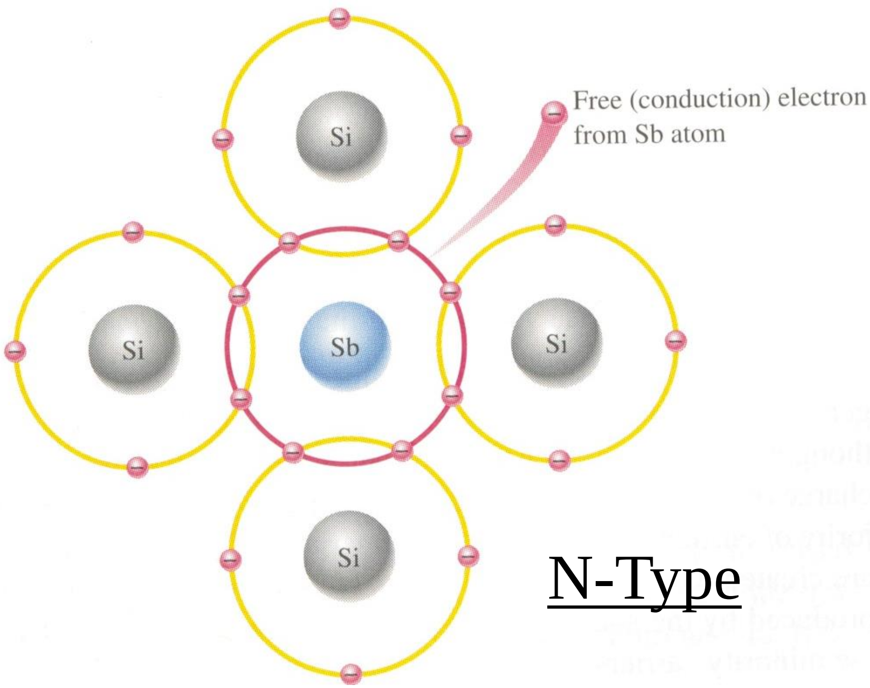
equivalent to motion of *holes* in the *valence band* in the direction of the applied field.

N-type and P-type Semiconductors

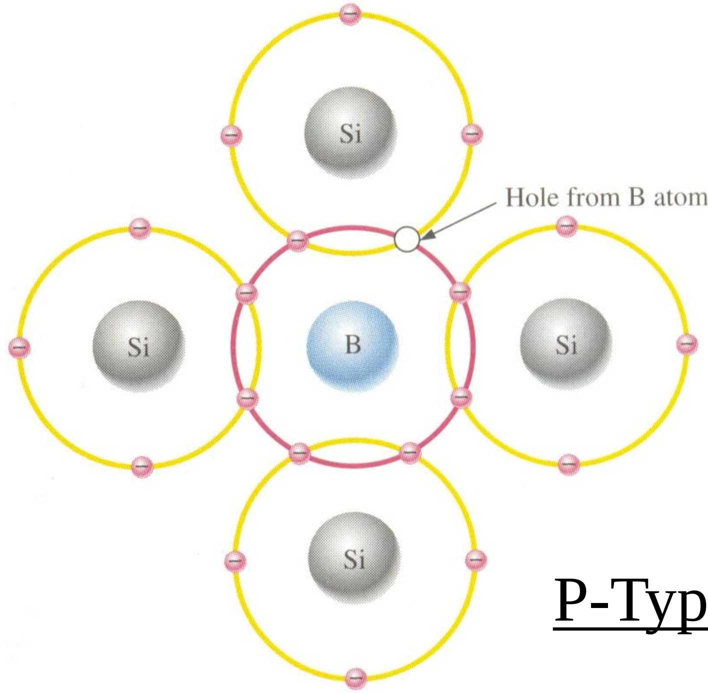
The conductivity of silicon can be greatly enhanced by adding *impurities*.

This process is known as *dopping*.

Based on the impurity material, two types of semiconductors can be obtained.



N-Type



P-Type

N-Type Materials

Pentavalent impurity atoms with 5 valence electrons are added, such as arsenic (As), phosphorus (Pb), bismuth (Bi), and antimony (Sb).

Each pentavalent impurity atom gives rise to one free electron, hence these atoms are referred to as the *donor atoms*.

Thermal energy gives rise to a number of electron-hole pairs.

The *majority* of current *carriers* are electrons and the *minority carriers* are holes. Hence, this type of semiconductor is called *n*-type.

The *conduction band current* is dominant.

P-Type Materials

Trivalent impurity atoms with 3 valence electrons are added, such as boron (B), indium (In), and gallium (Ga).

Each trivalent impurity atom gives rise to one hole, hence these atoms are referred to as the *acceptor atoms*.

Thermal energy gives rise to a number of electron-hole pairs.

The *majority* of current *carriers* are holes and the *minority carriers* are electrons. Hence, this type of semiconductor is called *p*-type.

The *valence band current* is dominant.