ECE 101

Fundamentals of Electronics

Transistor

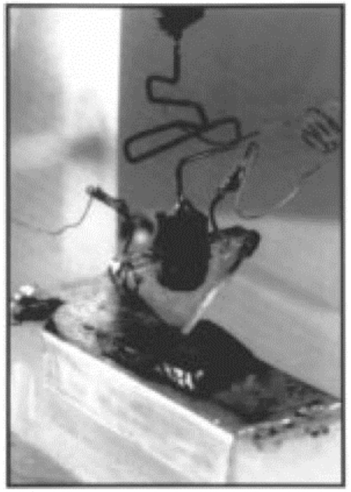
Transfer + varistor [transfer + resistor]

The idea

- **Three terminal device**
  - **Switch, amplifier**
  - Output across two terminals can be amplified by applying current/voltage across the other two terminals
  - BJT, **FET**

History

- **1947 – Bell Labs:** Shockley, Bardeen & Brattain
- **FET: 1926 –** conceptualized by Lilienfeld
- **Transistors as switch**

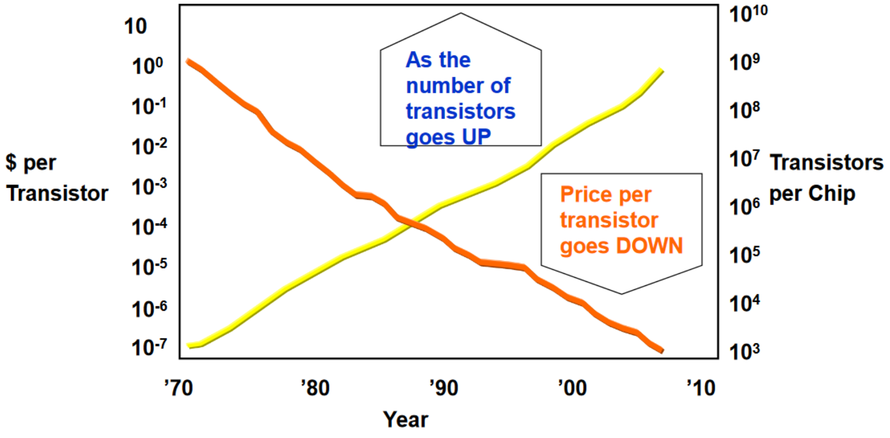


History: The transistor era – integration

- An IC is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material, normally silicon.

- The integration of large numbers of tiny transistors into a small chip results in circuits that are orders of magnitude smaller, faster, and less expensive than those constructed of discrete electronic components.

- Integrated circuits were made practical by mid-20th-century technology advancements in semiconductor device fabrication.
  - Since their origins in the 1960s, the size, speed, and capacity of chips have progressed enormously
  - 1968 – Intel was founded.



Moore's law and Scaling

Number of transistors would double every 18 months.

The transistor era - integration summary

- **Transistor being fabricated on one small piece of semiconductor.**

- **SSI** - Small Scale integration
  - less than 100 components (about 10 gates)

- **MSI** - Medium Scale integration
  - less than 500 components (more than 10 but less than 100 gates)

- **LSI** - Large Scale integration
  - components b/w 500 and 300000 (more than 100 gates)

- **VLSI** - Very Large Scale integration
  - it contains more than 300000 components per chip

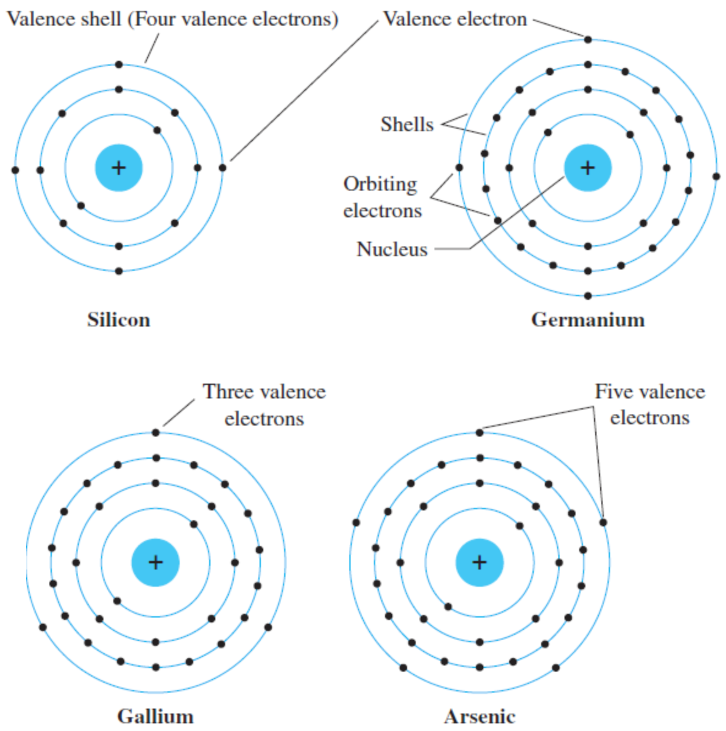
Introduction to semiconductor devices

- Electron – fundamental particle with unit negative charge.
  - Roughly the radius of an electron is 1 fm while that of an atom is 1 Angstrom.

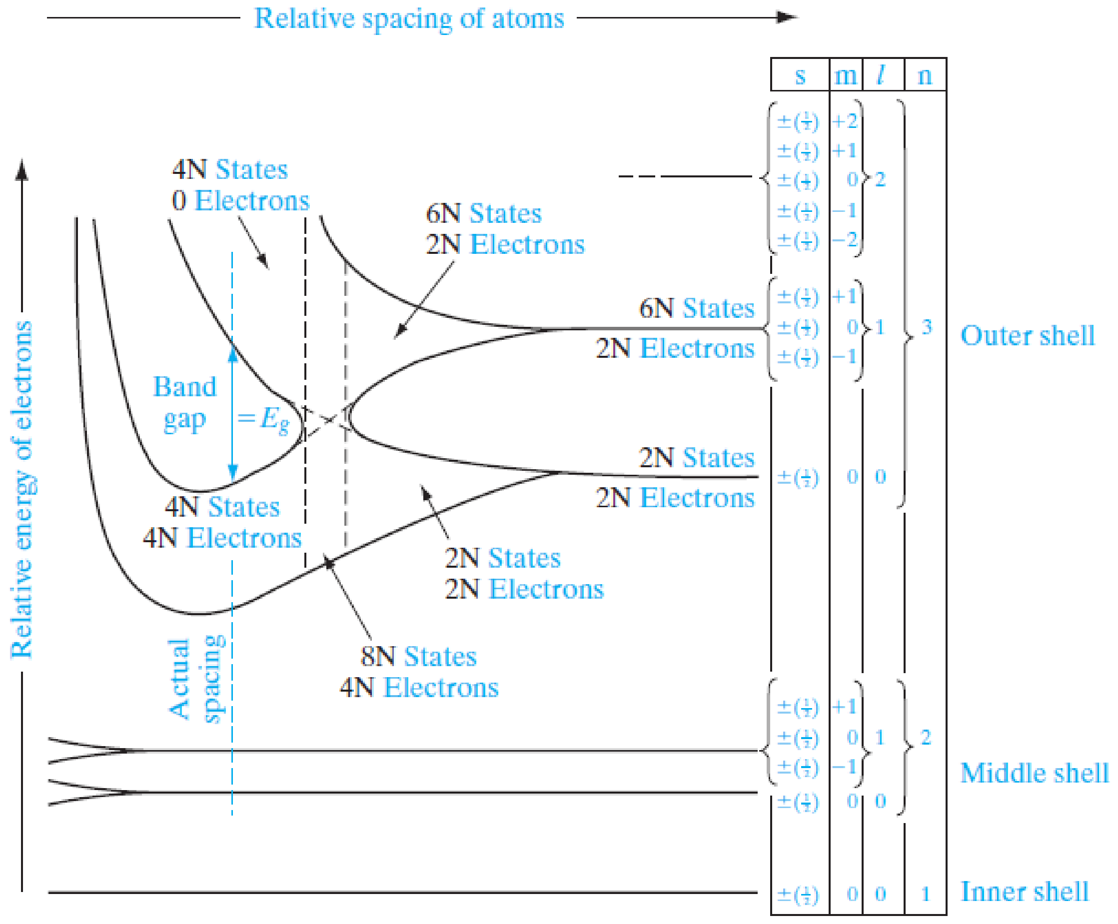
- What is a semiconductor: conductivity between metal and insulators
  - Conductivity of metals: 10^{7} $(\Omega\text{-m})^{-1}$ [Metals conduct both heat and electric current]
  - Conductivity of insulators: 10^{-10} $(\Omega\text{-m})^{-1}$
  - Conductivity of semiconductors: 10^{-6} to $10^{4}(\Omega\text{-m})^{-1}$

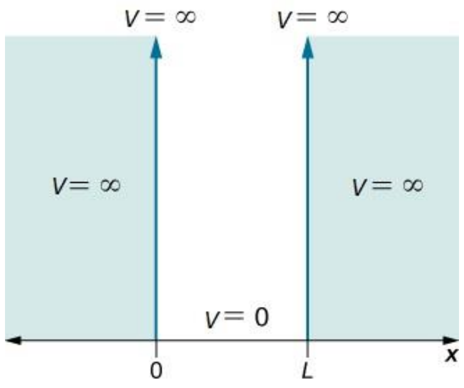
- Why semiconductors to make devices
  - We need controlled flow of electrons
  - Conductors allow continuous flow of electrons
  - Insulators disallow electron flow.
  - Semiconductors' flow of electron can be tuned and controlled.

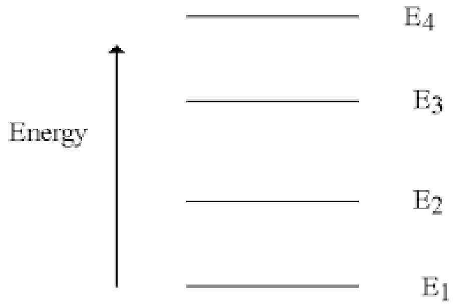
- Semiconductors
  - Covalent bonds
  - Si, Ge, GaAs

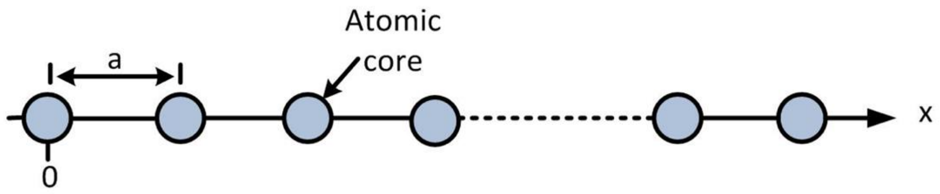


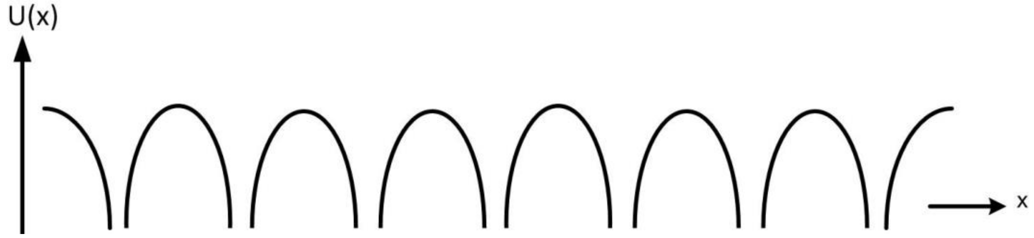
What happens when lots of such atoms come close to each other.





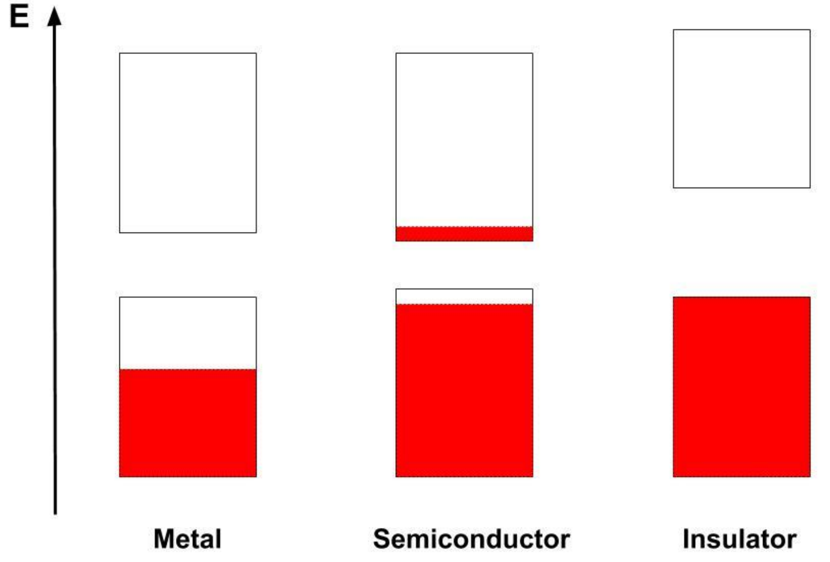


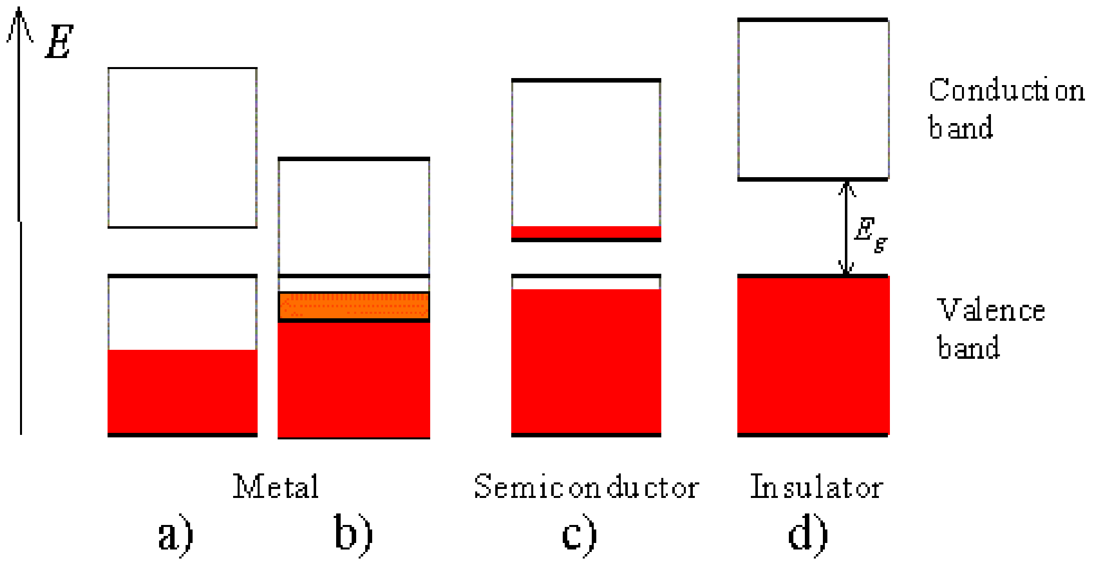




Bands and bandgaps

Band structure of metals, semiconductors and insulators

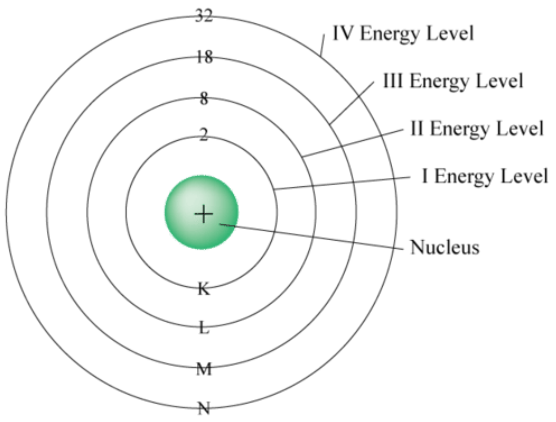




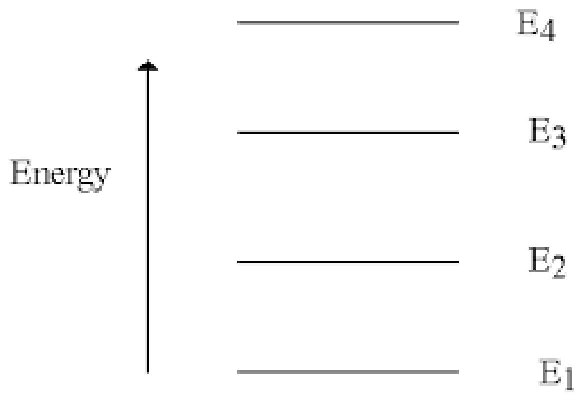
$$\boxed{f(E) = \frac{1}{1 + e^{(E-E_F)/kT}}}$$

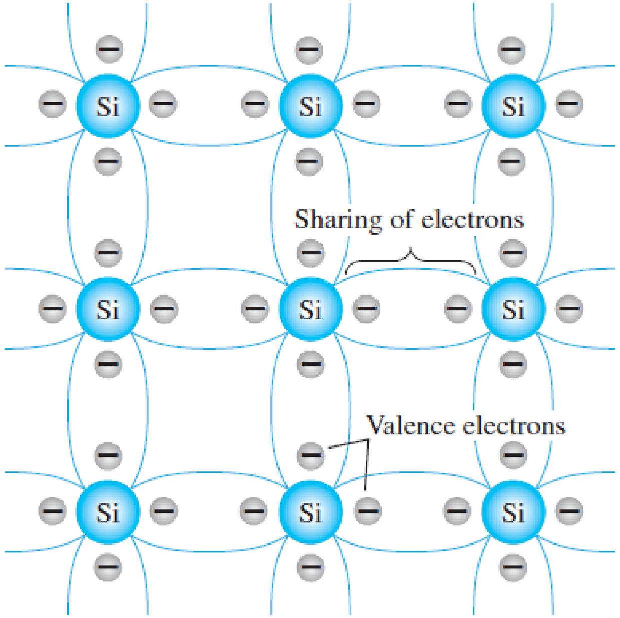
Fermi–Dirac statistics.

Photoelectric effect
Quantum mechanics

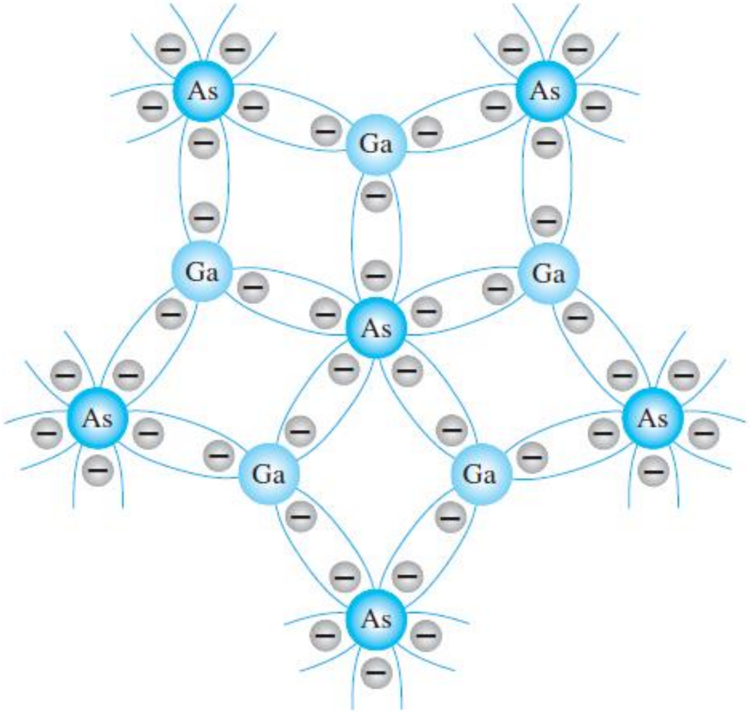


Atomic energy levels





Covalent bonding in Si crystal



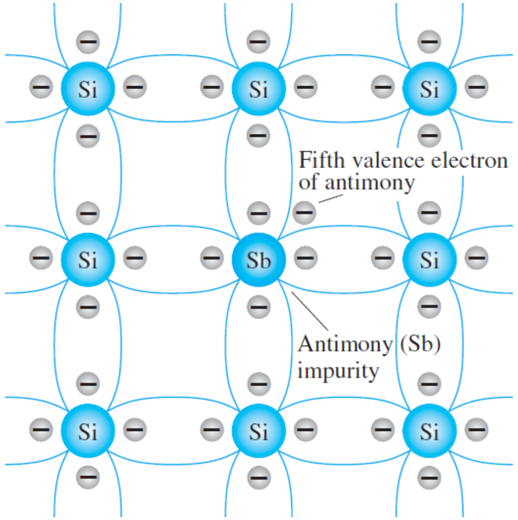
Covalent bonding in GaAs crystal

Semiconductor	Intrinsic Carriers (per cubic centimeter)
GaAs	1.7×10^6
Si	1.5×10^{10}
Ge	2.5×10^{13}

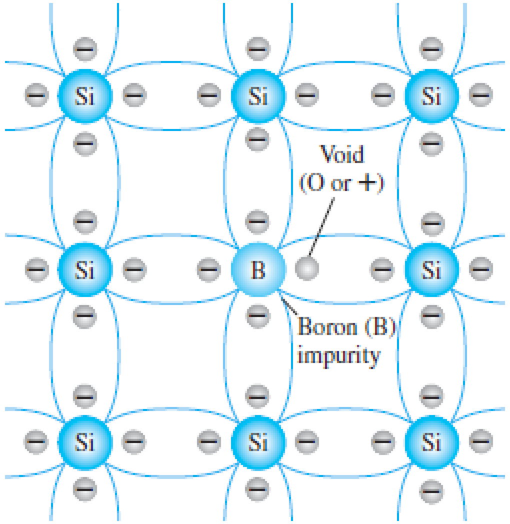
Semiconductor	μ_n ($cm^2/V \cdot s$)
Si	1500
Ge	3900
GaAs	8500

Charge carriers in semiconductors, doping

- Doping of semiconductors
  - The notion of holes
  - **Intrinsic and extrinsic semiconductors**
    - Difference in the number of holes
  - The n- and p-type materials are the basic building blocks of semiconductor devices.

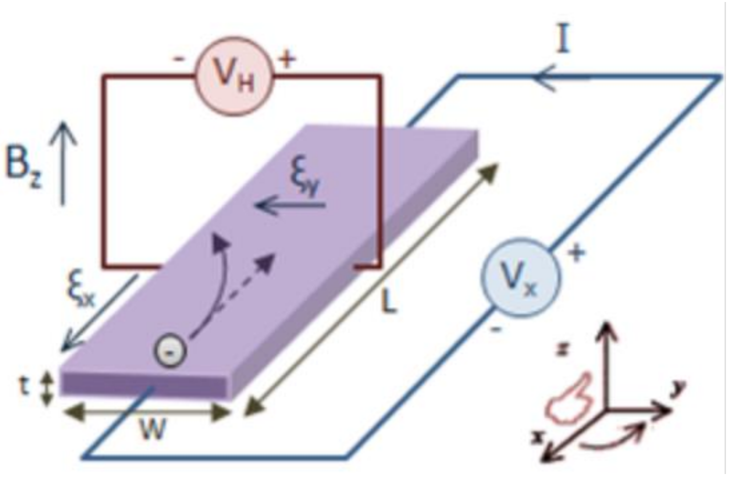


n-type material



p-type material

- Current flow in metals is due to the flow of electrons.
- Current flow in semiconductors is due to both electrons and holes

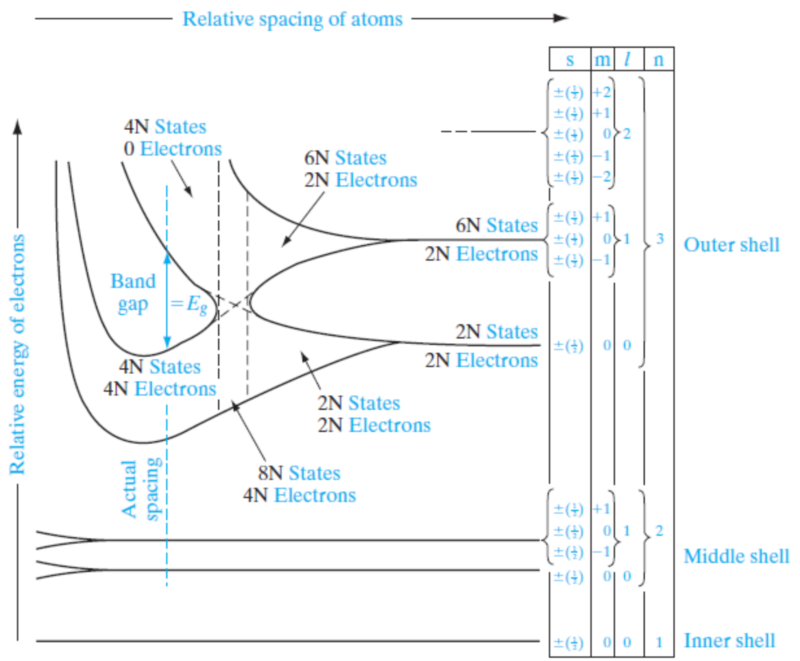


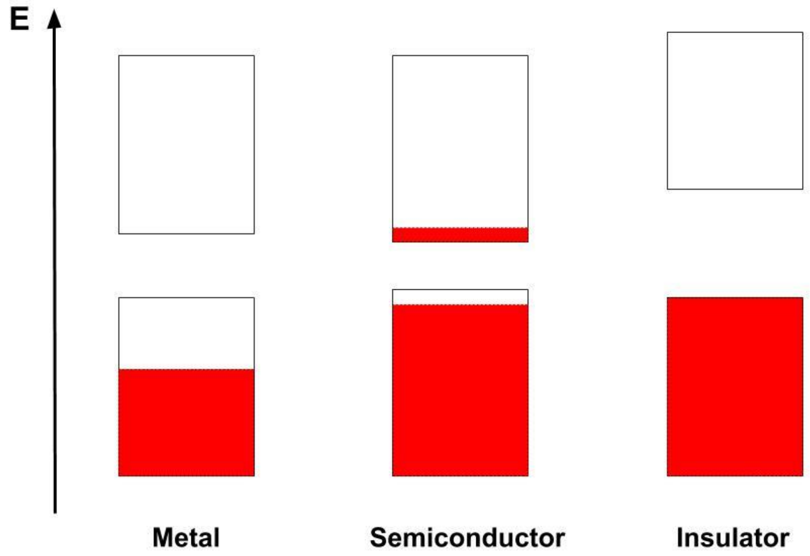
Hall Effect

- **Majority and minority carriers.**

Carrier generation-recombination [temperature, light]

Summary





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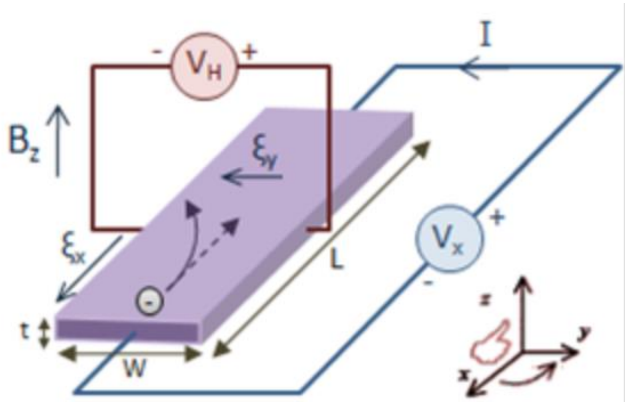
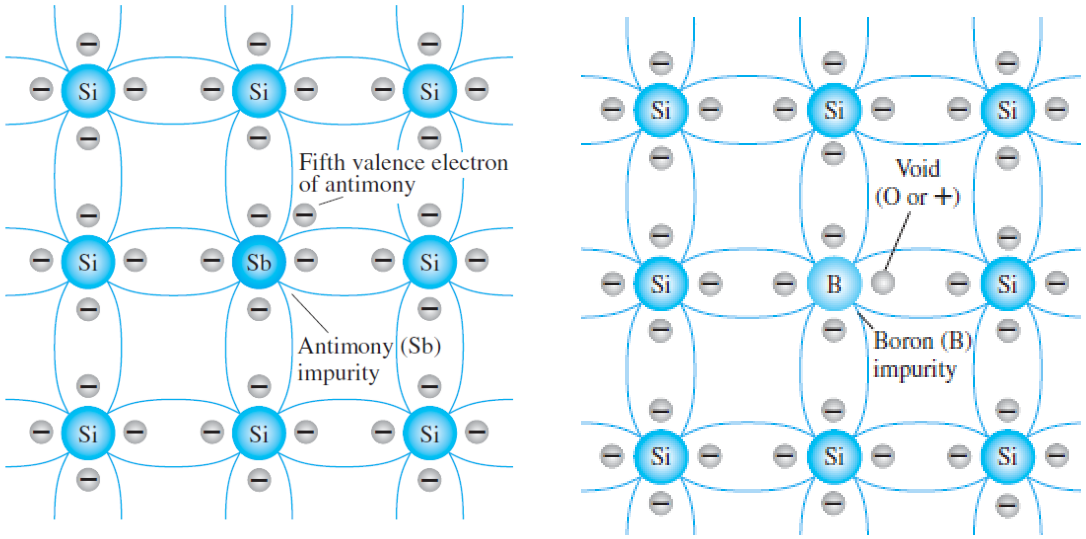
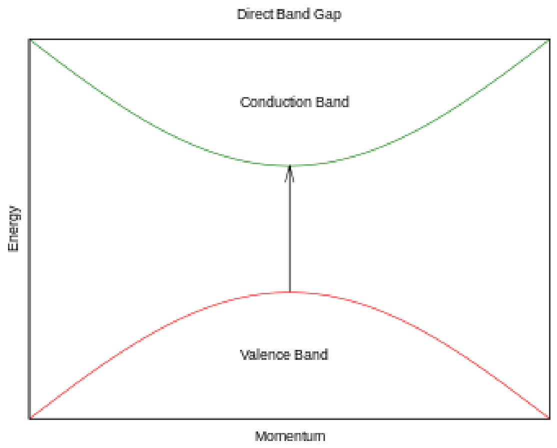
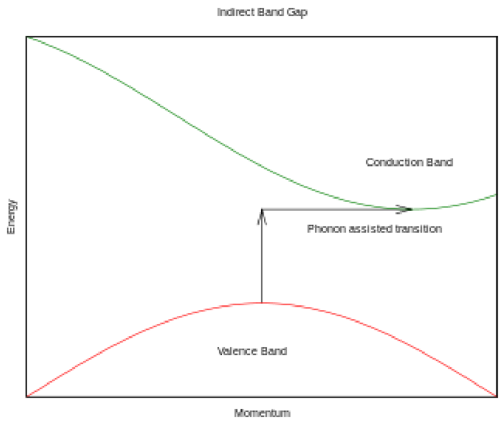


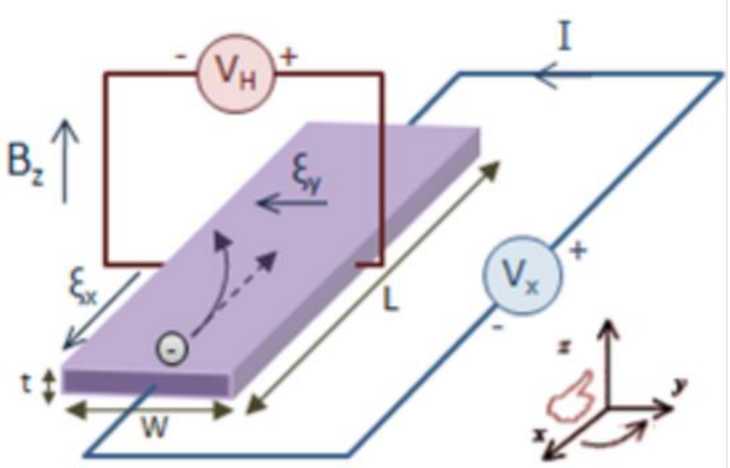
Doping



Carrier transport in solids



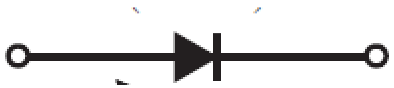


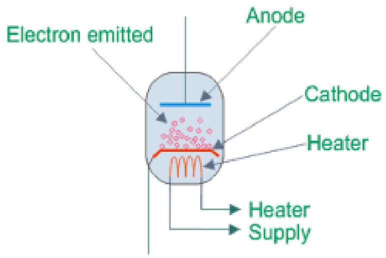


$$\mathscr{E}_y = \frac{J_x}{qp_0}\mathscr{B}_z = R_H J_x \mathscr{B}_z, \quad R_H \equiv \frac{1}{qp_0}$$

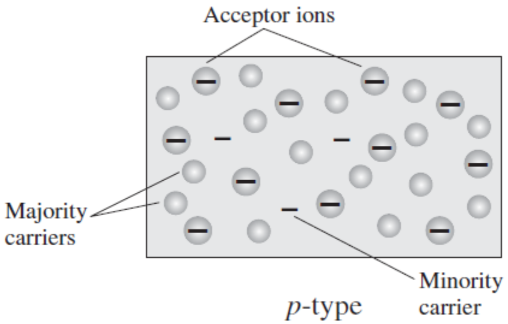
$$V_{\rm H} = \frac{I_x B_z}{nte}$$

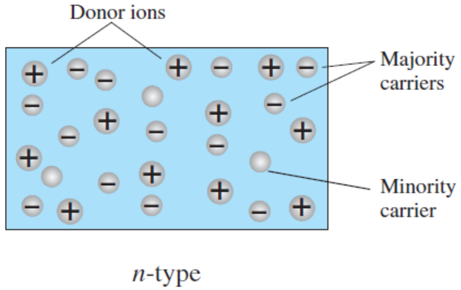
Diode: semiconductor junction

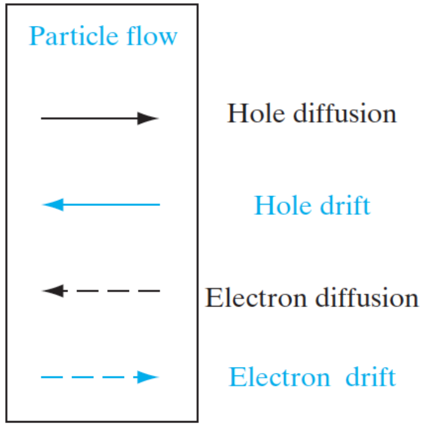


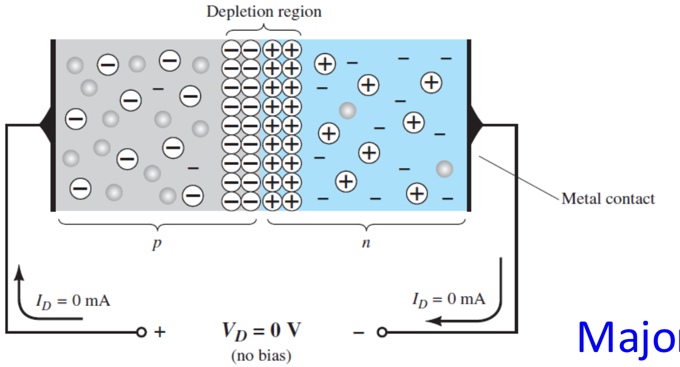


- Once we have both n-type and p-type materials available with us, what happens when we put two different kind of materials together.









Static and mobile charge.

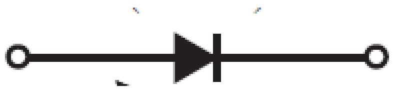
$$J_p(\text{drift}) + J_p(\text{diff.}) = 0$$

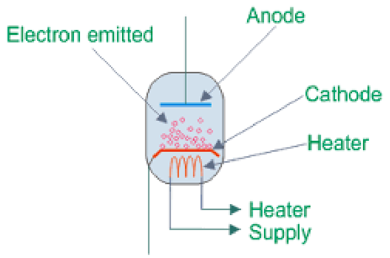
$$J_n(\text{drift}) + J_n(\text{diff.}) = 0$$

Majority and minority currents.

Equilibrium and steady state

Diode: semiconductor junction





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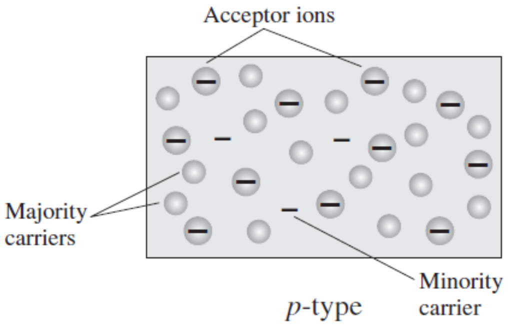

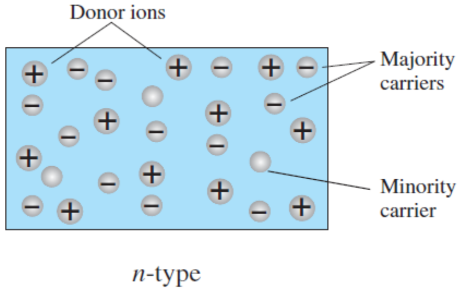

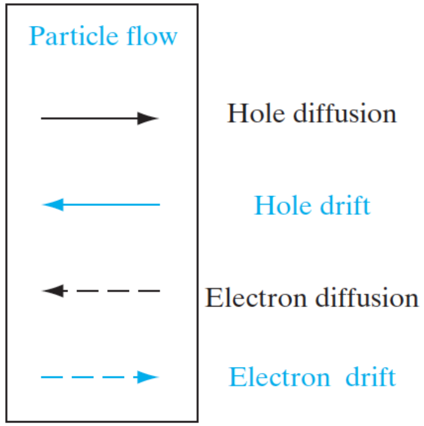

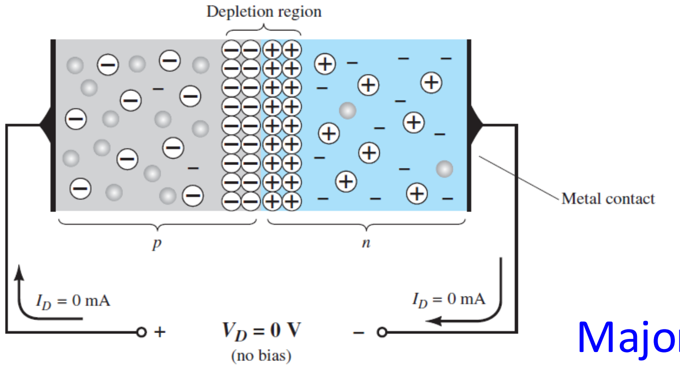

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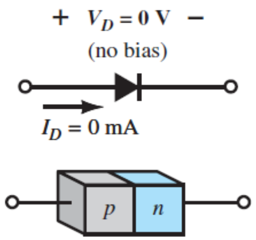
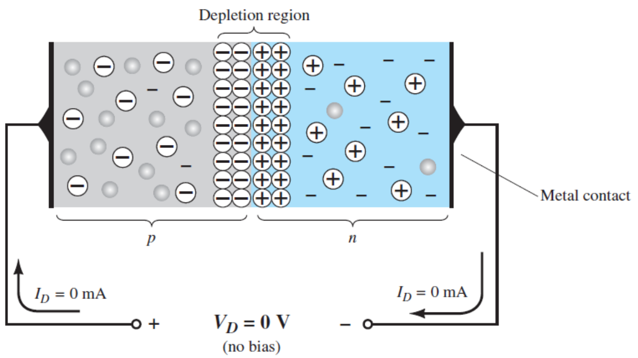
PN junction: under bias

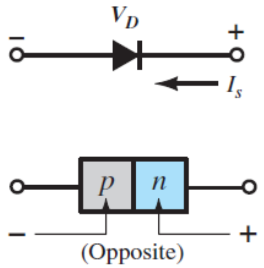
No bias

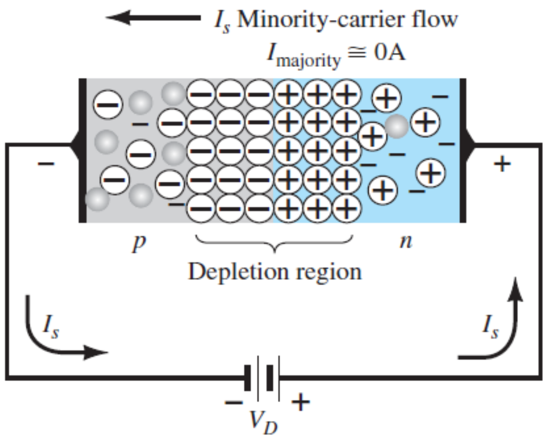




Depletion region

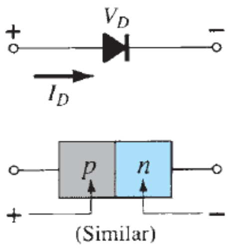
Reverse bias

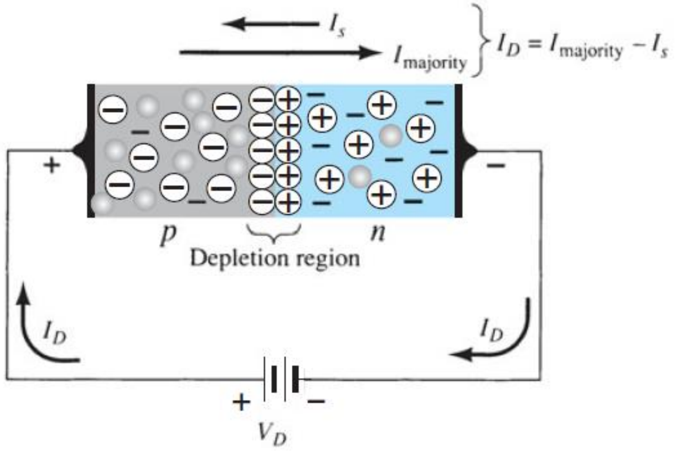




The current that exists under reverse-bias conditions is called the reverse saturation current: nA - µA

Forward bias



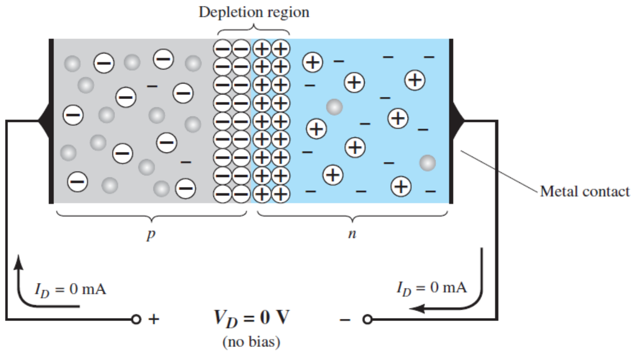


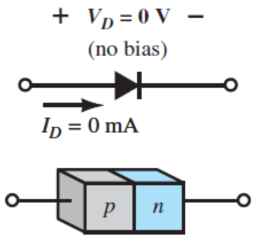
$$I_D = I_s(e^{V_D/nV_T} - 1)$$

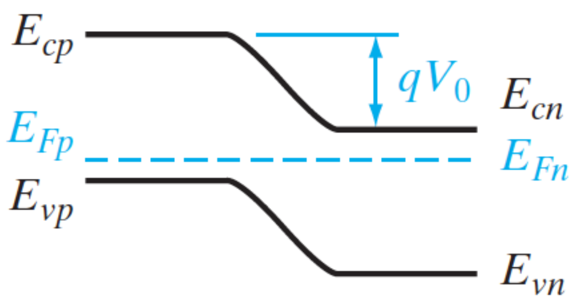
n – ideality factor of diode

PN junction: diode

Equilibrium conditions





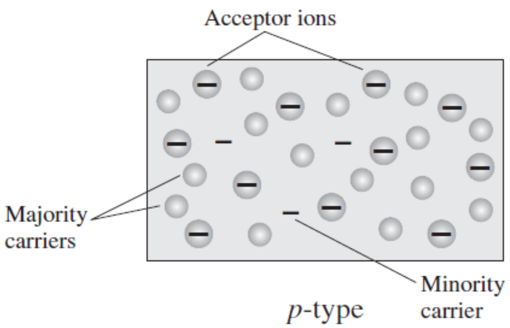


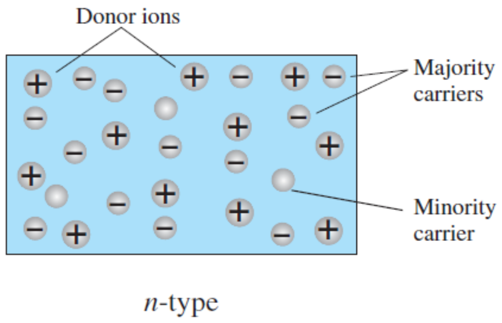
$$V_0 = \frac{kT}{q} \ln \frac{N_a}{n_i^2 / N_d} = \frac{kT}{q} \ln \frac{N_a N_d}{n_i^2}$$

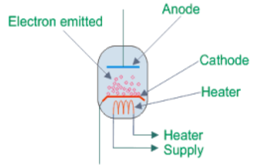
$$\boxed{W = \left[\frac{2\epsilon V_0}{q} \left(\frac{N_a + N_d}{N_a N_d} \right) \right]^{1/2} = \left[\frac{2\epsilon V_0}{q} \left(\frac{1}{N_a} + \frac{1}{N_d} \right) \right]^{1/2}}$$

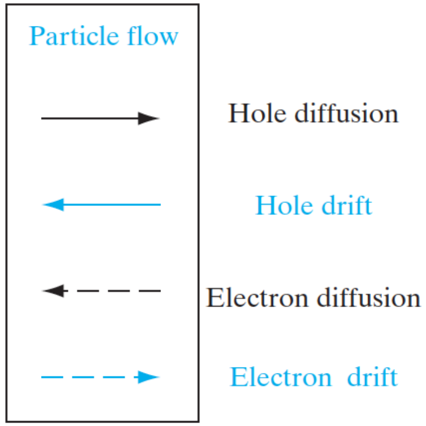
Depletion region

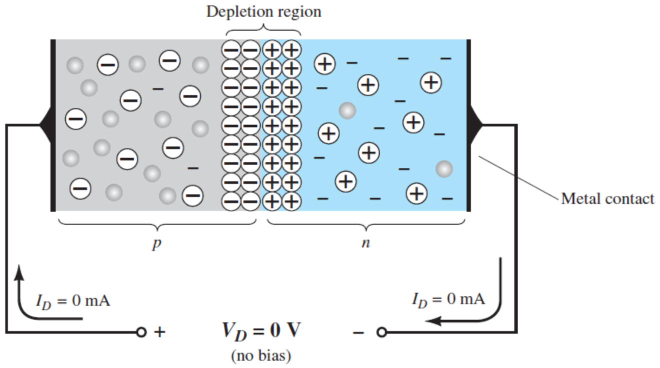
Summary



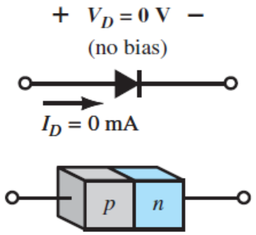








Equilibrium conditions



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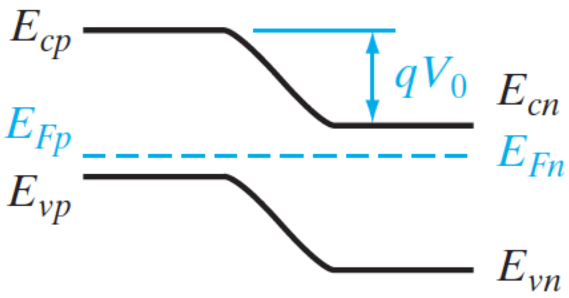

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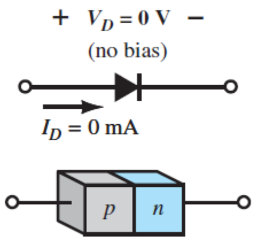
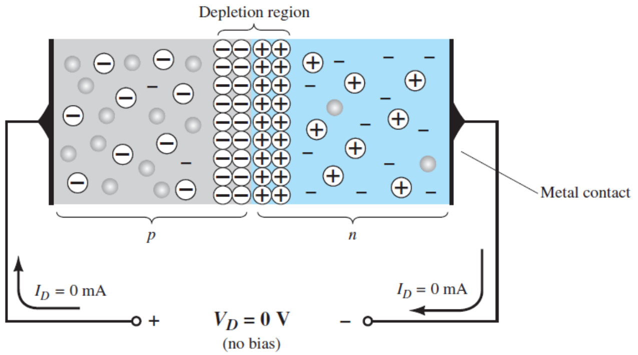
Majority and minority currents.

PN junction: under bias

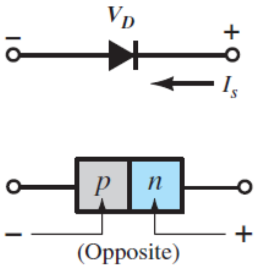
No bias

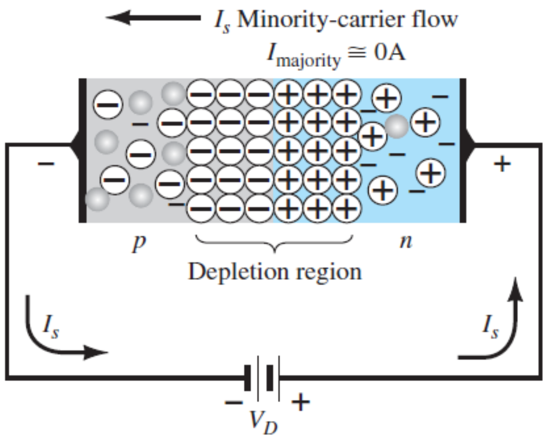




Depletion region

Reverse bias





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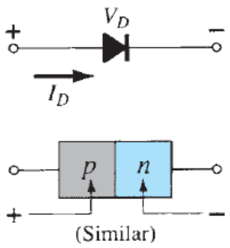
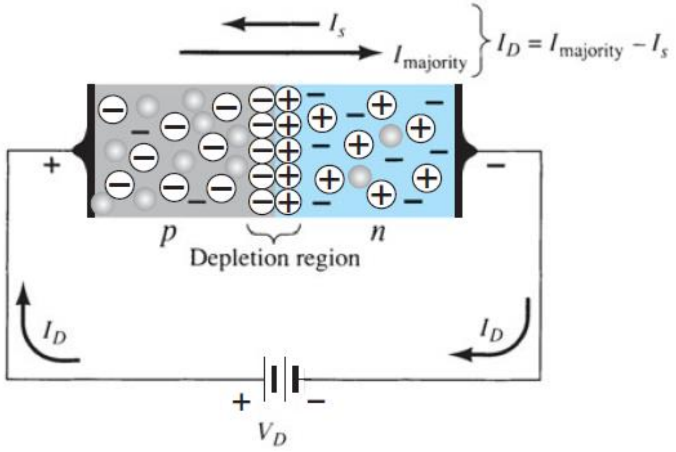
Forward bias





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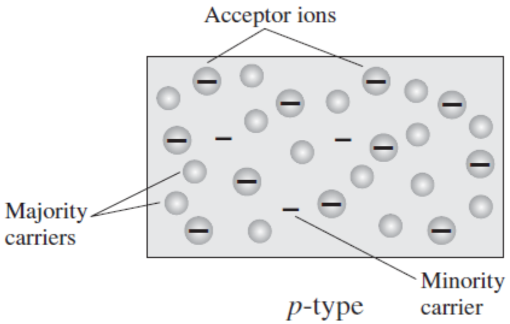
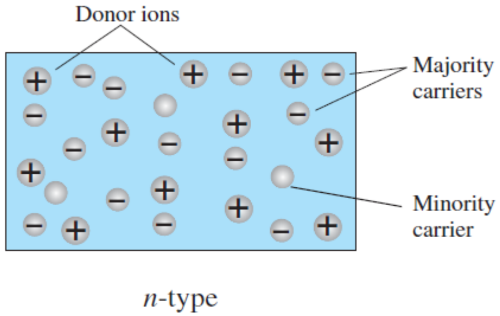
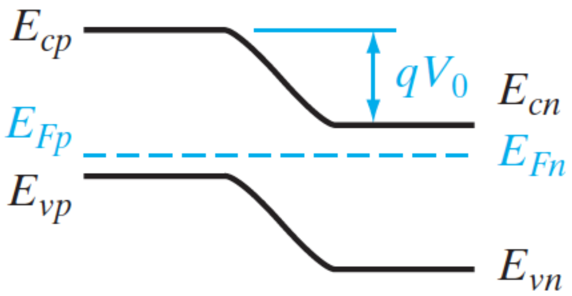
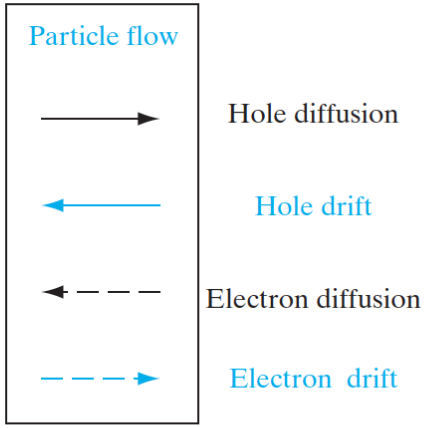
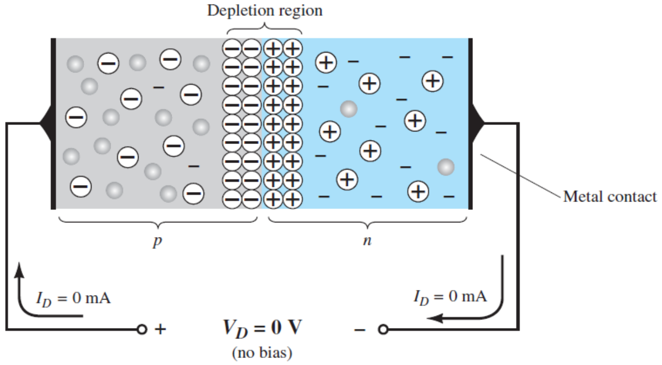
Review





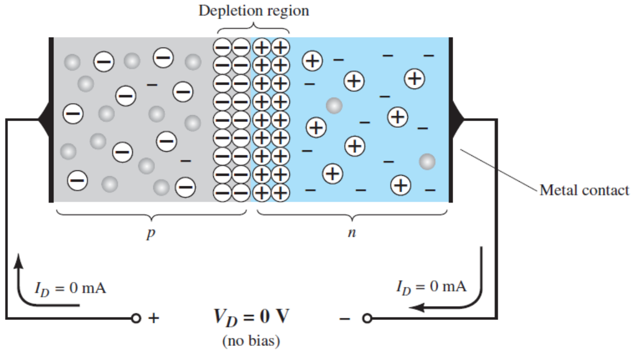




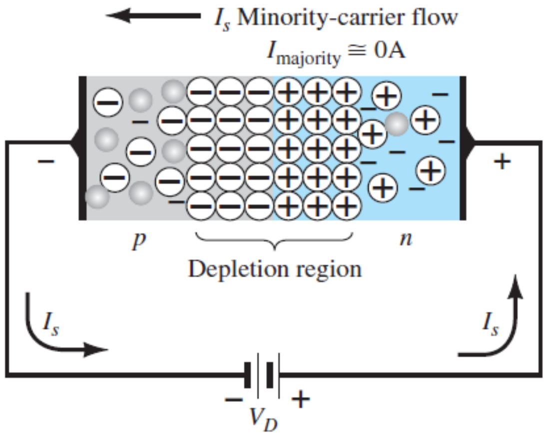


$$V_0 = \frac{kT}{q}\ln\frac{N_a}{n_i^2/N_d} = \frac{kT}{q}\ln\frac{N_aN_d}{n_i^2}$$

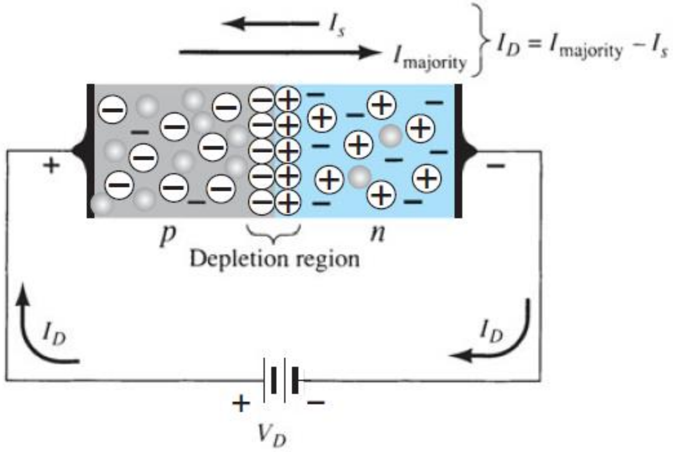
$$\boxed{W = \left[\frac{2\epsilon V_0}{q}\left(\frac{N_a + N_d}{N_aN_d}\right)\right]^{1/2} = \left[\frac{2\epsilon V_0}{q}\left(\frac{1}{N_a} + \frac{1}{N_d}\right)\right]^{1/2}}$$



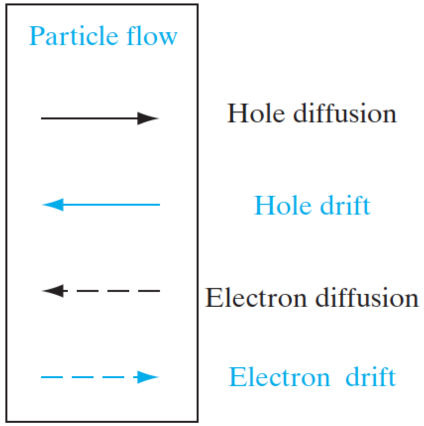
No bias

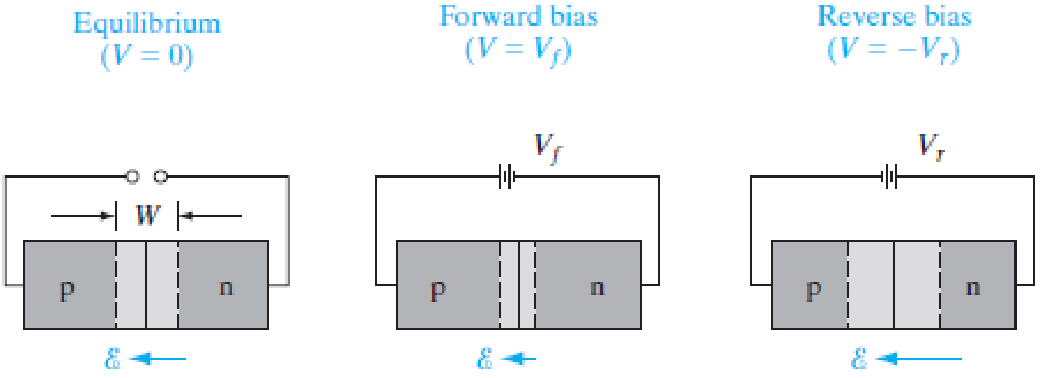


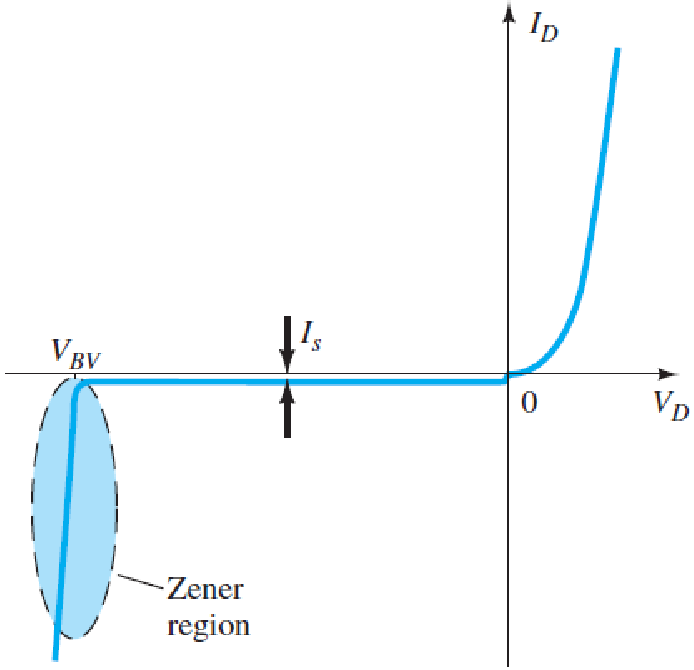
Reverse bias

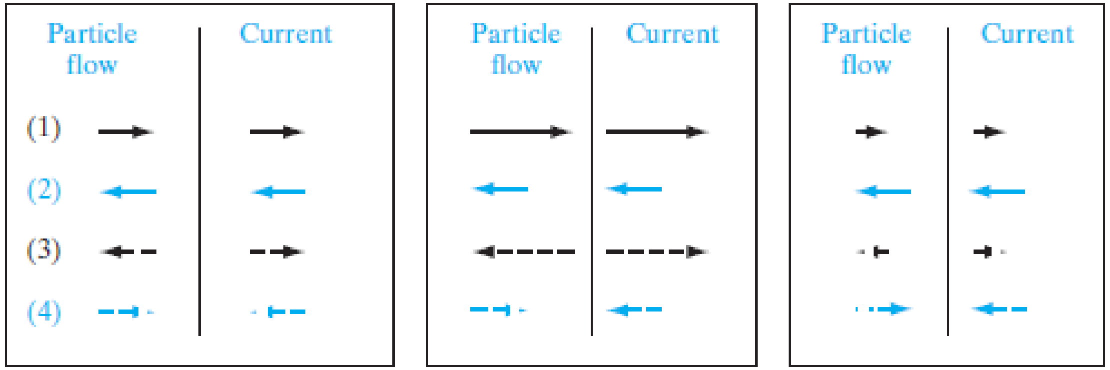


Forward bias









(1) Hole diffusion
(2) Hole drift
(3) Electron diffusion
(4) Electron drift

$$I_D = I_s(e^{V_D/nV_T} - 1)$$

n – ideality factor of diode

Thank you