Basic Electronics Engineering (Spring 2024)

Resources of PPT:

- www.google.com

- Digital Design, 4th Edition
  M. Morris Mano and Michael D. Ciletti

Semiconductor Fundamentals

Reference Book:

1. R. BOYLESTAD and L. NASHELSKY, "Electronic Devices And Circuit Theory", Prentice Hall.
2. Sedra and Smith, "Microelectronic Circuits", Oxford University Press

Source:

https://allbooksfordownloading.files.wordpress.com/2017/01/electronic-devices-circuit-theory-9th-edition-boylestad-2.pdf

https://ia601603.us.archive.org/0/items/ElectronicDevicesAndCircuitTheory/Electronic%20Devices%20and%20Circuit%20Theory.pdf

Semiconductor Fundamentals

Charge carriers:

Electrons	Holes
$Q = -1.6 \times 10^{-19}$ C	$Q = +1.6 \times 10^{-19}$ C

Static Mass $m_0 = 9.11 \times 10^{-31}$kg

Effective mass $m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$

Velocity of electron: v

Velocity of light: $c = 3 \times 10^8$ m/s.

Electron volt=$Q * V = 1.6 \times 10^{-19} \times 1$ J $= 1.6 \times 10^{-19}$ J.

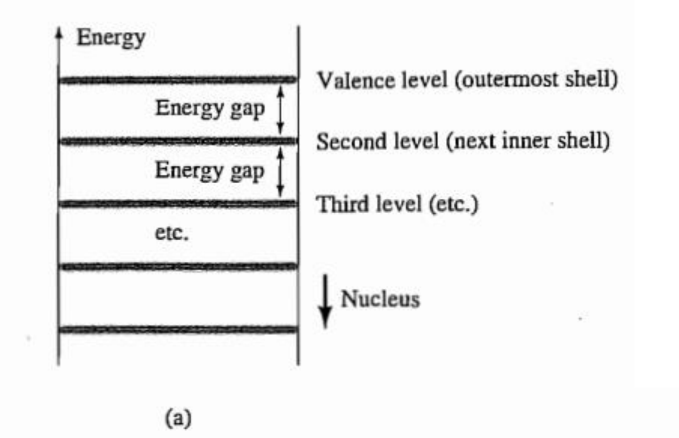
Total energy $= \frac{1}{2} m v^2 = Q * V = h * f = h * \frac{c}{\lambda}$

Planck's constant = $h = 6.626 \times 10^{-34}$ J-s.

Frequency = f Hz.

Wavelength = λ m.

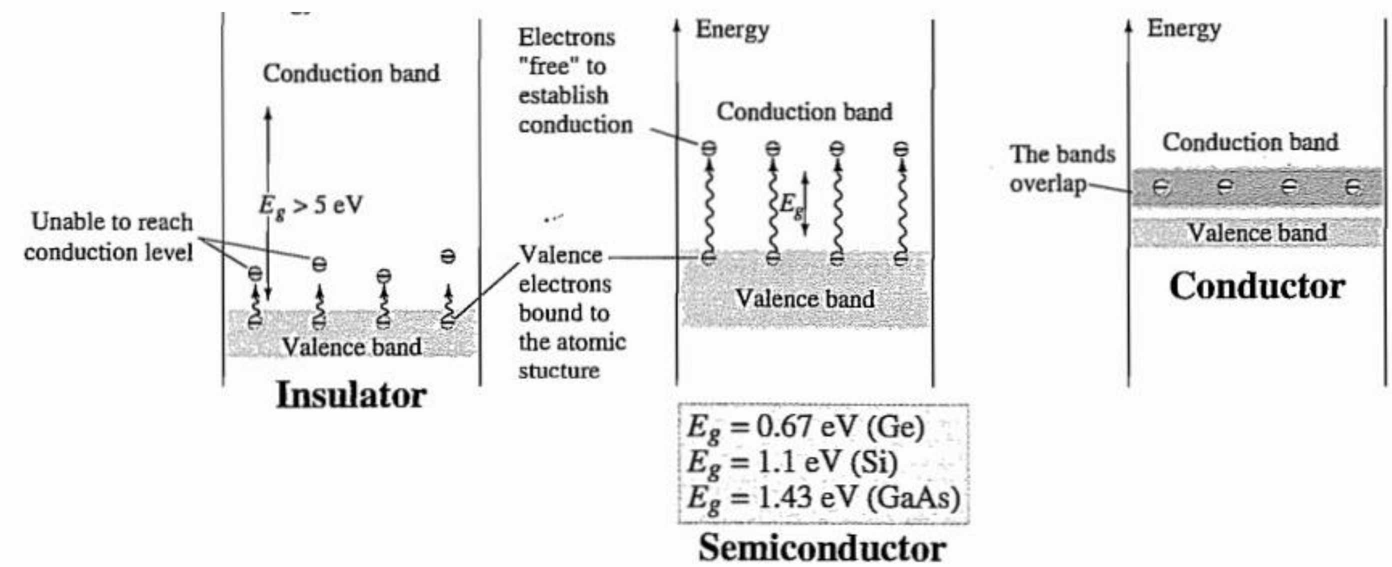
Semiconductor Fundamentals



Electrons can possess only some discrete energy levels, known as energy bands.

Based on the energy gap, there are three types of materials:

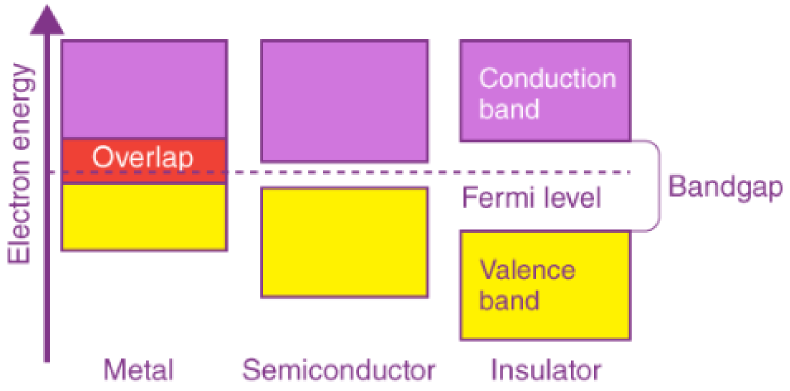
- ➢ Conductor/ Metal
- ➢ Insulator
- ➢ Semiconductor

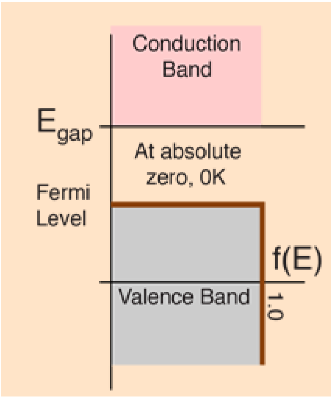


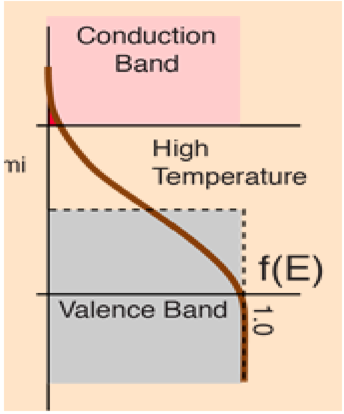
Semiconductor Fundamentals

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

$f(E)$: The probability of occupancy of the state with energy E.
E_F: Fermi energy level is defined as the maximum energy point that an electron could reach at absolute zero temperature.
k_b: Boltzmann's constant = 1.38×10^{-23} J/K.







No electrons can be above the Fermi level at 0K, since none have energy above the Fermi level and there are no available energy states in the band gap.

At high temperatures, some electrons can reach the conduction band and contribute to electric current.

Bandgap energy $= E_g = E_c - E_V$

Semiconductor Fundamentals

Semiconductor

Intrinsic

An intrinsic semiconductor has no doping impurity. The conductivity of this semiconductor will be zero at room temperature, according to the energy band theory. Two examples of intrinsic semiconductors are Si and Ge.

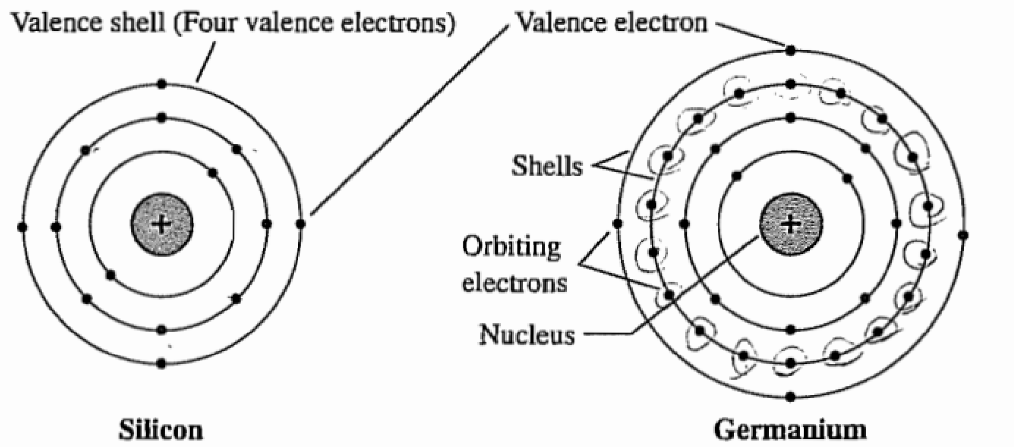
Extrinsic

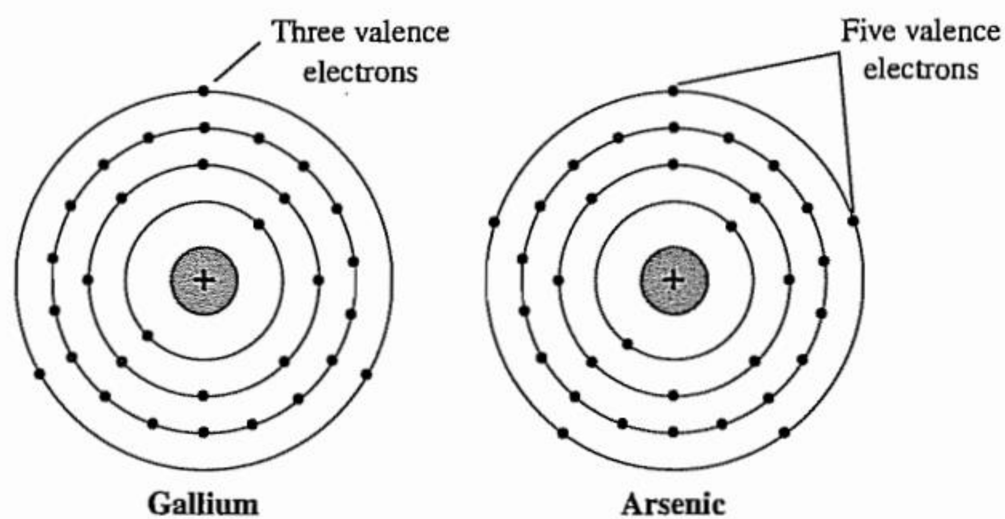
An extrinsic semiconductor contains doping impurity. Examples of extrinsic semiconductors are GaAs. Based on the dopant, it can be of two types.

p-type

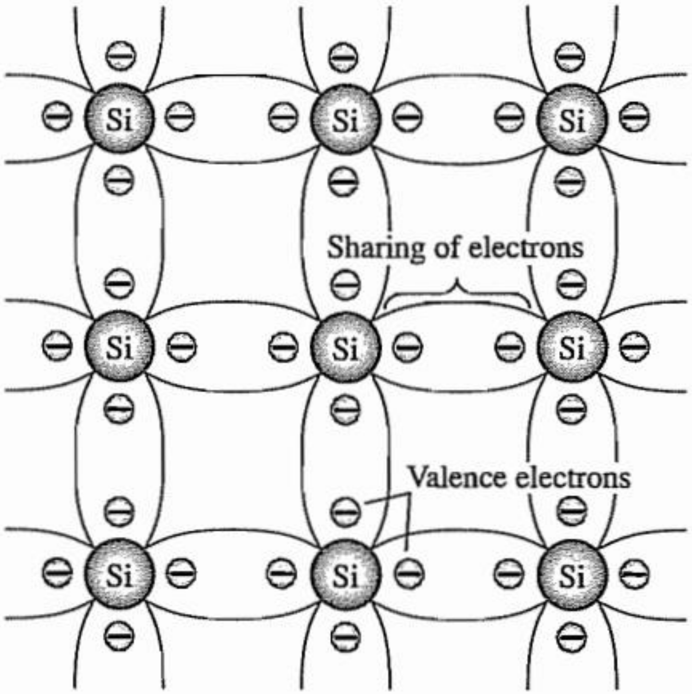
n-type

Semiconductor Fundamentals

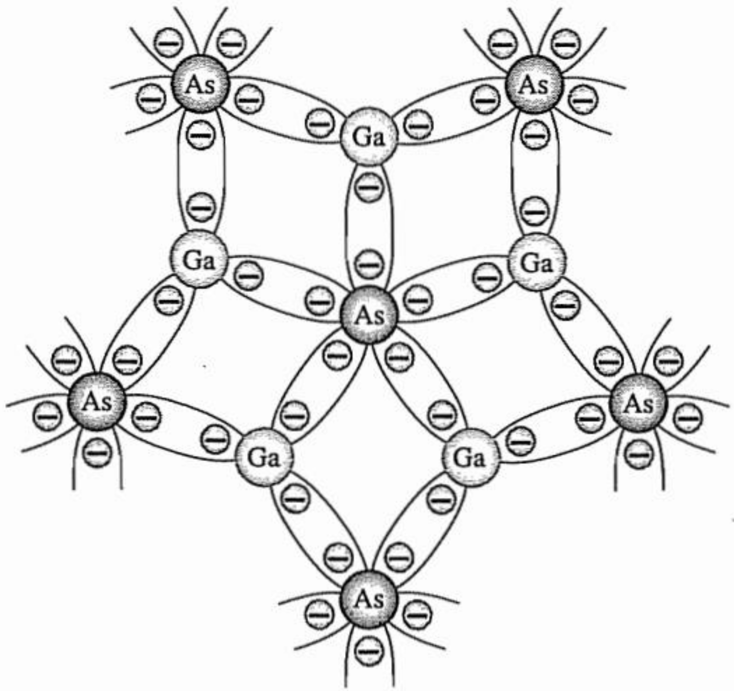




Semiconductor Fundamentals



Covalent bonding of the silicon atom.



Covalent bonding of the GaAs crystal.

Intrinsic Carriers

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

Semiconductor Fundamentals

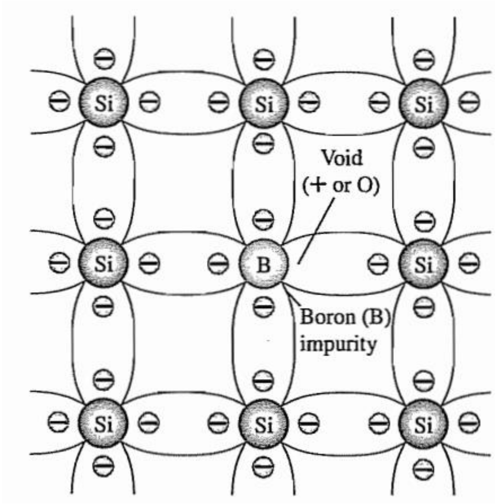
Extrinsic Semiconductor:

•Extrinsic semiconductors are divided into two categories as a result of doping: atoms with an additional electron (n-type for negative, from group V like Arsenic, Antimony) and atoms with one fewer electron (p-type for positive, from group III like boron, gallium, indium).

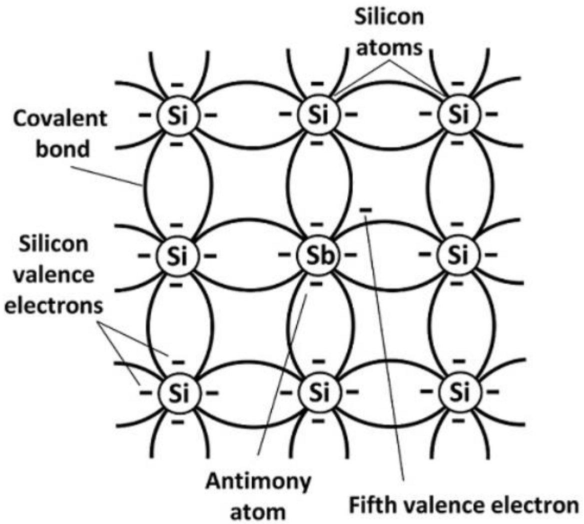
•Doping is the purposeful introduction of impurities into a very pure, or intrinsic, semiconductor in order to change its electrical characteristics. The kind of semiconductor determines the impurities.

•Diffused impurities with five valence electrons are called donors.

•Diffused impurities with three valence electrons are called acceptors.

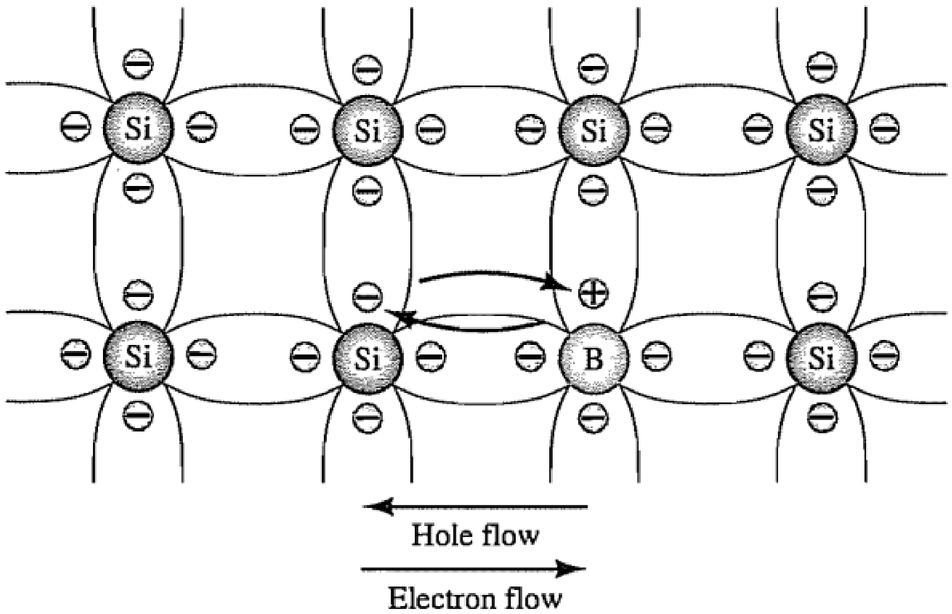


p-type material



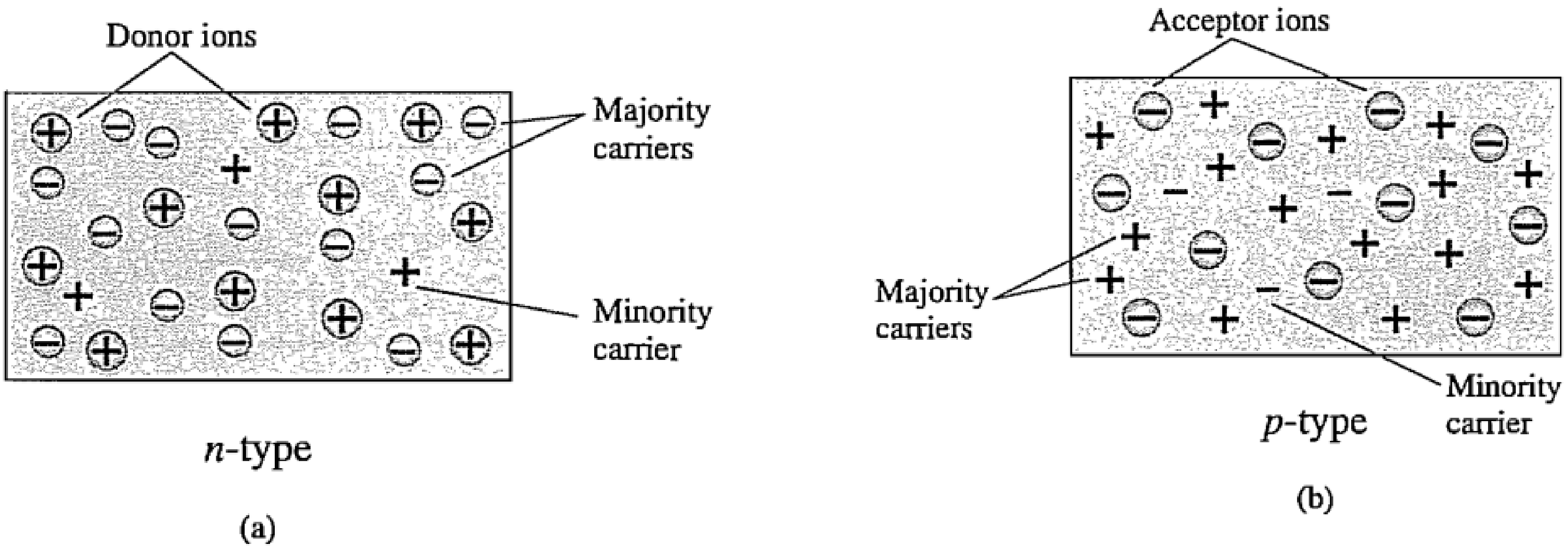
n-type material

Semiconductor Fundamentals



Electron versus hole flow.

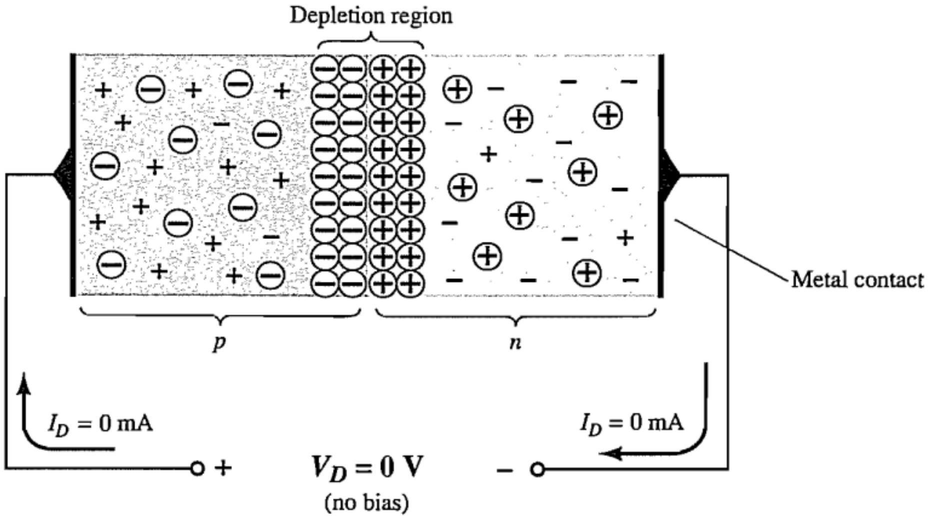
Semiconductor Fundamentals

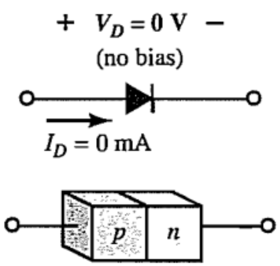


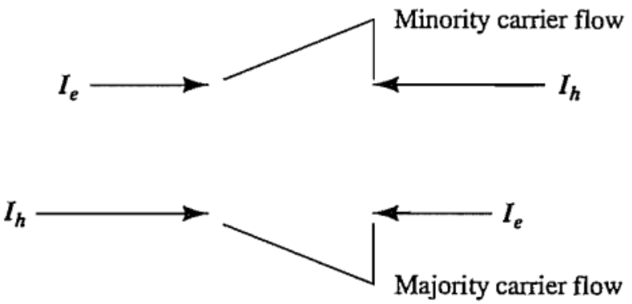
(a) n-type material; (b) p-type material.

pn-junction diode

No Applied Bias ($V = 0$ V)



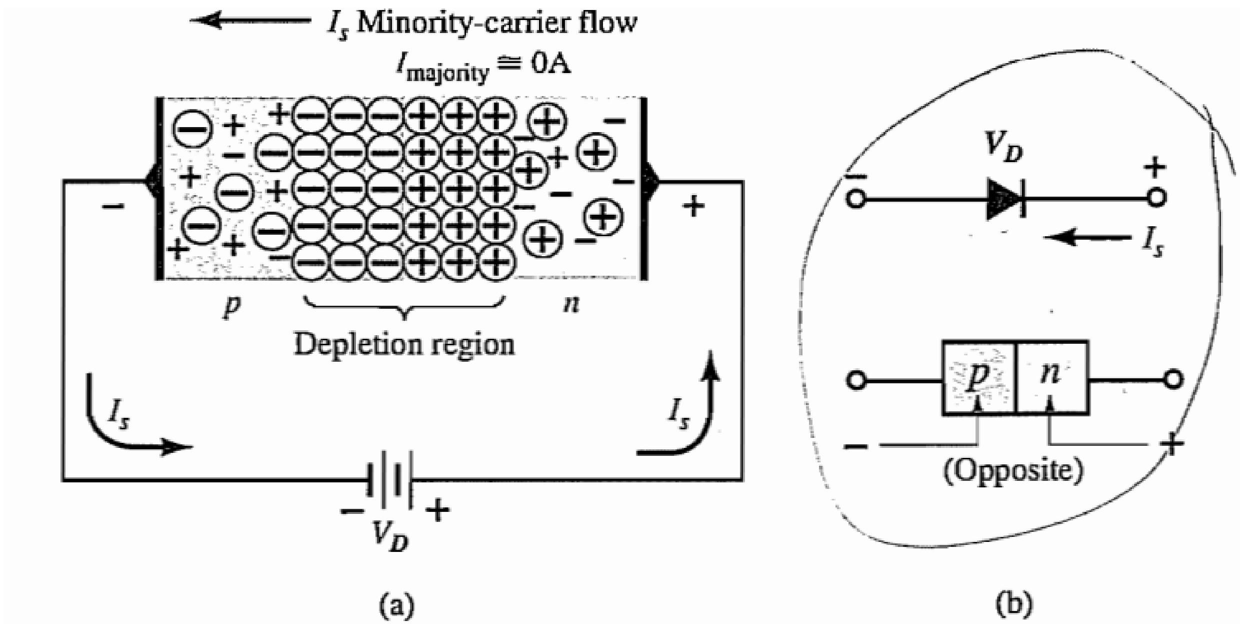




This region of uncovered positive and negative ions is called the depletion region due to the "depletion" of free carriers in the region.

pn-junction diode

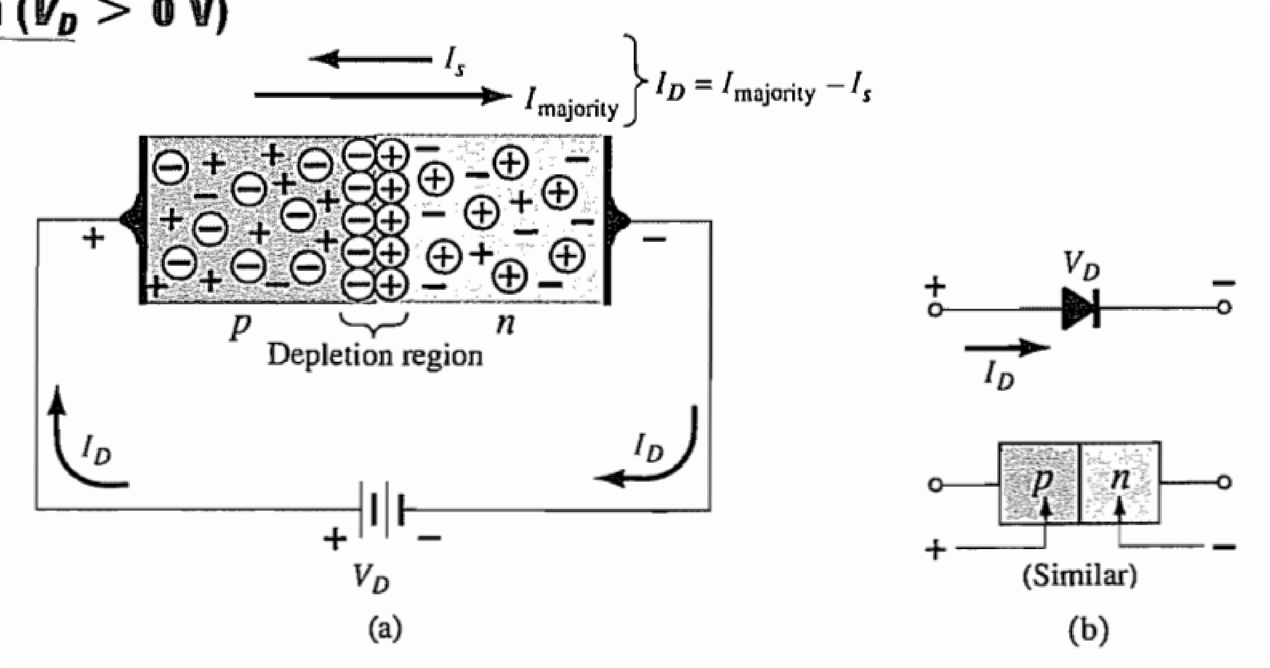
Reverse-Bias Condition ($V_D < 0$ V)



The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by I_s.

pn-junction diode

Forward-Bias Condition ($V_D > 0$ V)

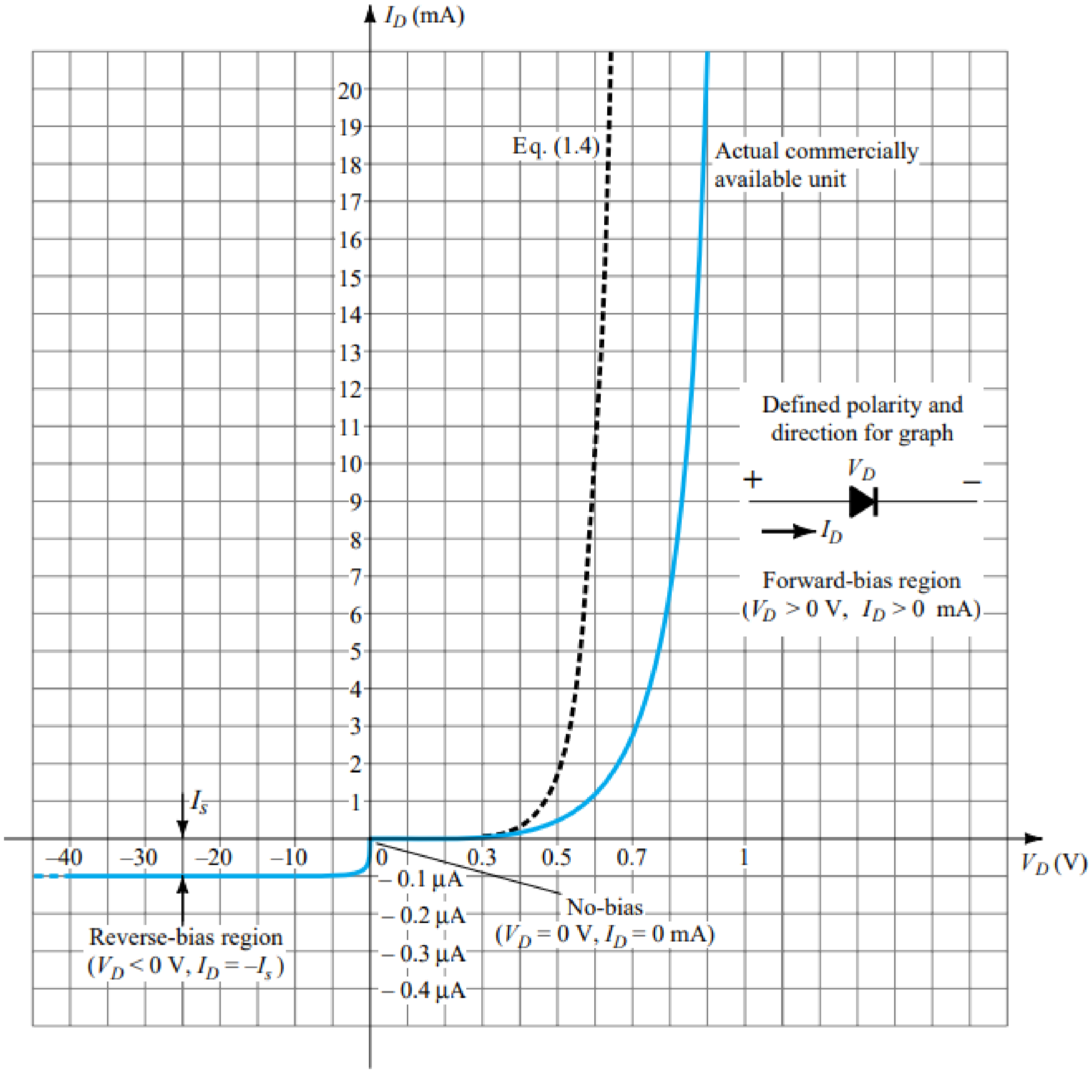


$$\boxed{I_D = I_s(e^{V_D/nV_T} - 1)}$$

$$V_T = \frac{kT}{q}$$

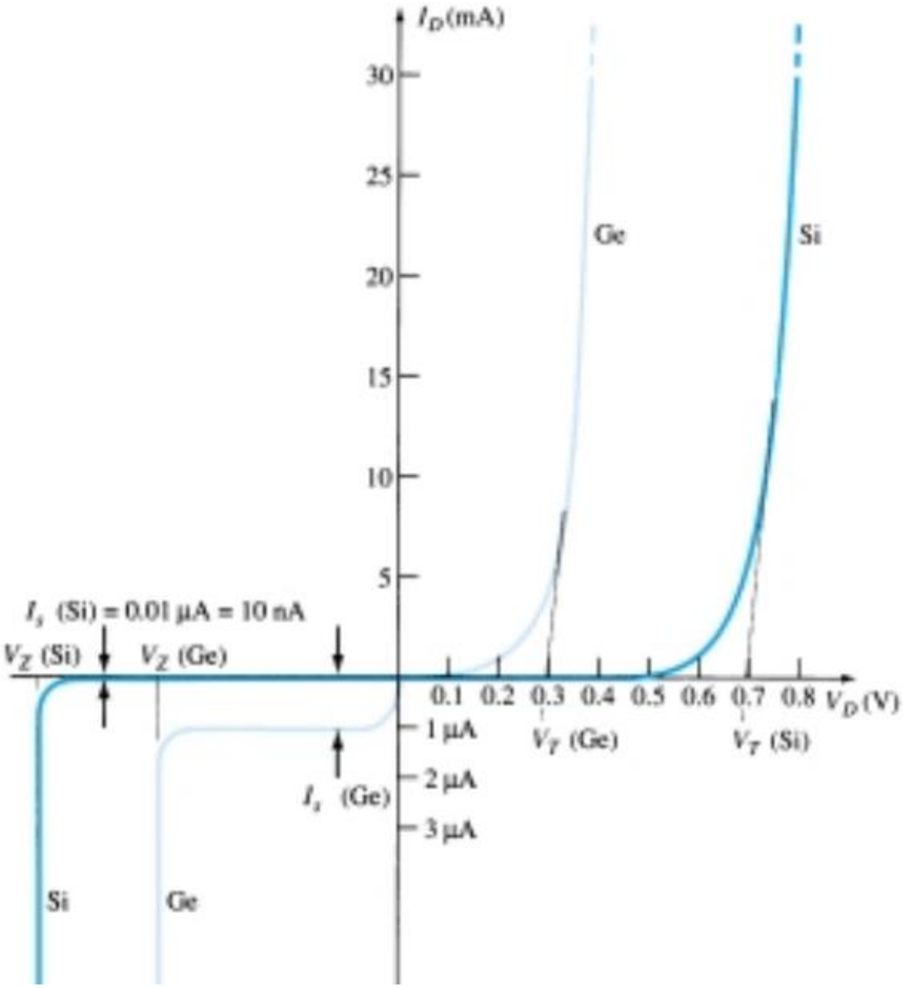
Reverse saturation current: I_s
Diode current: I_D
Diode voltage: V_D
Diode voltage: V_T
Boltzmann's Constant: k
Temperate in Kelvin: T
Ideality factor: $n = 1$
$n = 2$

pn-junction diode



V-I characteristics of pn-junction diode

pn-junction diode



Cut-in Voltage: $V_T = 0.3\ V$ for Ge diode
= 0.7 V for Si diode

pn-junction diode

Temperature Effects:

The reverse saturation current I_s will just about double in magnitude for every 10°C increase in temperature.

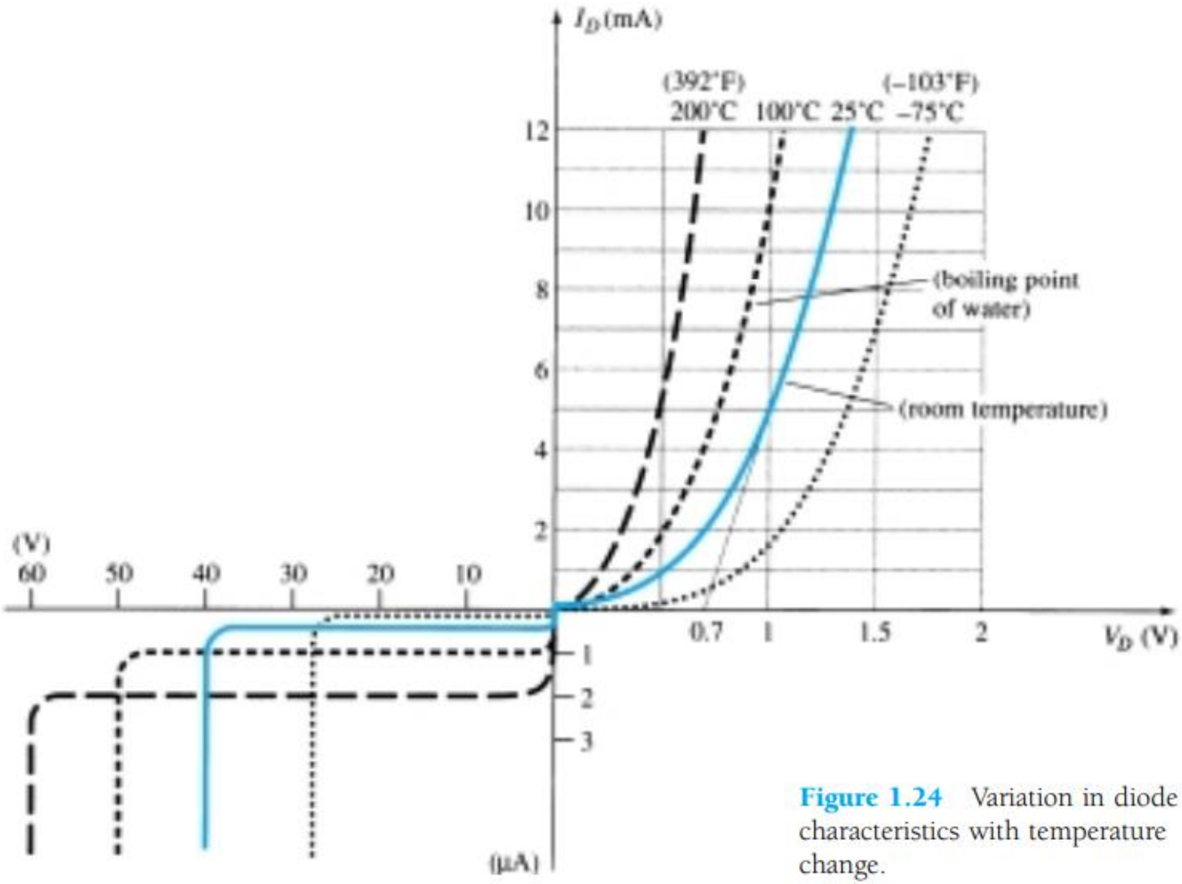
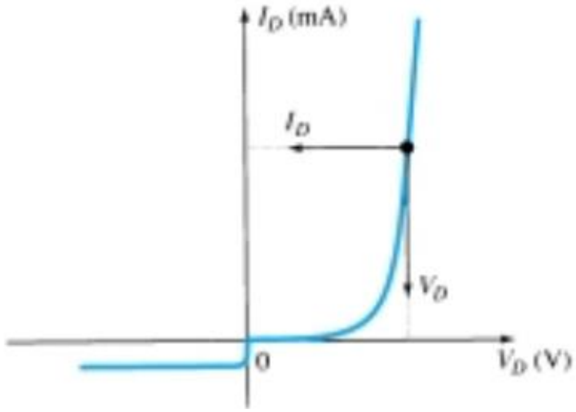


Figure 1.24 Variation in diode characteristics with temperature change.

pn-junction diode

DC or Static Resistance $R_D = \dfrac{V_D}{I_D}$



Determine the dc resistance levels for the diode of Fig. 1.26 at
(a) $I_D = 2$ mA
(b) $I_D = 20$ mA
(c) $V_D = -10$ V

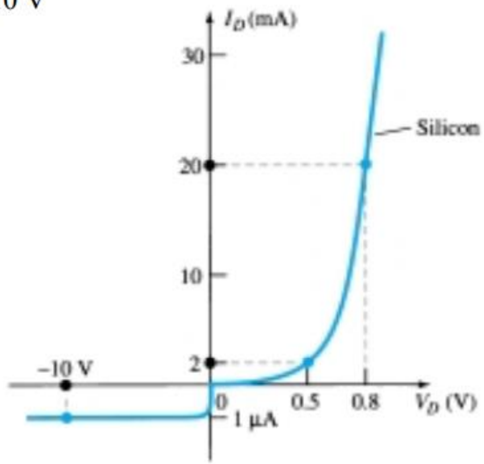


Figure 1.26 Example 1.1

(a) At $I_D = 2$ mA, $V_D = 0.5$ V (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{0.5\text{ V}}{2\text{ mA}} = \mathbf{250\ \Omega}$$

(b) At $I_D = 20$ mA, $V_D = 0.8$ V (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{0.8\text{ V}}{20\text{ mA}} = \mathbf{40\ \Omega}$$

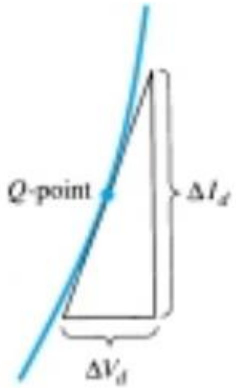
(c) At $V_D = -10$ V, $I_D = -I_s = -1\ \mu$A (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{10\text{ V}}{1\ \mu\text{A}} = \mathbf{10\ M\Omega}$$

pn-junction Diode

AC or Dynamic Resistance

$$r_d = \frac{\Delta V_d}{\Delta\, I_d}$$



$$\frac{d}{dV_D}(I_D) = \frac{d}{dV}[I_s(e^{kV_D/T_K} - 1)]$$

$$\frac{dI_D}{dV_D} = \frac{k}{T_K}(I_D + I_s)$$

At room temperature 25° C, T=273+25 =298 K,

$$\frac{dV_D}{dI_D} \cong \frac{0.026}{I_D}$$

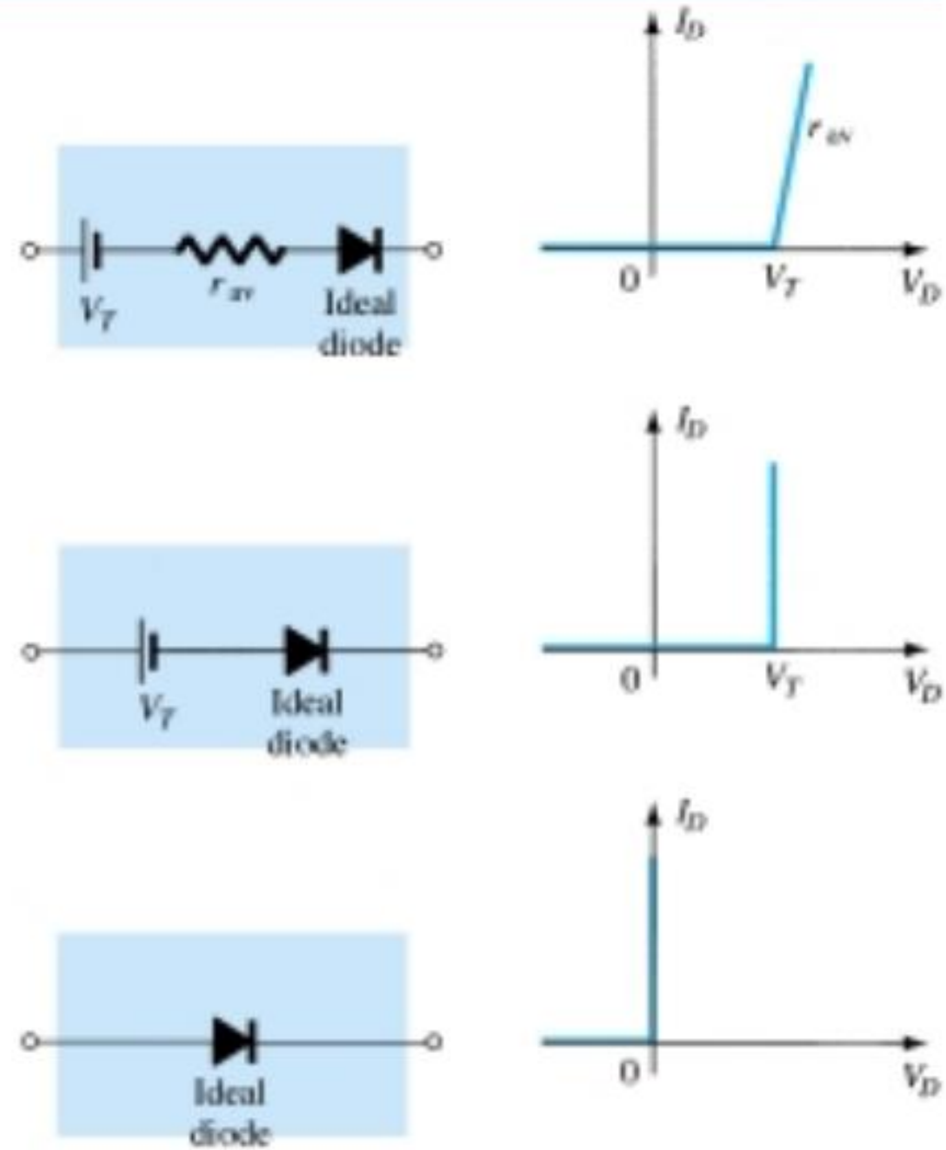
$$\boxed{r_d = \frac{26\text{ mV}}{I_D}}_{\text{Ge,Si}}$$

pn-junction Diode Equivalent Circuit

Piecewise-linear model

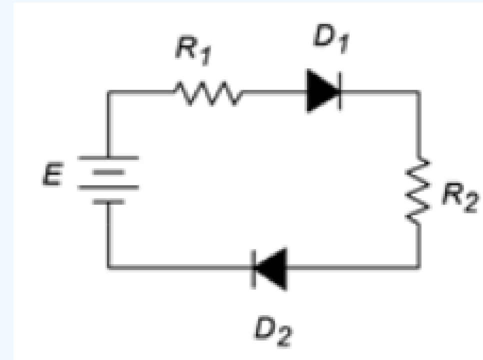
Simplified model

Ideal device



pn-junction Diode Circuit Example

Determine the circulating current for the circuit . Also find the diode and resistor voltages. Assume the power supply is 9 volts, the diodes are silicon and R1 = 1 k Ω , R2 = 2 k Ω .



According to KVL, the applied source must equal the sum of the voltage drops across the resistors and diodes as this is a single loop. Both diodes are forward-biased (conventional current entering the anodes).

$$I = \frac{E - V_{knee1} - V_{knee2}}{R_1 + R_2}$$

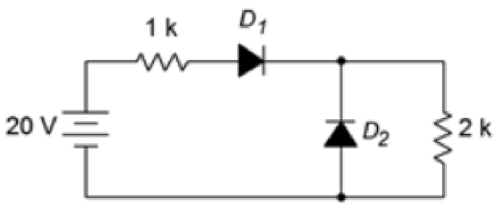
$$I = \frac{9V - 0.7V - 0.7V}{1k\Omega + 2k\Omega}$$

$$I = 2.533mA$$

What happens if the diode has finite resistance value?

pn-junction Diode Circuit Example

Determine the diode and resistor voltages for the circuit. Assume the diodes are silicon.



The first thing to notice is that D1 is forward-biased while D2 is reverse-biased. Therefore, the 20 volt source must equal the drop across D1 and the two resistors. D2 will take on whatever the drop across the 2 k Ω works out to as they are in parallel.

$$I = \frac{E - V_{D1}}{R_1 + R_2}$$

$$I = \frac{20V - 0.7V}{1k\Omega + 2k\Omega}$$

$$I = 6.433mA$$

Note that virtually no current flows down through D2 as it is reverse-biased. Using Ohm's law, the drop across the first resistor is 6.433 volts and for the second resistor, 12.867 volts.

Source:
https://eng.libretexts.org/Bookshelves/Electrical_Engineering/Electronics/Book%3A_Semiconductor_Devices_-_Theory_and_Application_(Fiore)/02%3A_PN_Junctions_and_Diodes/2.4%3A_Diode_Circuit_Models