Semiconductor Diode

Dr Mohammad Abdur Rashid

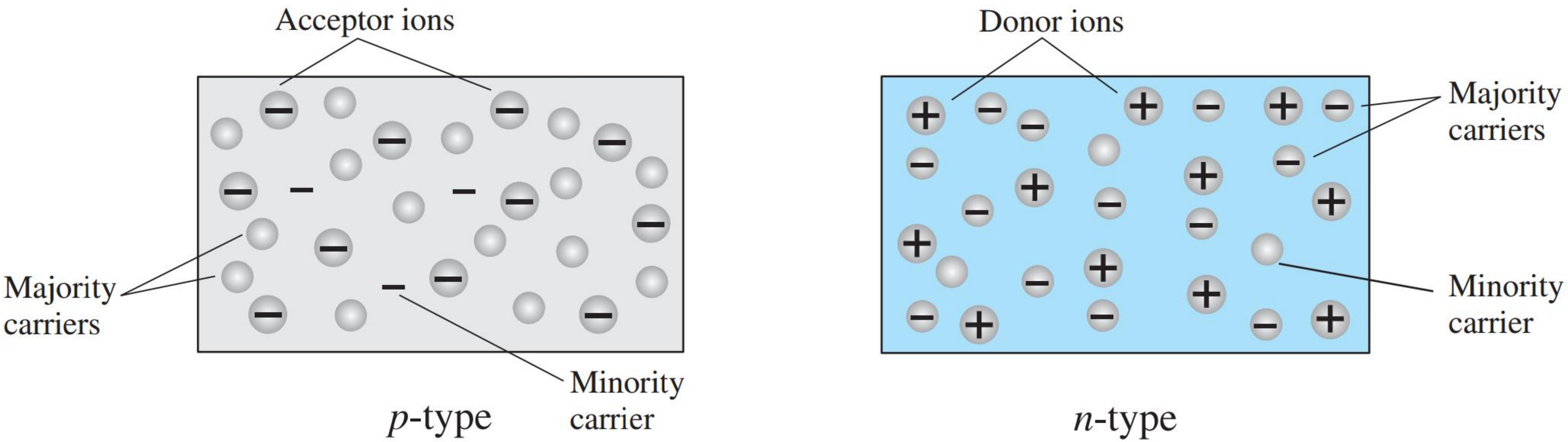
Readings

Elementary Solid State Physics – M. Ali Omar

Chapter 7: Semiconductors II: Devices

Section: 7.1 – 7.3

Extrinsic semiconductor



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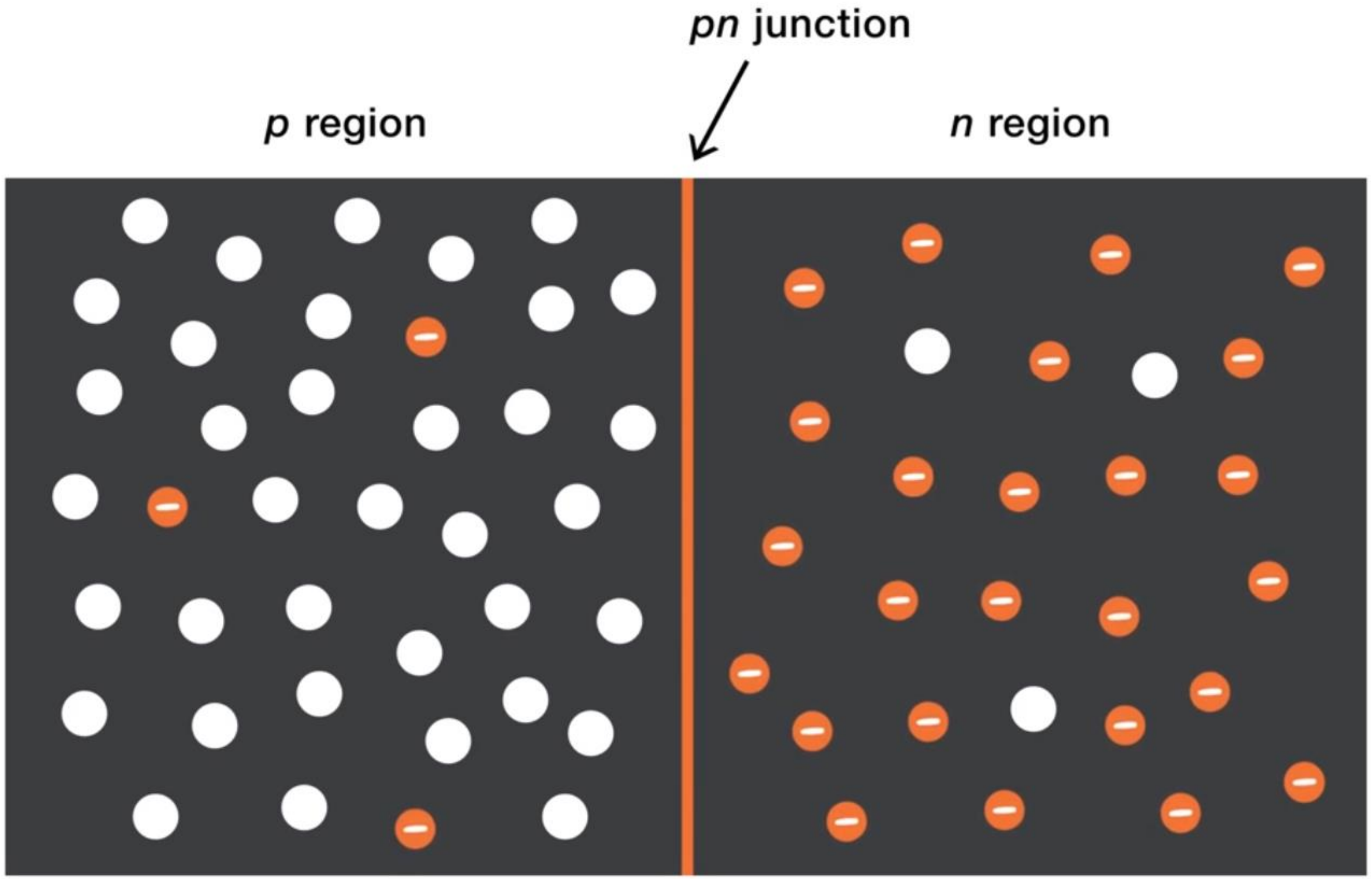
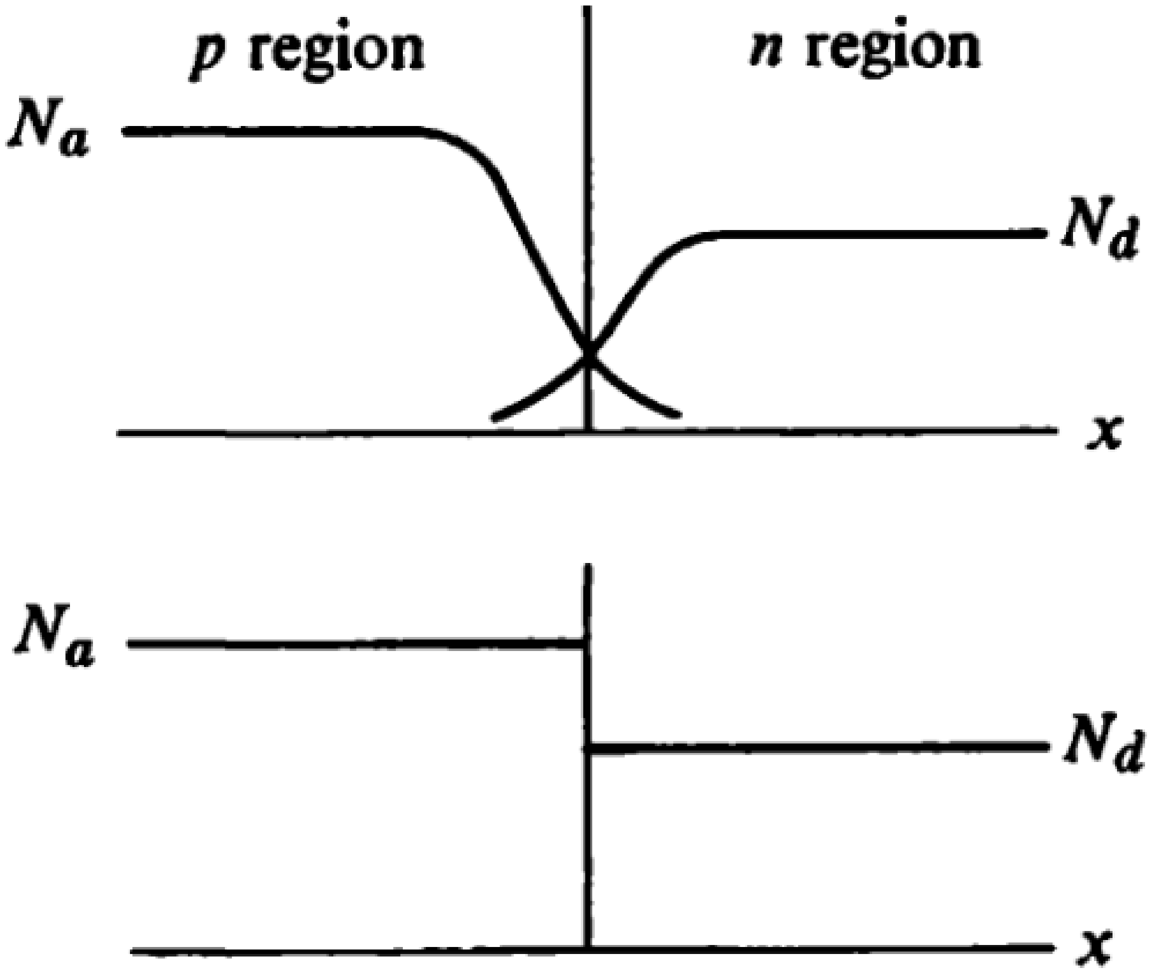
p-*n* junction



p-*n* junction



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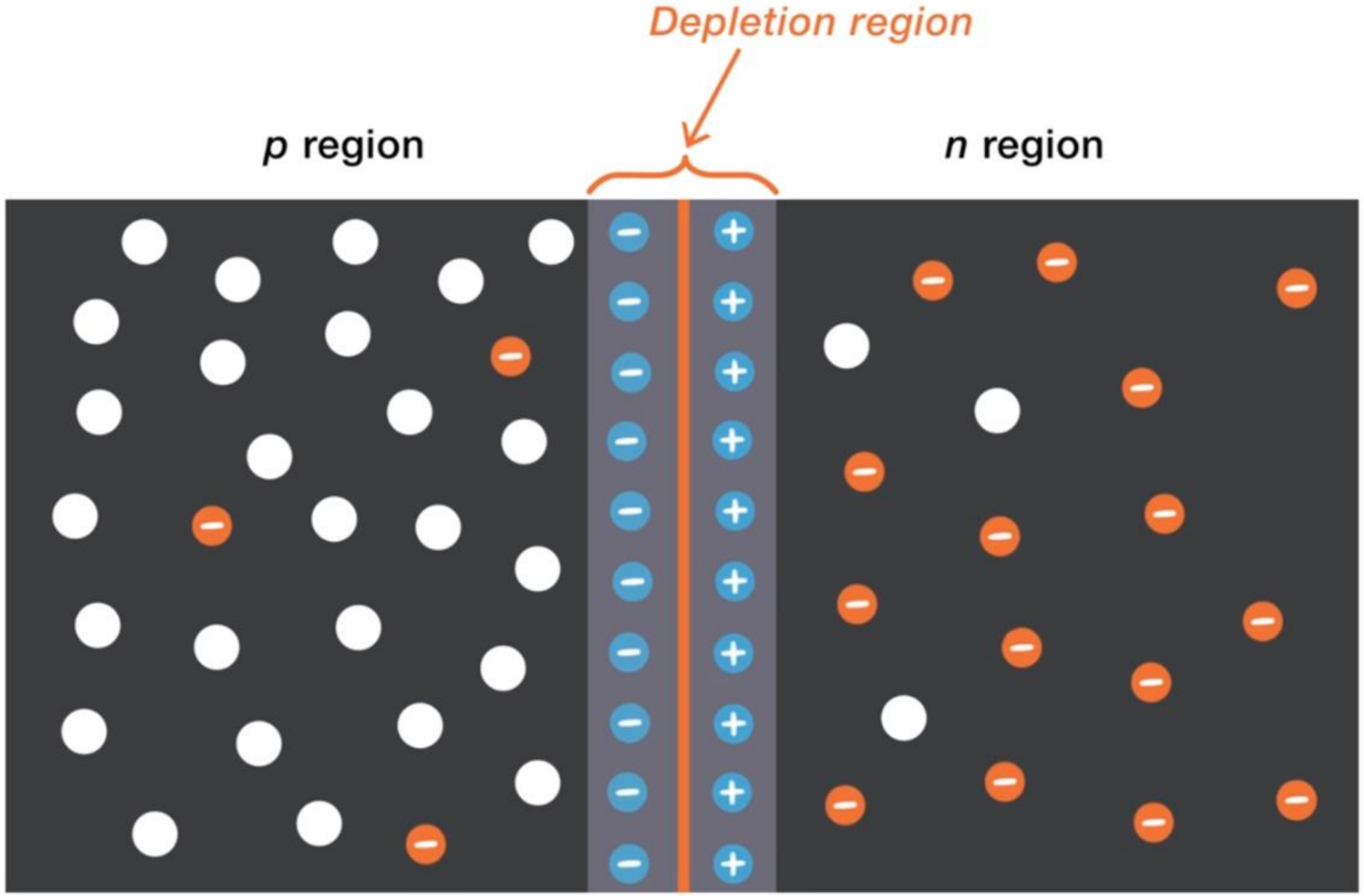
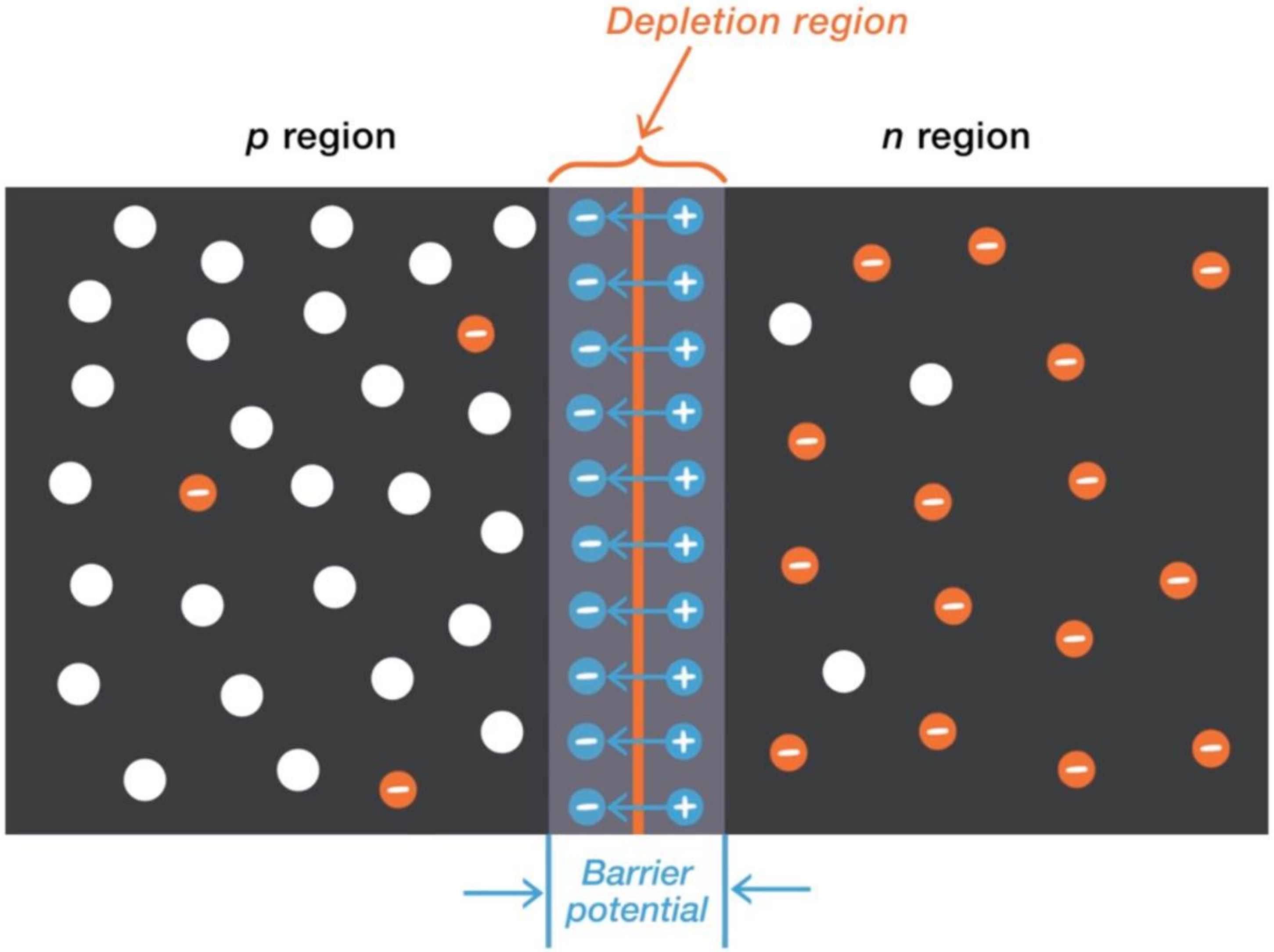
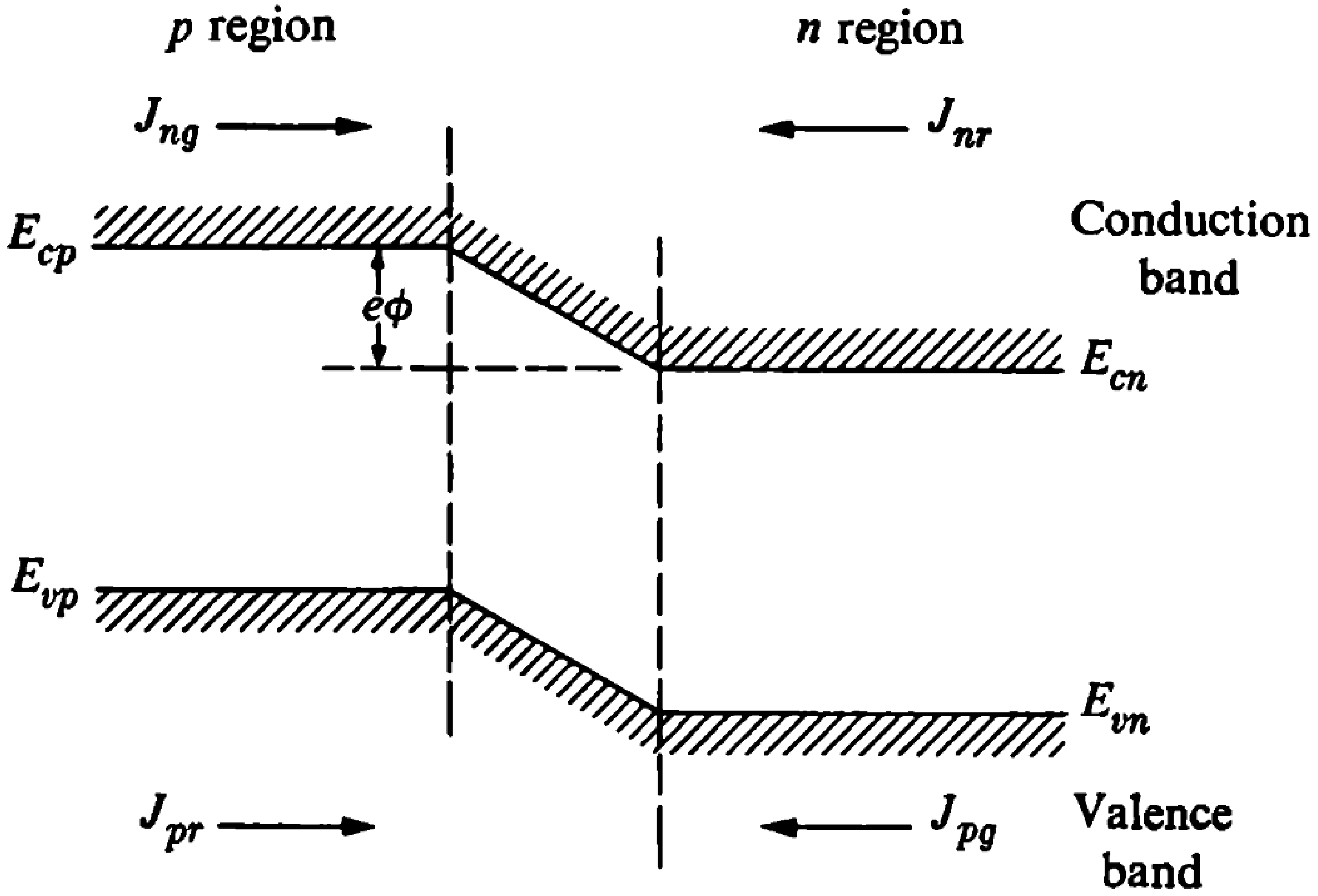
p-*n* junction



p-*n* junction



p-*n* junction



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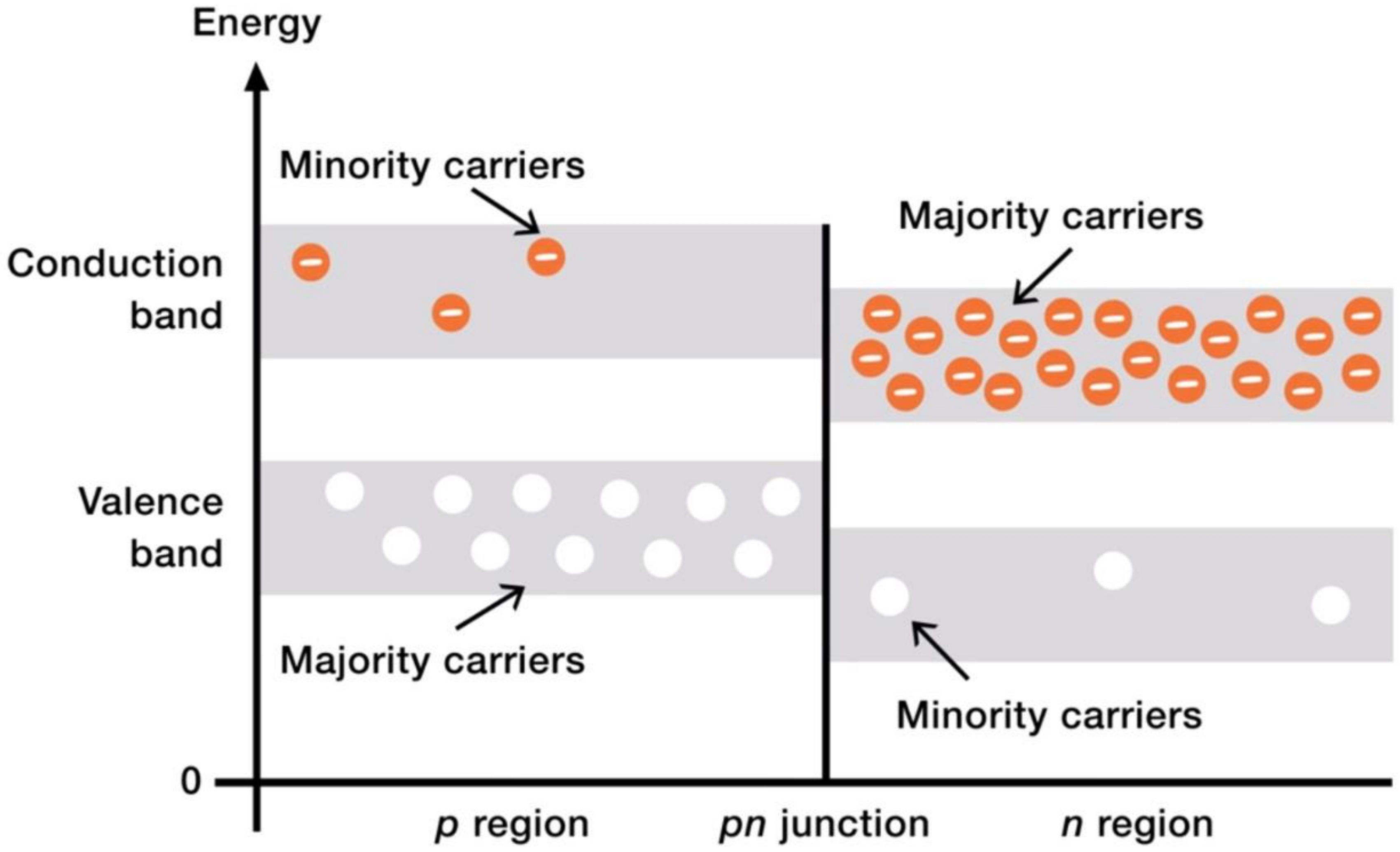
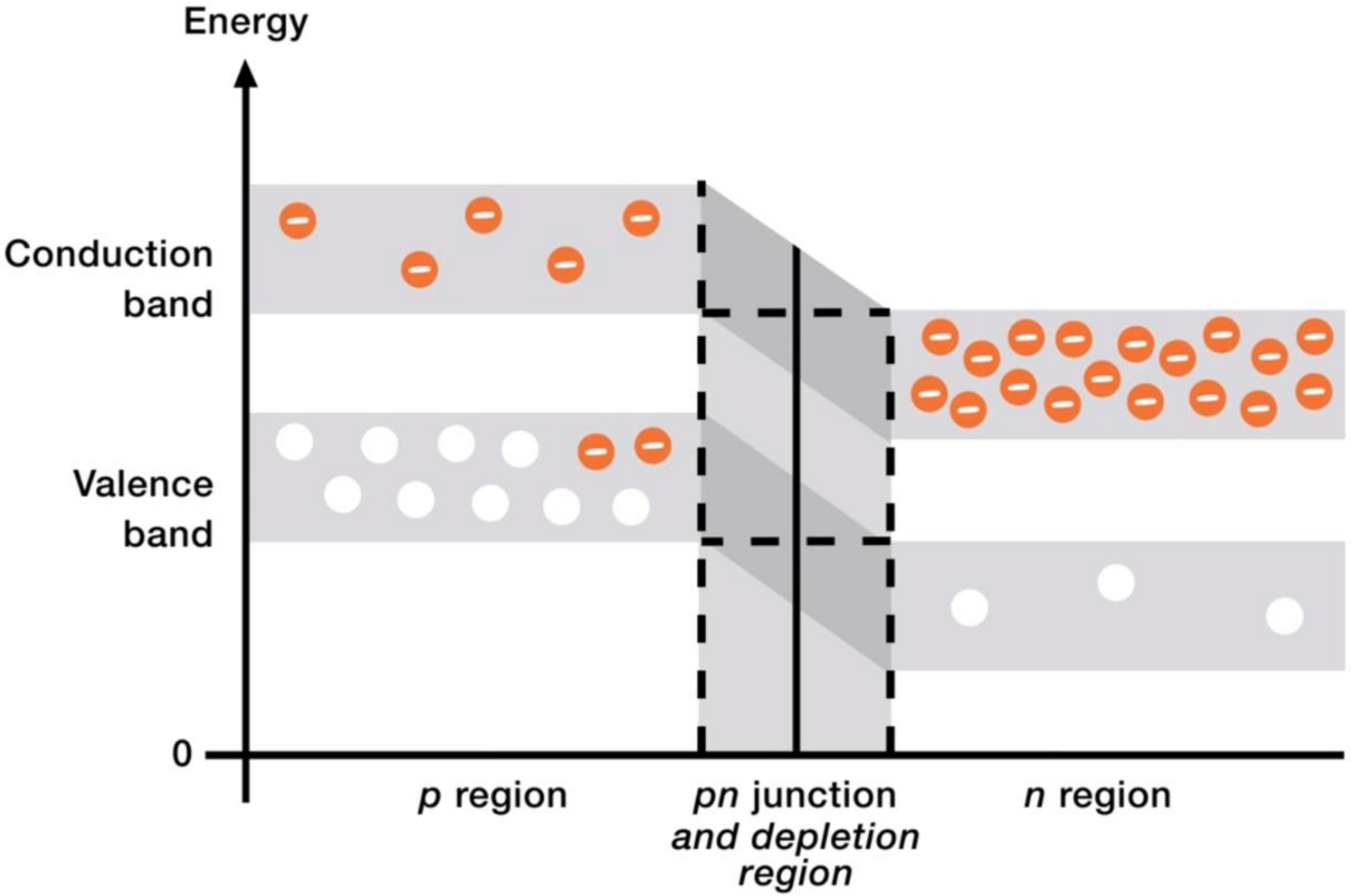
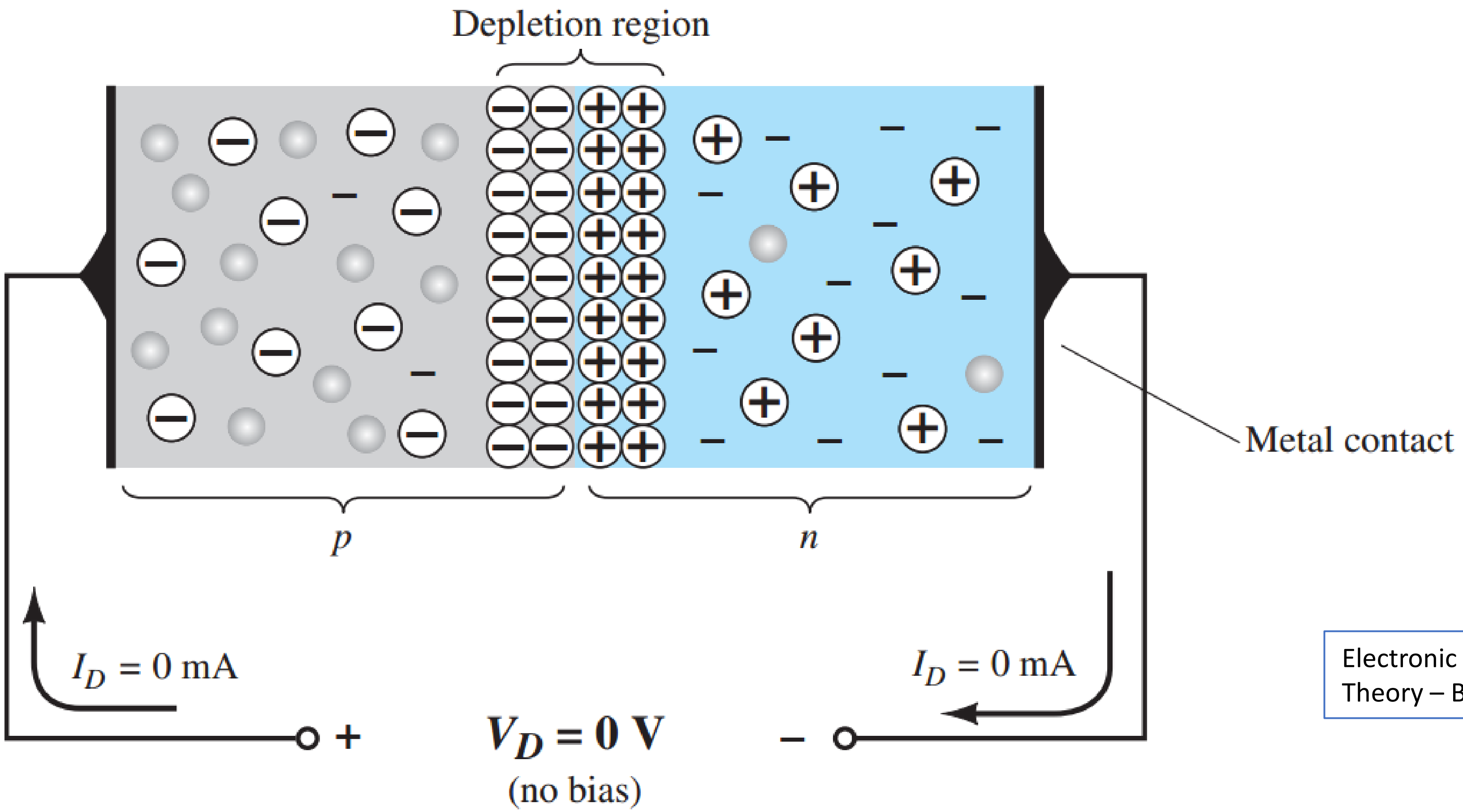
p-*n* junction


Energy
Minority carriers
Majority carriers
Conduction band
Valence band
Majority carriers
Minority carriers
0
p region
pn junction
n region

p-*n* junction


Energy
Conduction band
Valence band
0
p region
pn junction and depletion region
n region

Distribution of charge



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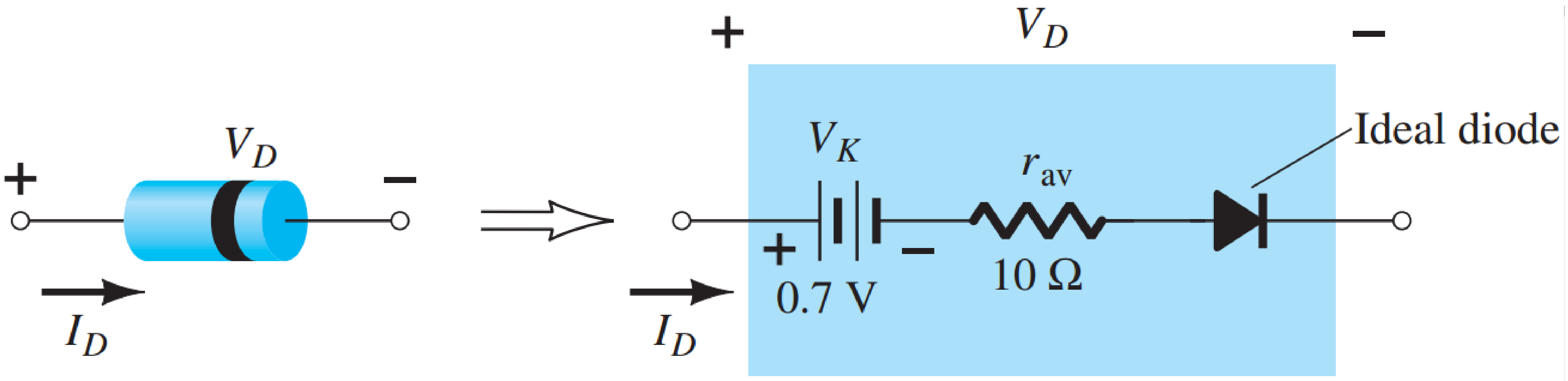
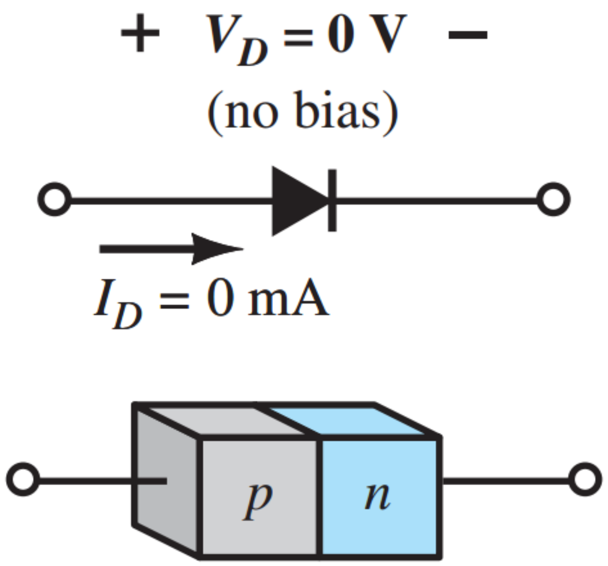
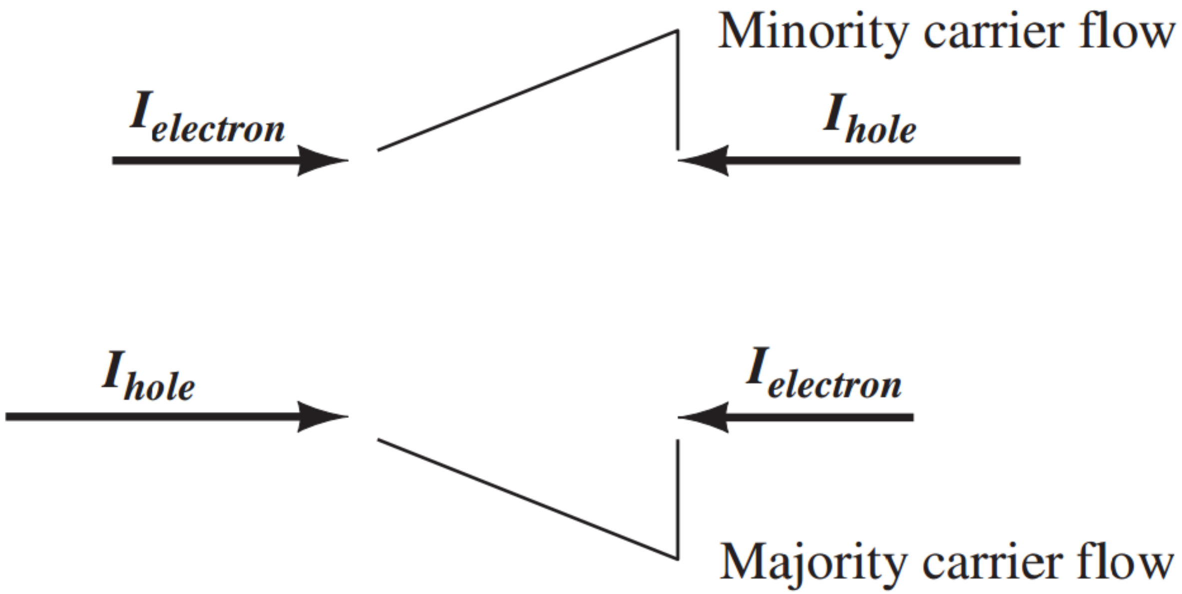
Diode symbol



Carrier flow direction





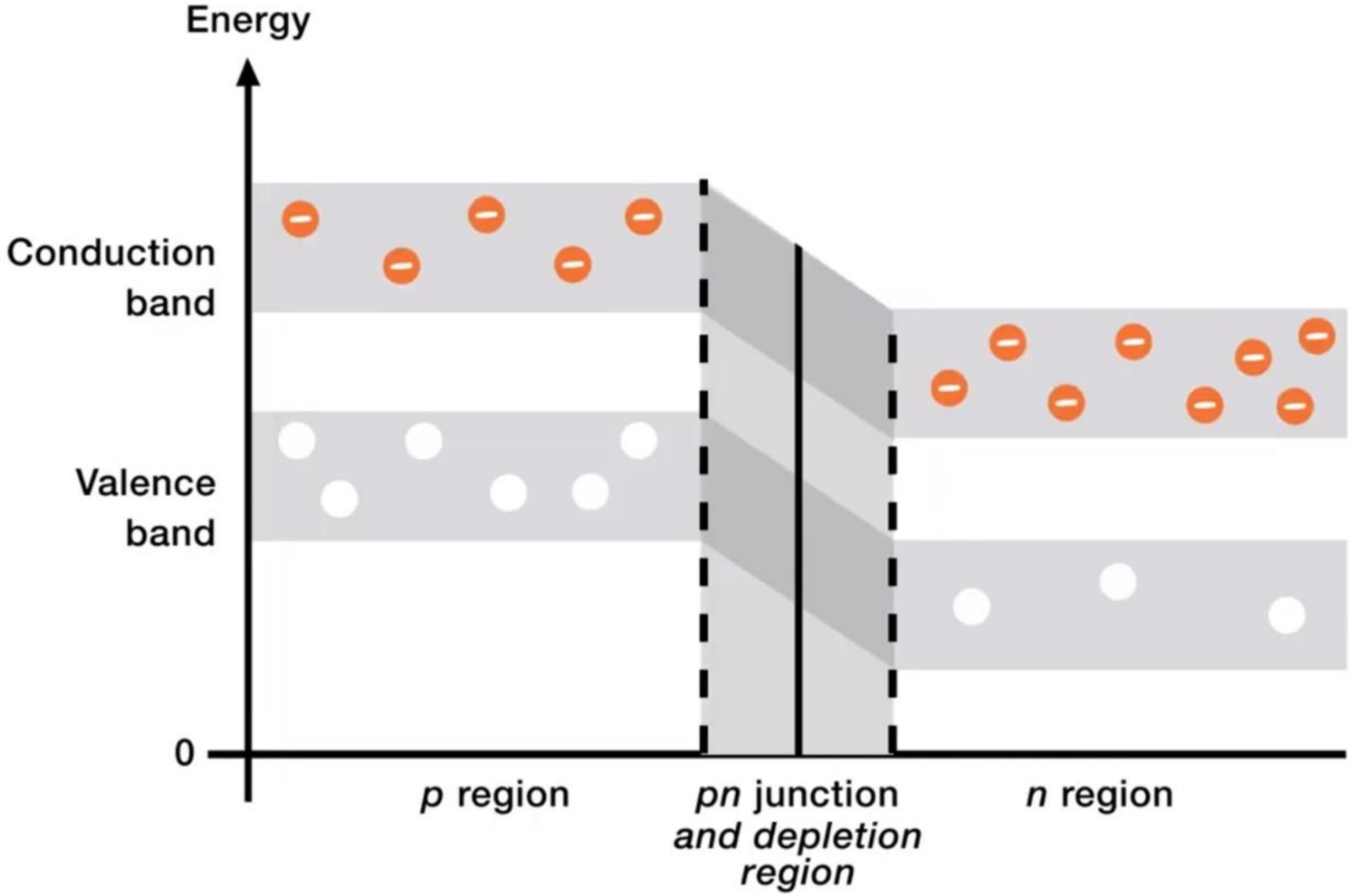
Electronic Devices and Circuit Theory – Boylestad, Nashelsky

Readings

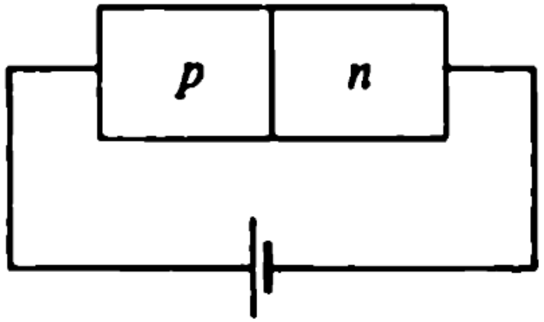
Electronic Devices and Circuit Theory
– Robert L. Boylestad and Louis Nashelsky

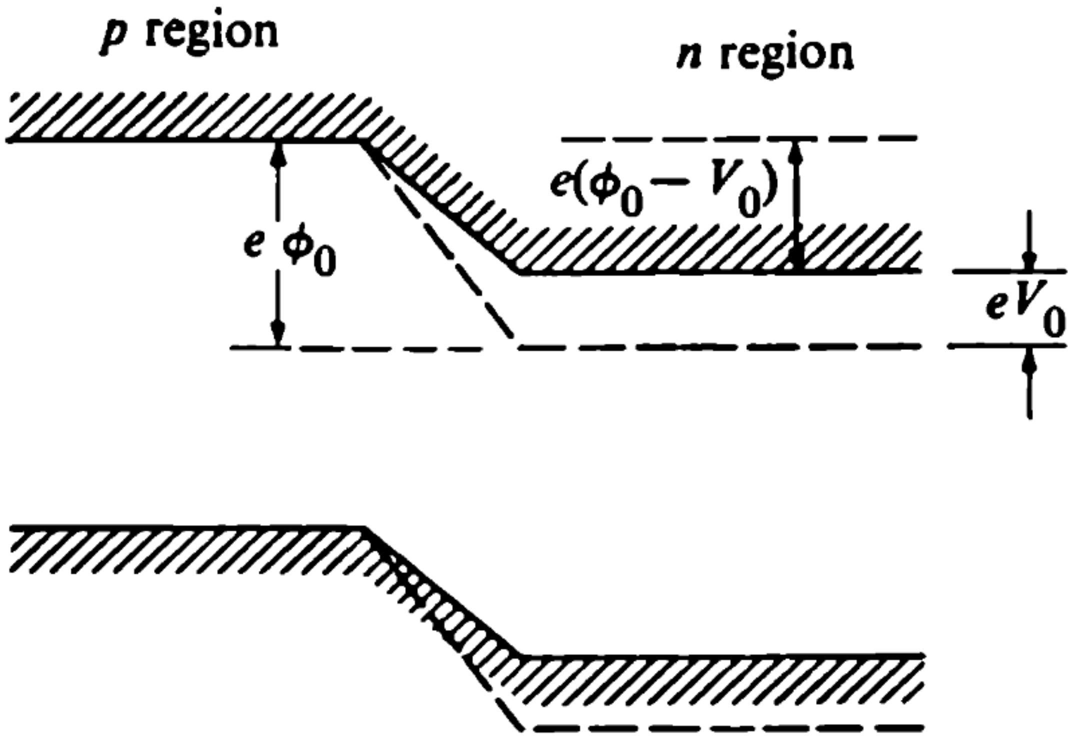
Chapter 1: Semiconductor Diodes

No Applied Bias



Forward-Bias Condition





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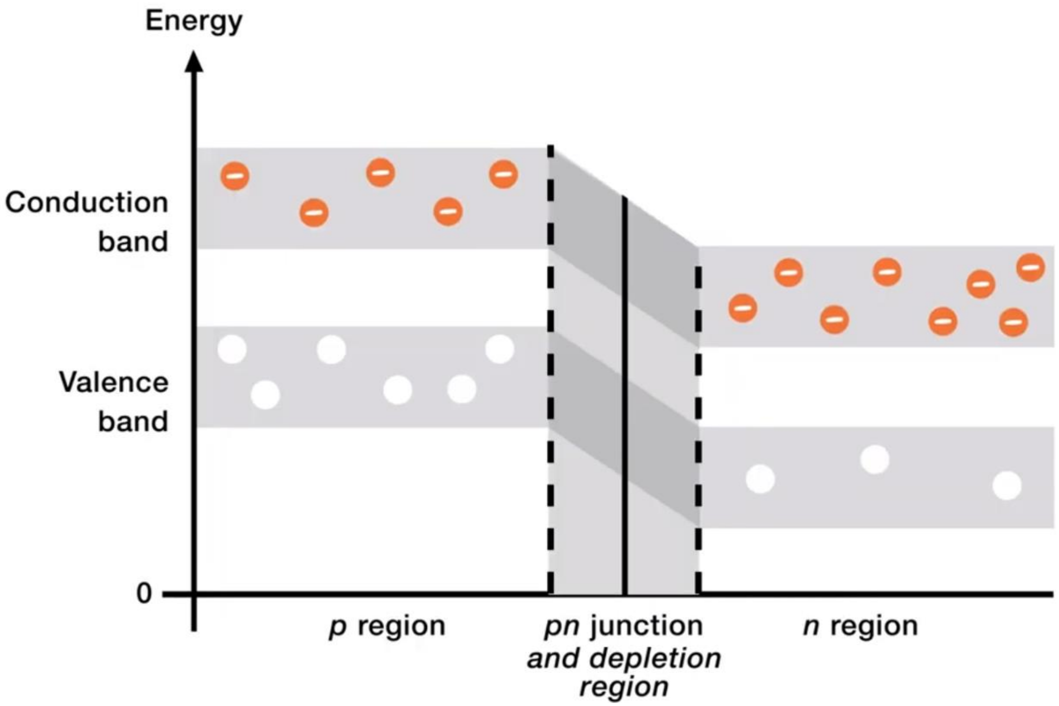
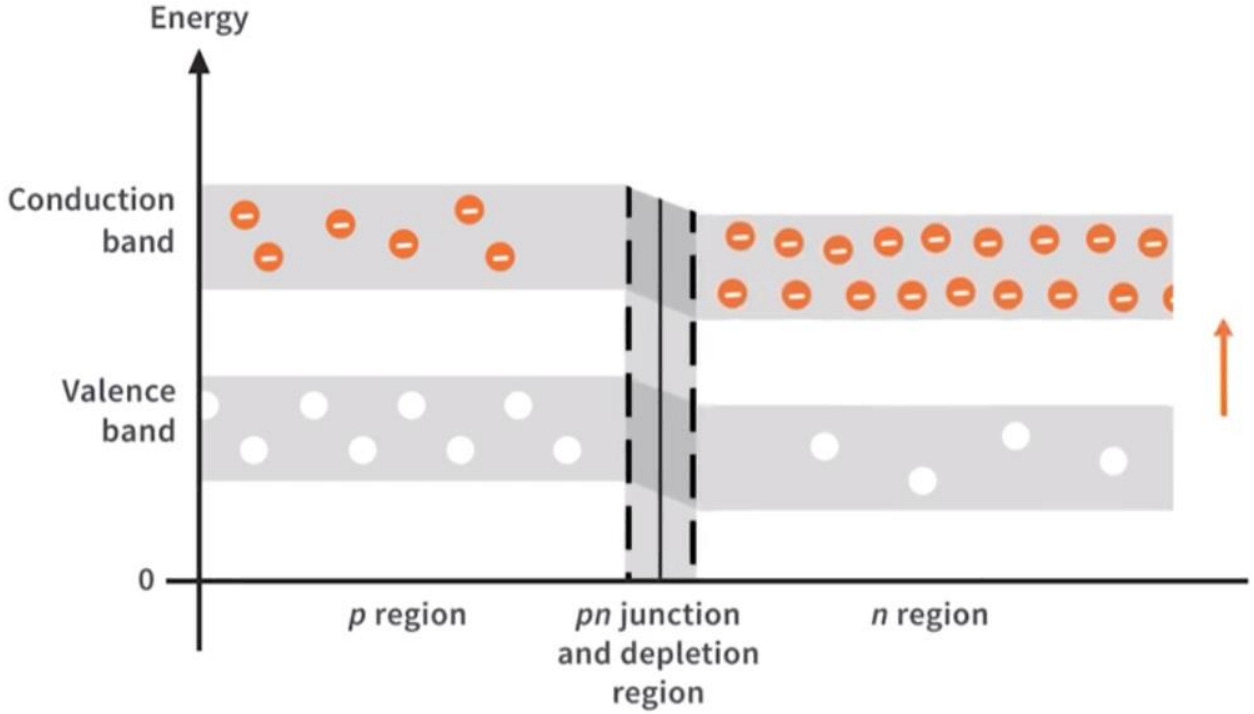
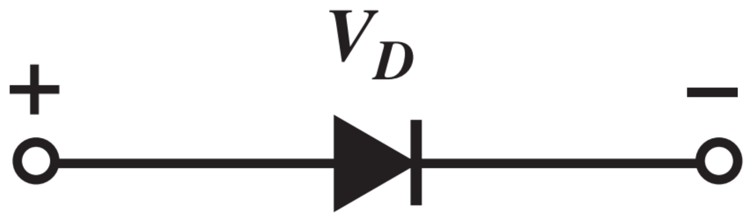
Forward-Bias Condition



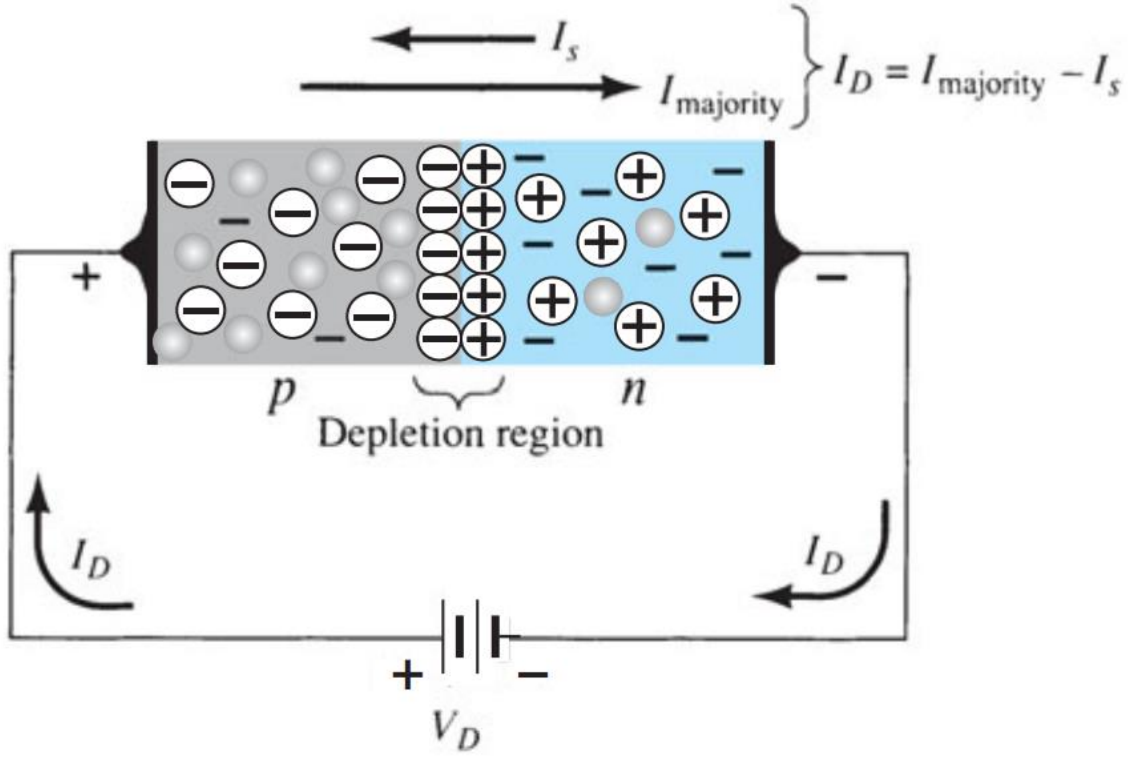




Knee Voltages

Semiconductor	V_K(V)
Ge	0.3
Si	0.7
GaAs	1.2

Forward-Bias Condition



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Forward-Bias Condition

It can be demonstrated through the use of solid-state physics that the general characteristics of a semiconductor diode can be defined by the following equation, referred to as Shockley's equation, for the forward- and reverse-bias regions:

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

where I_s is the reverse saturation current

V_D is the applied forward-bias voltage across the diode

n is an ideality factor, which is a function of the operating conditions and physical construction; it has a range between 1 and 2 depending on a wide variety of factors ($n = 1$ will be assumed throughout this text unless otherwise noted).

Forward-Bias Condition

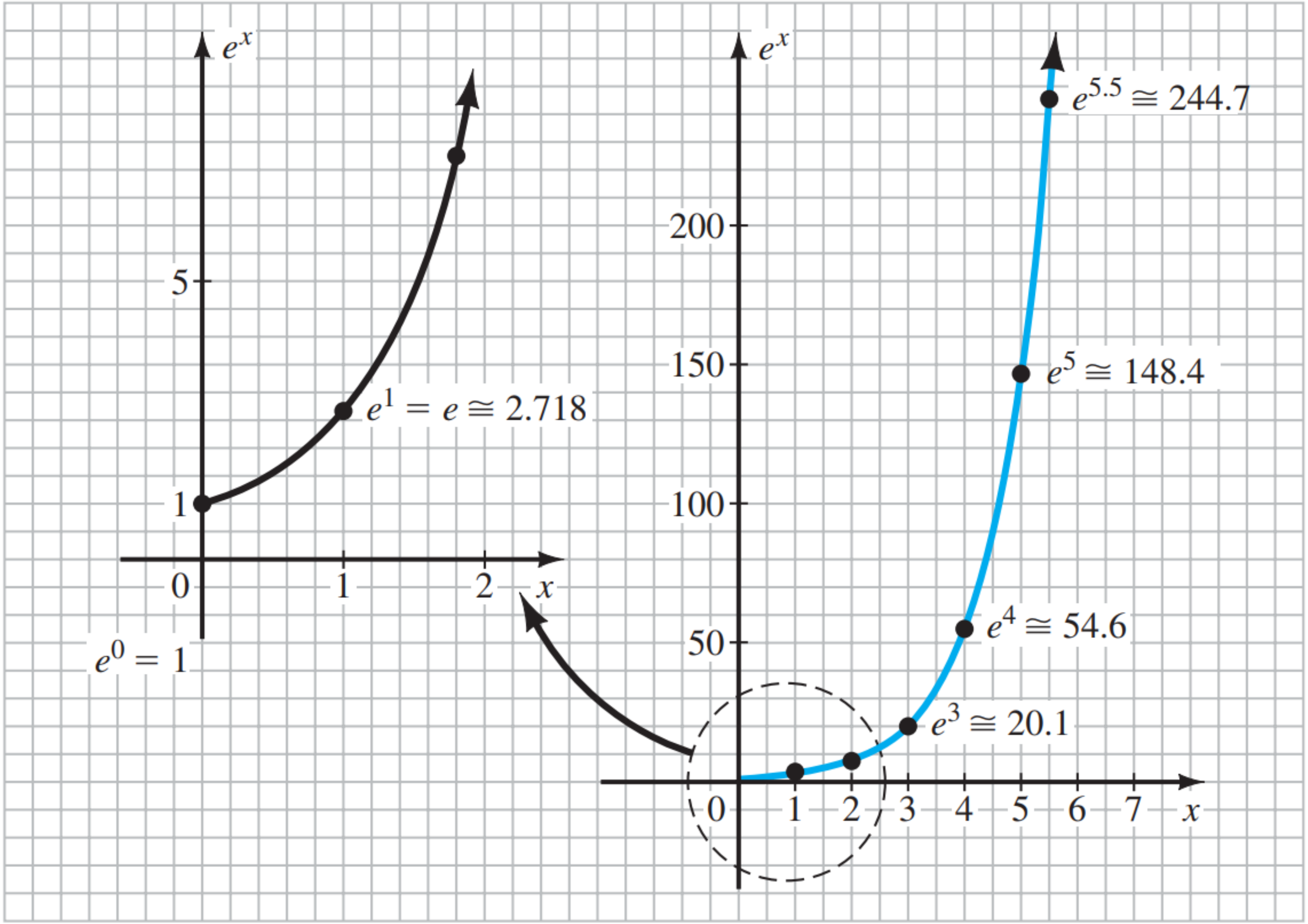
$$I_D = I_s(e^{V_D/nV_T} - 1)$$

The voltage V_T in Eq. (1.1) is called the *thermal voltage* and is determined by

$$V_T = \frac{kT_K}{q} \quad \text{(V)}$$

where k is Boltzmann's constant $= 1.38 \times 10^{-23}$ J/K
T_K is the absolute temperature in kelvins $= 273 +$ the temperature in °C
q is the magnitude of electronic charge $= 1.6 \times 10^{-19}$ C

Plot of exp(x)



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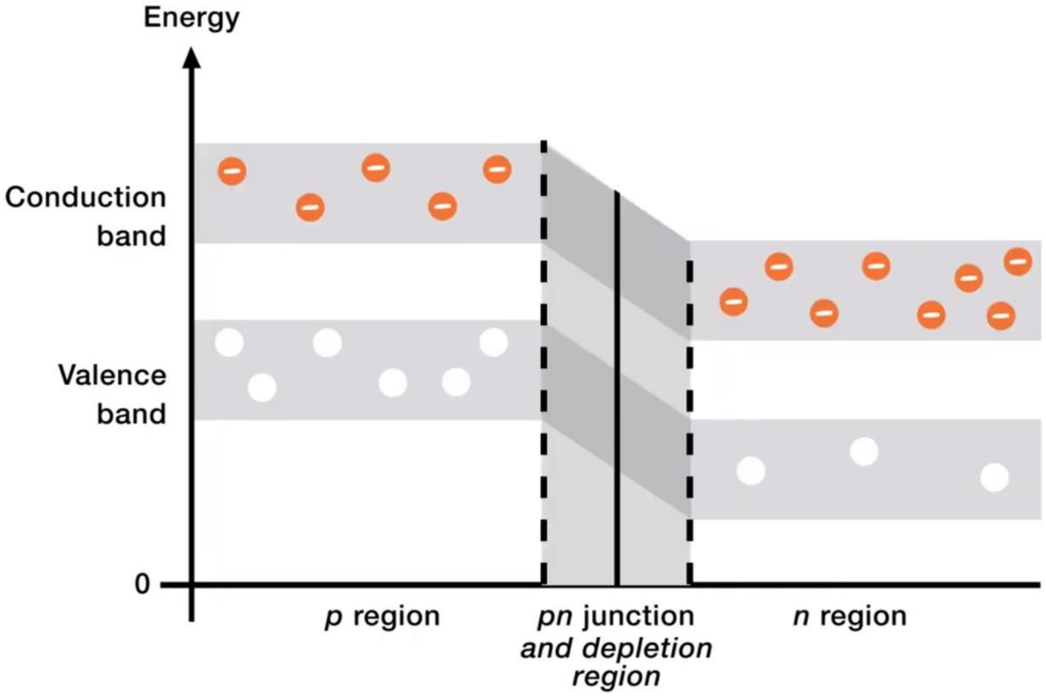
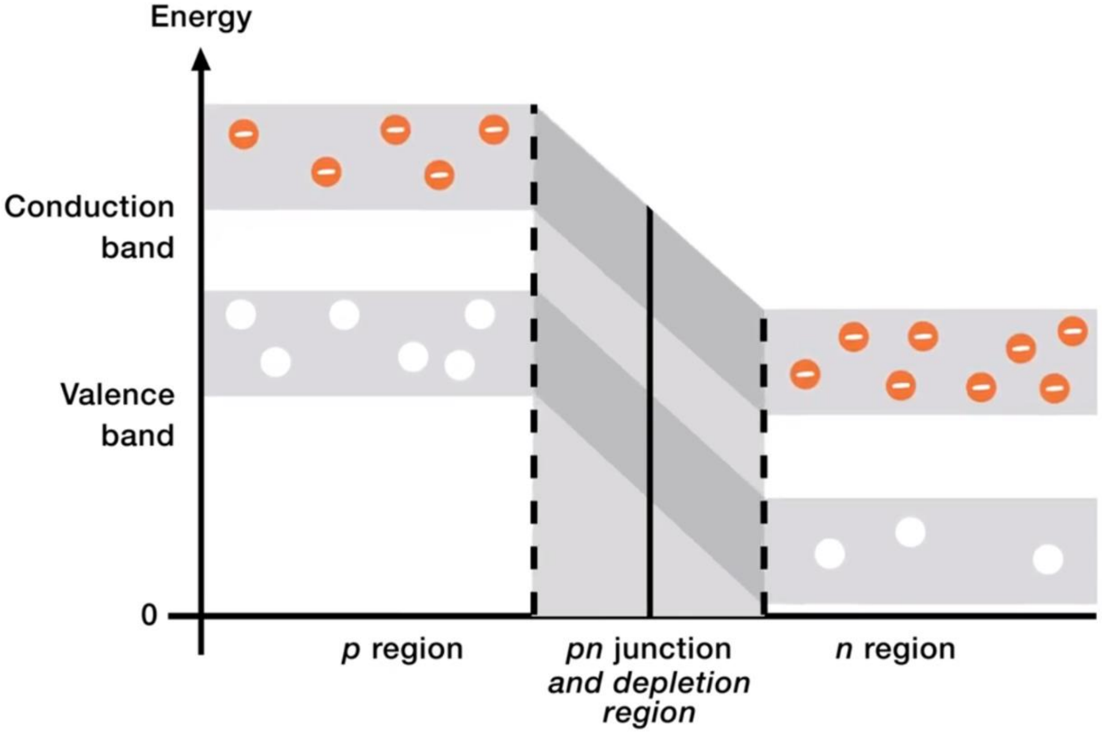
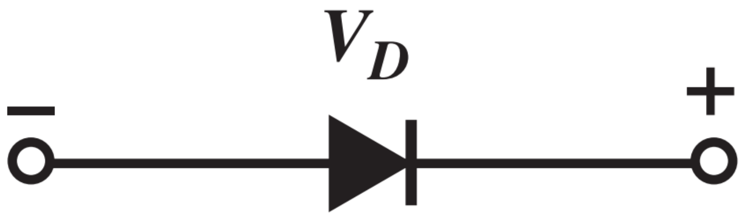
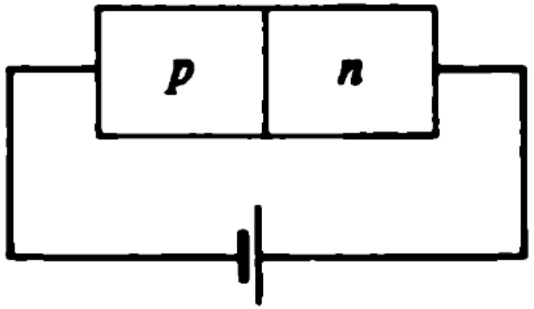
Reverse-Bias Condition

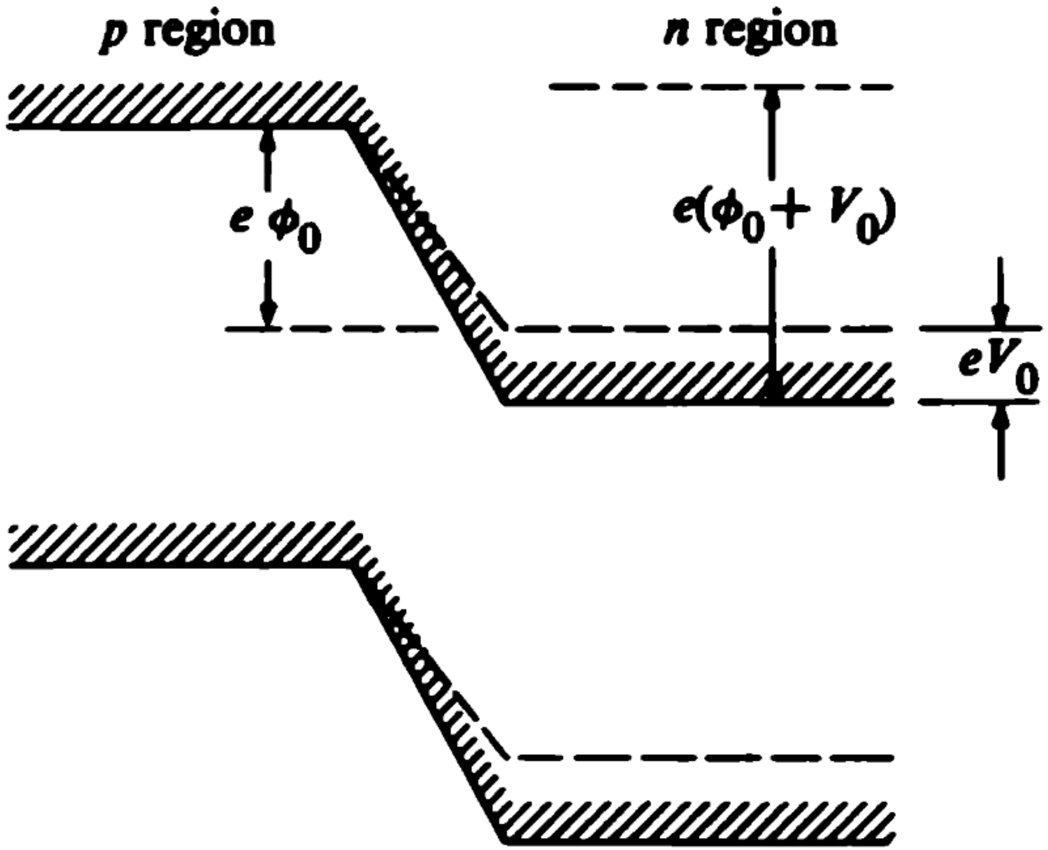






Reverse-Bias Condition





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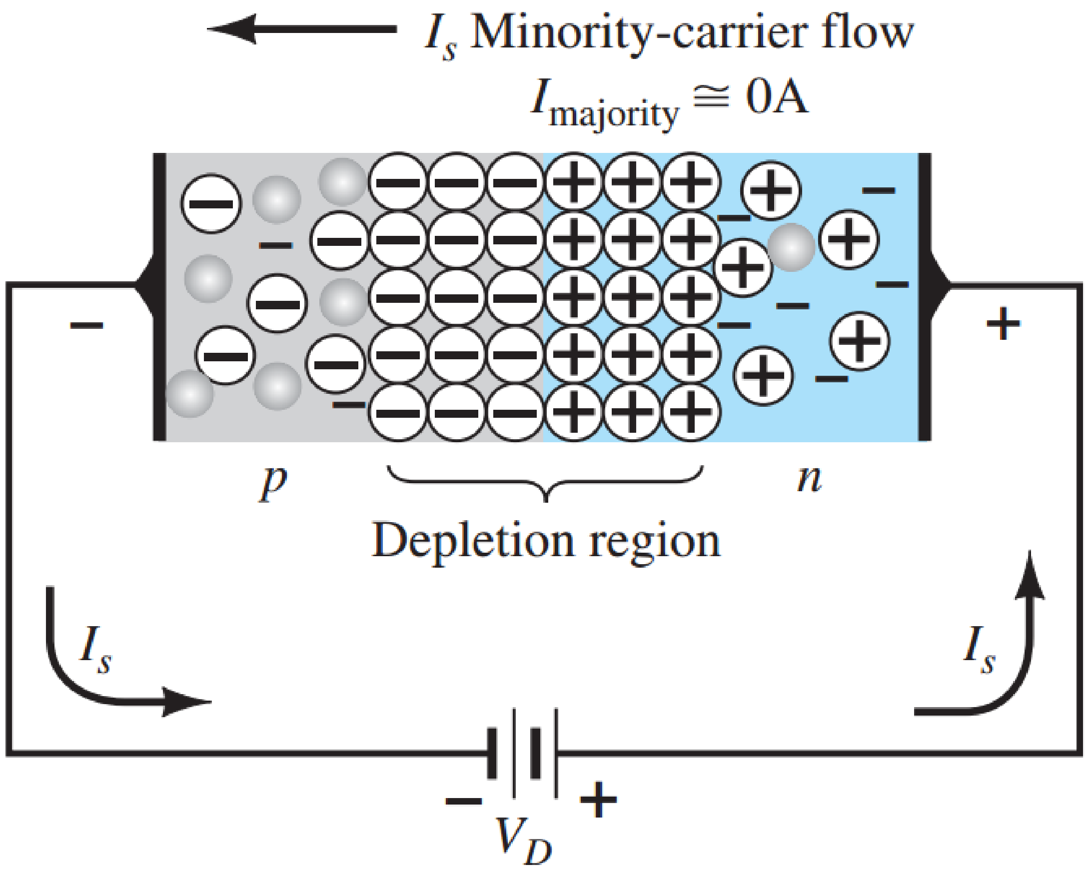
Reverse-Bias Condition



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Current versus voltage characteristics

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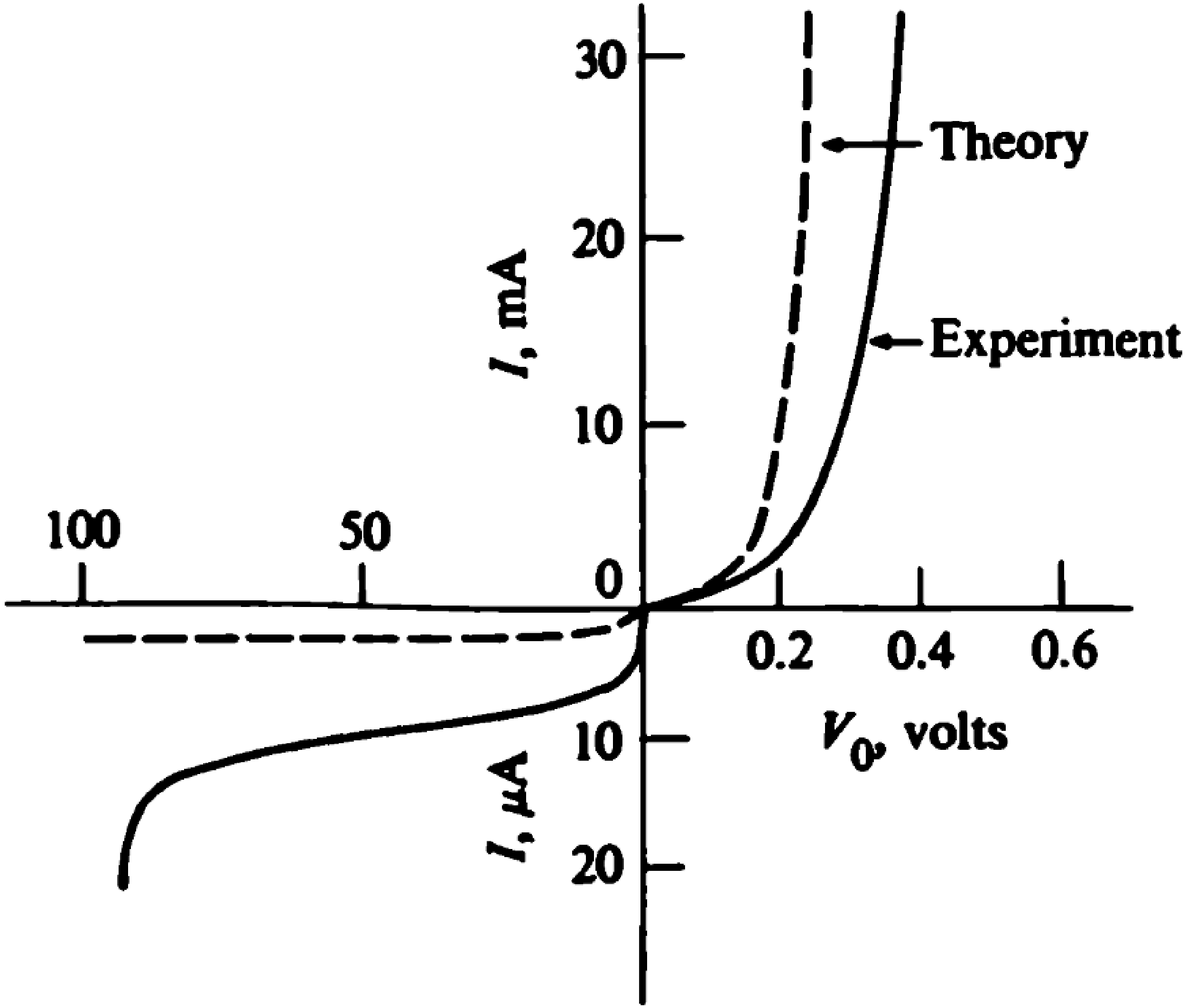
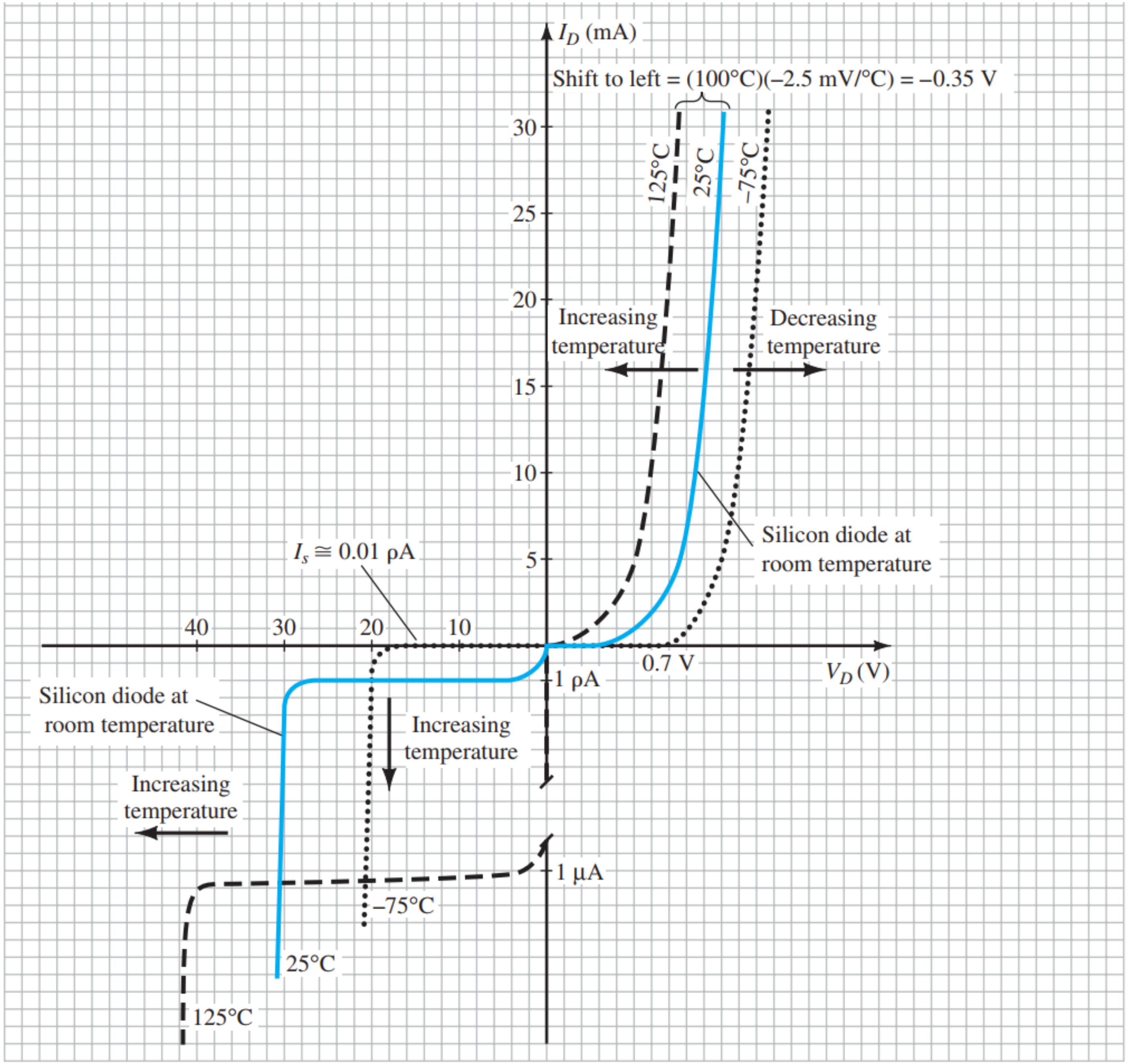


Temperature Effects



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Ideal versus parctical

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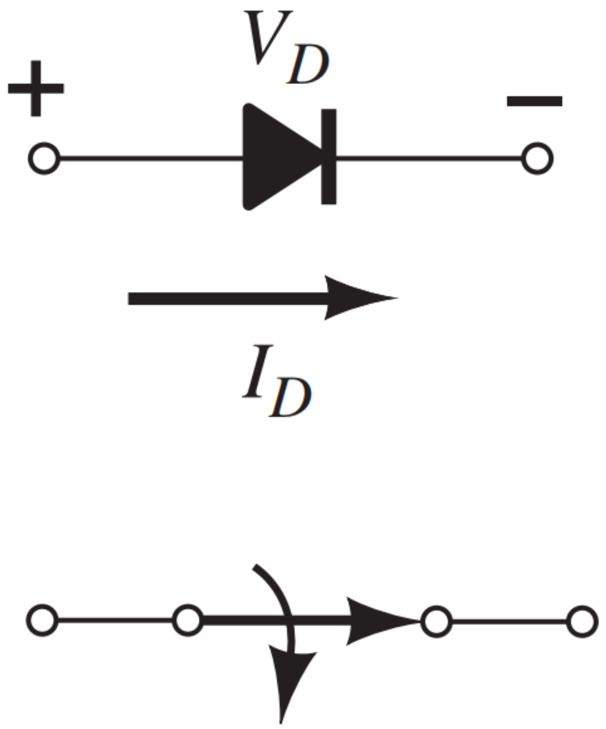
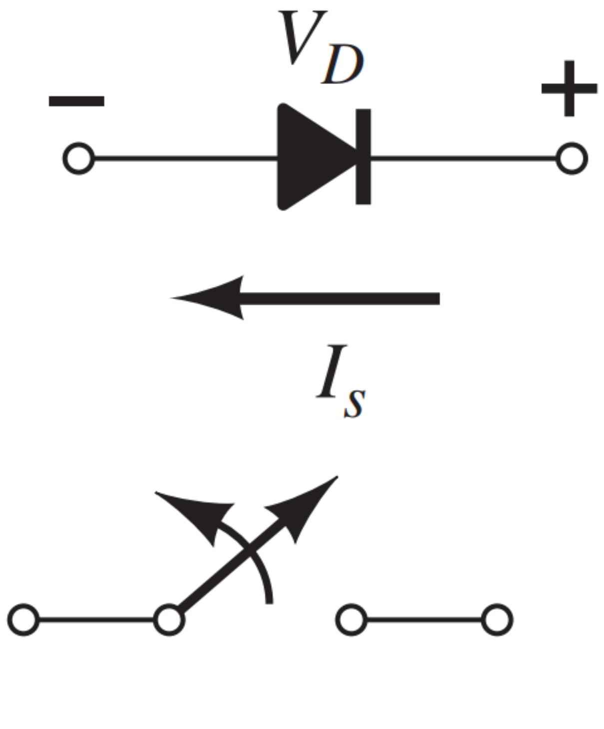
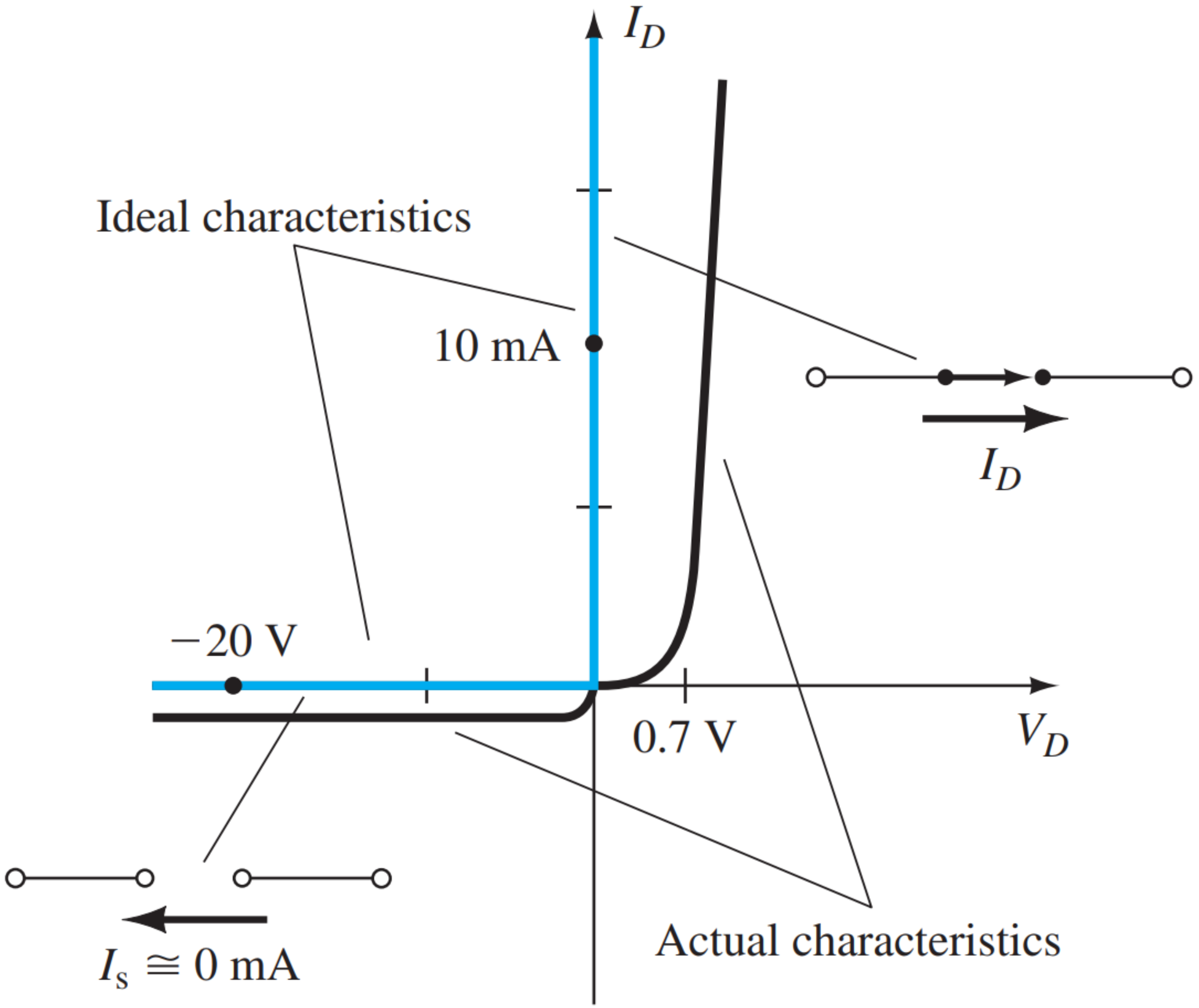


Forward-biased



Reverse-biased

Ideal versus parctical



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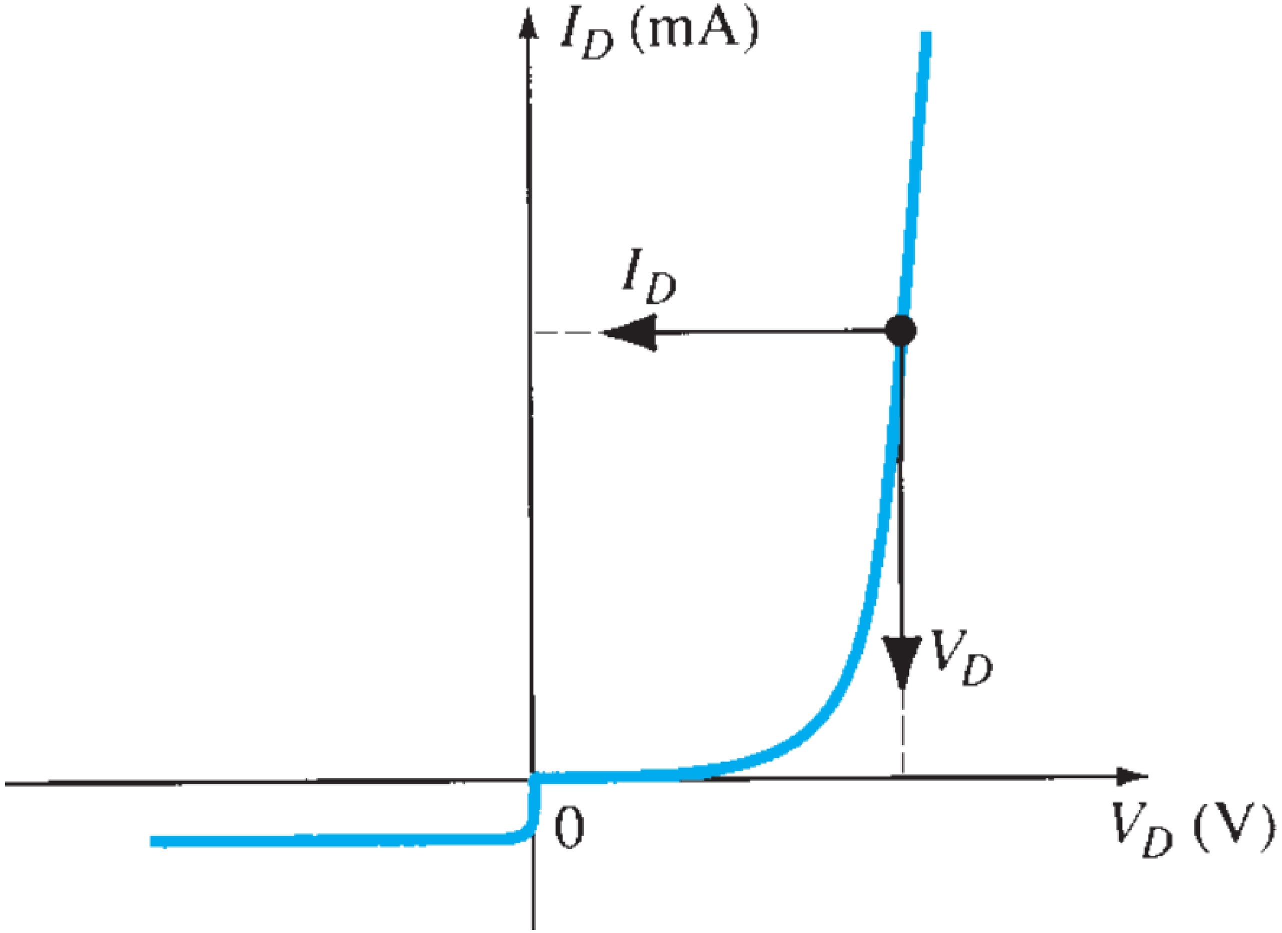
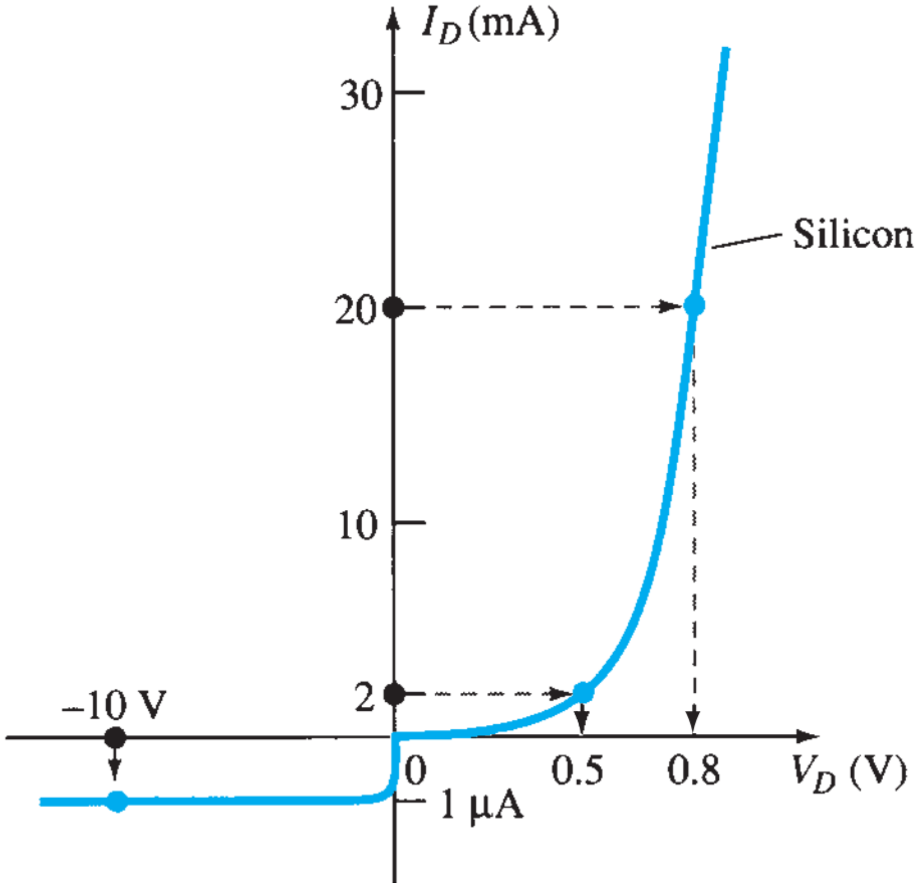
DC or Static Resistance

$$R_D = \frac{V_D}{I_D}$$



DC or Static Resistance



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

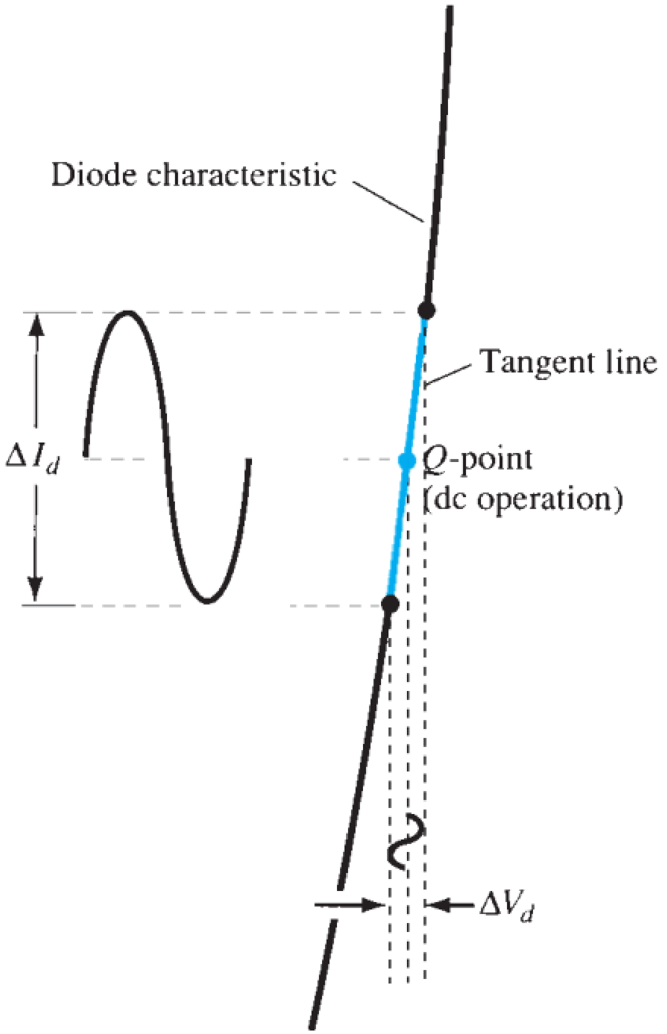
$$R_D = \frac{V_D}{I_D} = \frac{0.5\text{ V}}{2\text{ mA}} = \mathbf{250\ \Omega}$$

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

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

AC or Dynamic Resistance

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



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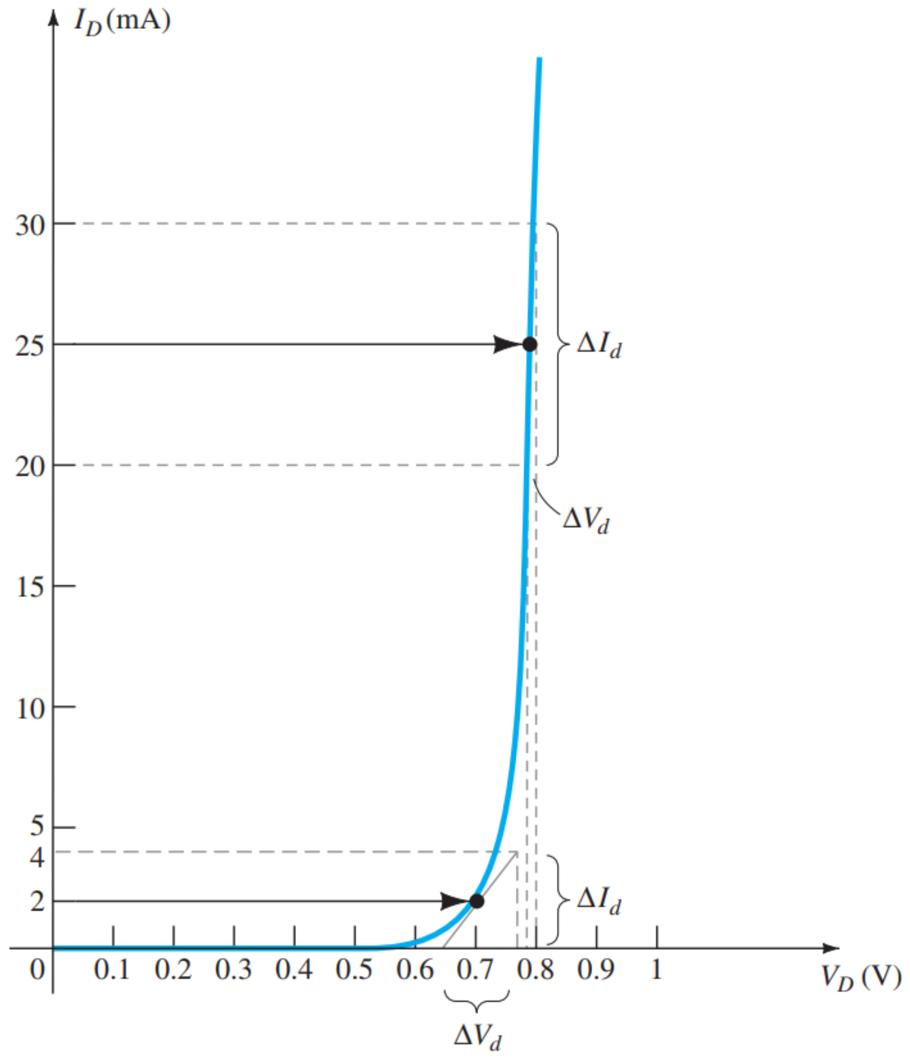
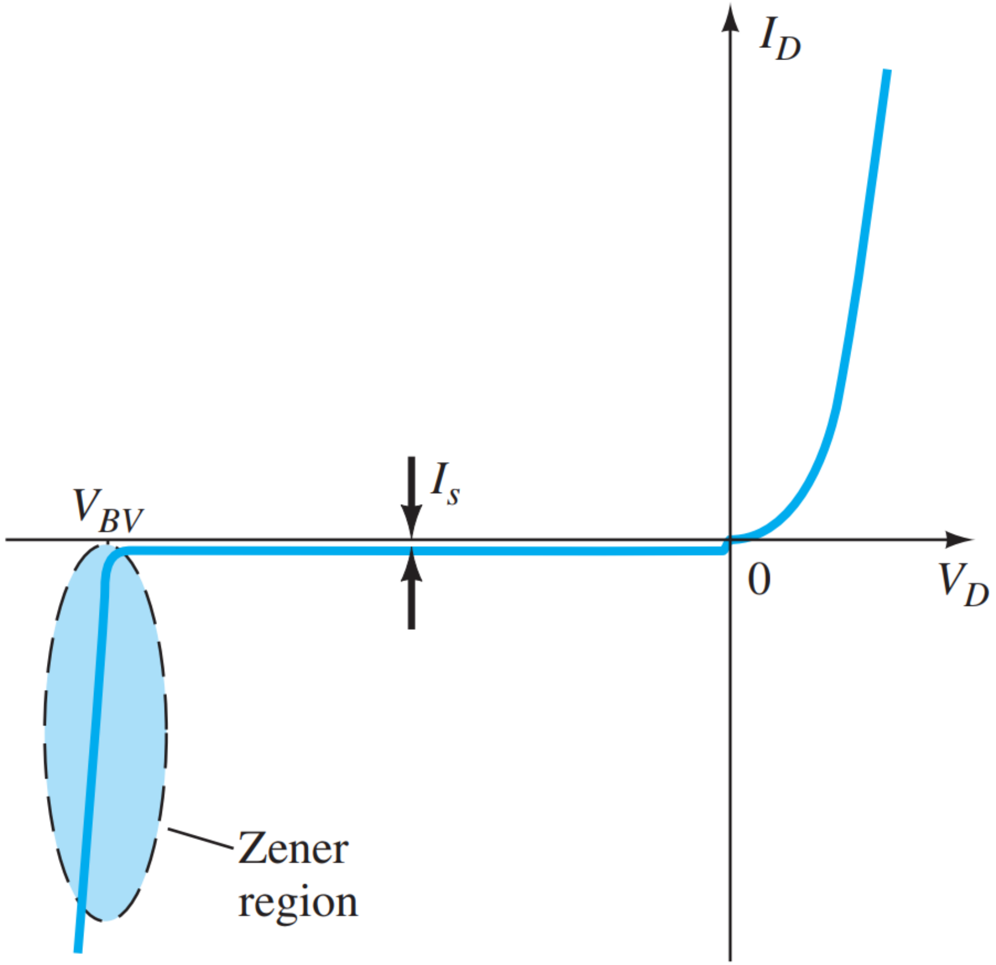
AC or Dynamic Resistance

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.02\ \text{V}}{10\ \text{mA}} = \mathbf{2\ \Omega}$$

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.11\ \text{V}}{4\ \text{mA}} = \mathbf{27.5\ \Omega}$$



Breakdown region



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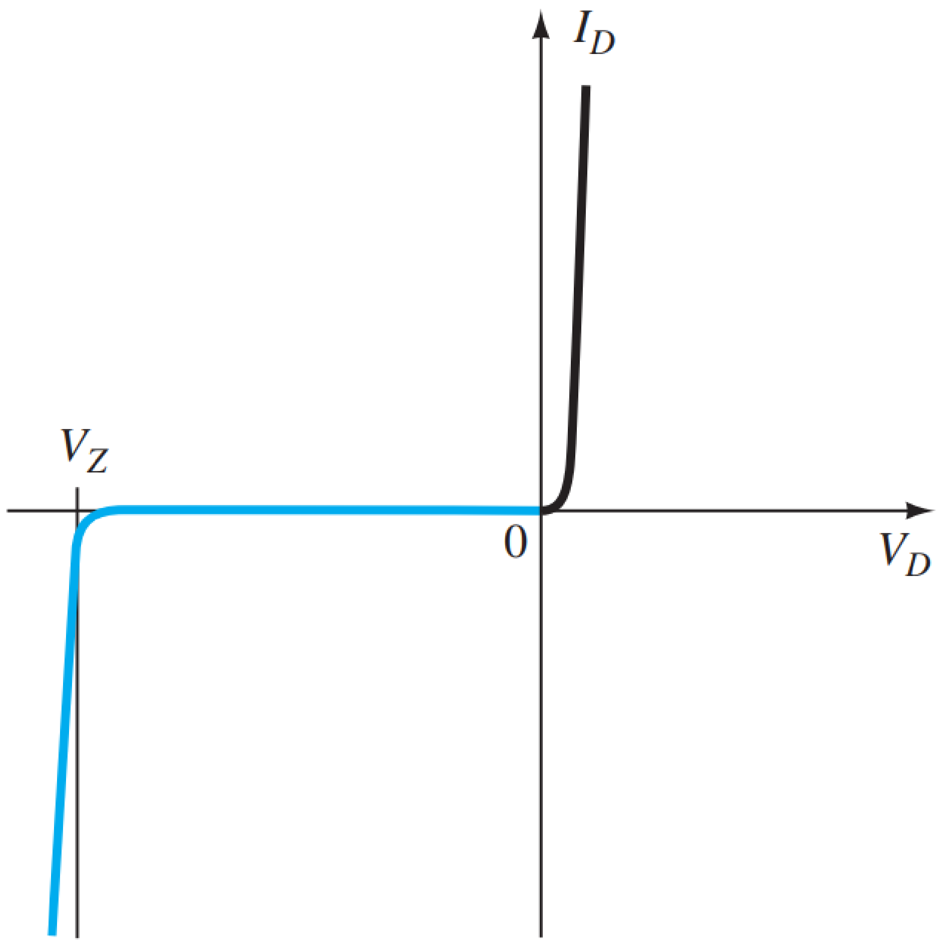
Breakdown region

(1) **Avalanche breakdown**, in which some of the electrons accelerated by the large reverse voltage acquire enough energy to excite electron-hole pairs, which if sufficiently energetic, go on to excite additional electron-hole pairs, and so forth.

(2) **Zener breakdown**, which is based on the observation that at very high reverse voltage the thickness (not the height) of the potential barrier between the two sides of the junction becomes so small that quantum tunneling becomes possible. At that point, the current does increase rapidly.

Zener diode



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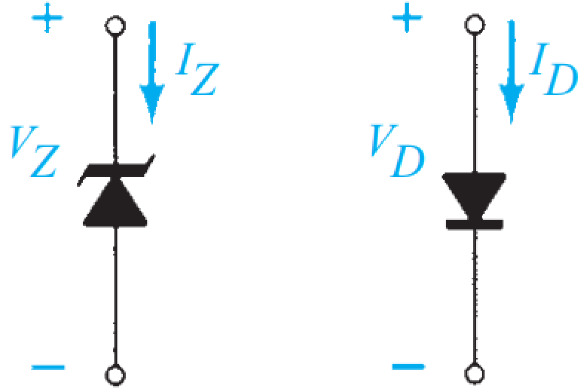
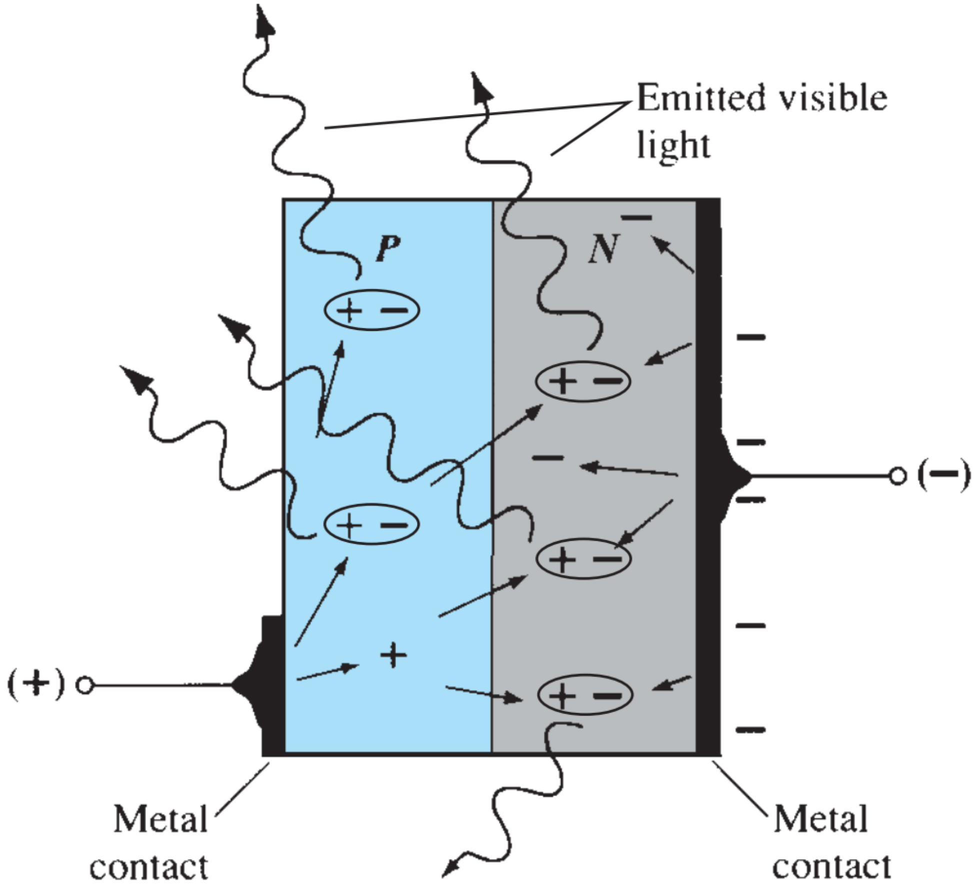


Light-Emitting Diode (LED)



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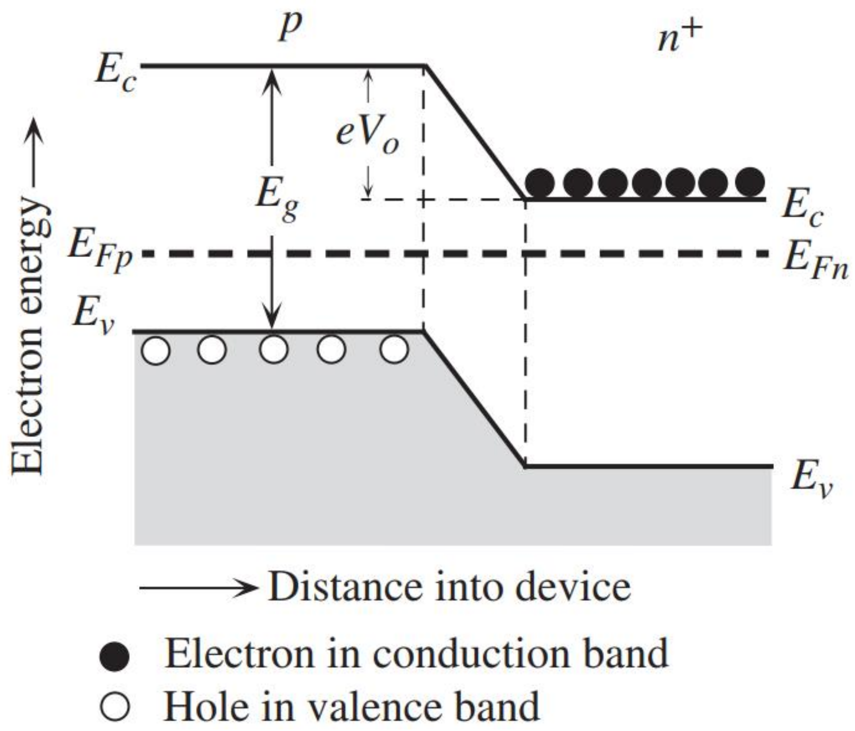
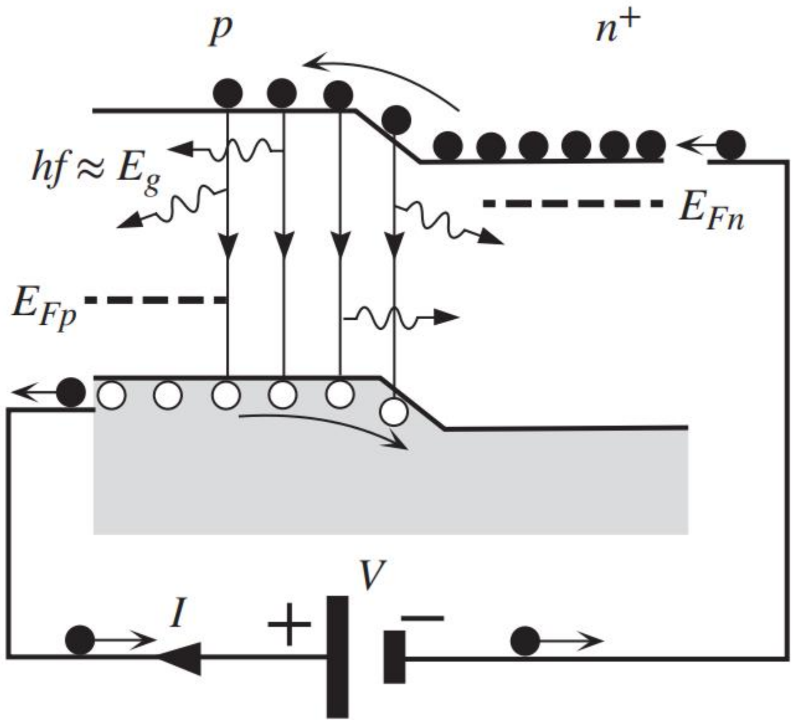
Light-Emitting Diode (LED)



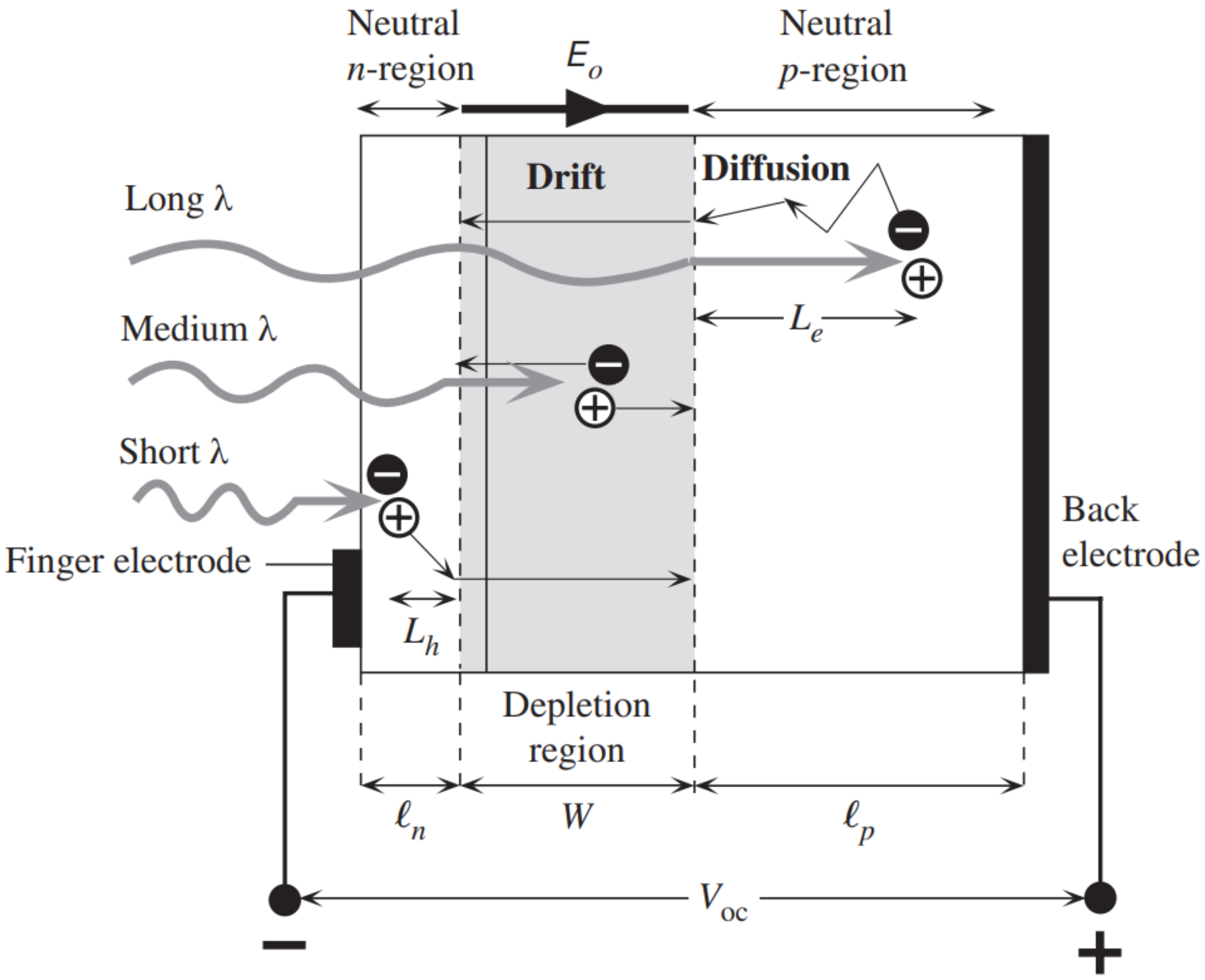


Principles of Electronic Materials and Devices – S.O. Kasap

Light-Emitting Diodes

Color	Construction	Typical Forward Voltage (V)
Amber	AlInGaP	2.1
Blue	GaN	5.0
Green	GaP	2.2
Orange	GaAsP	2.0
Red	GaAsP	1.8
White	GaN	4.1
Yellow	AlInGaP	2.1

The basic principle of operation of the solar cell



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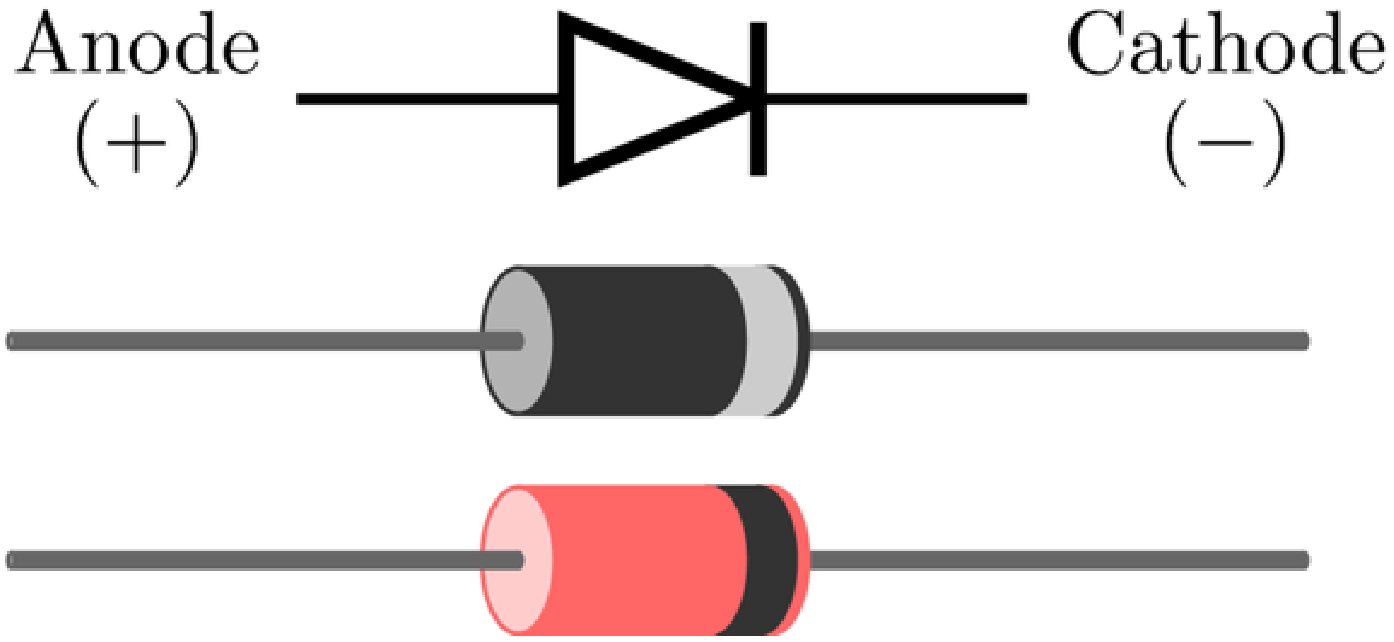
Light-Emitting Diodes

In Si and Ge diodes the greater percentage of the energy converted during recombination at the junction is dissipated in the form of heat within the structure, and the emitted light is insignificant.

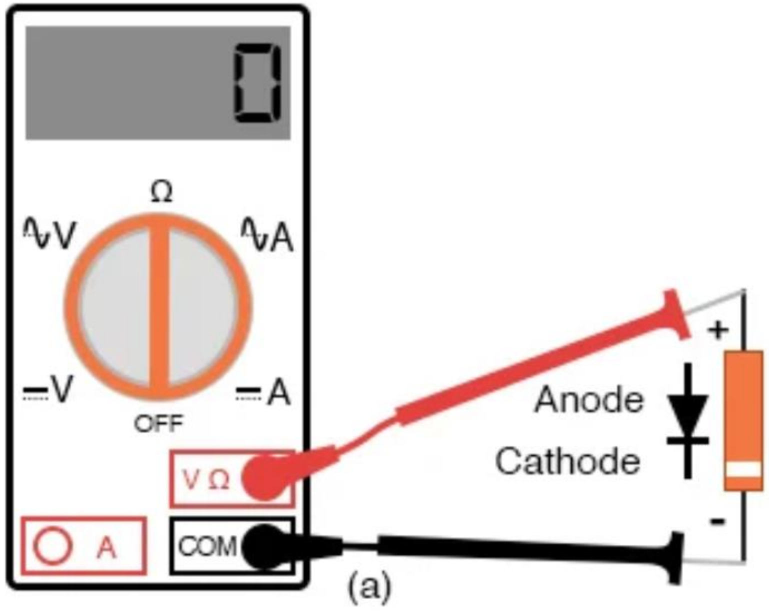
Diodes constructed of GaAs emit light in the infrared (invisible) zone during the recombination process at the p–n junction

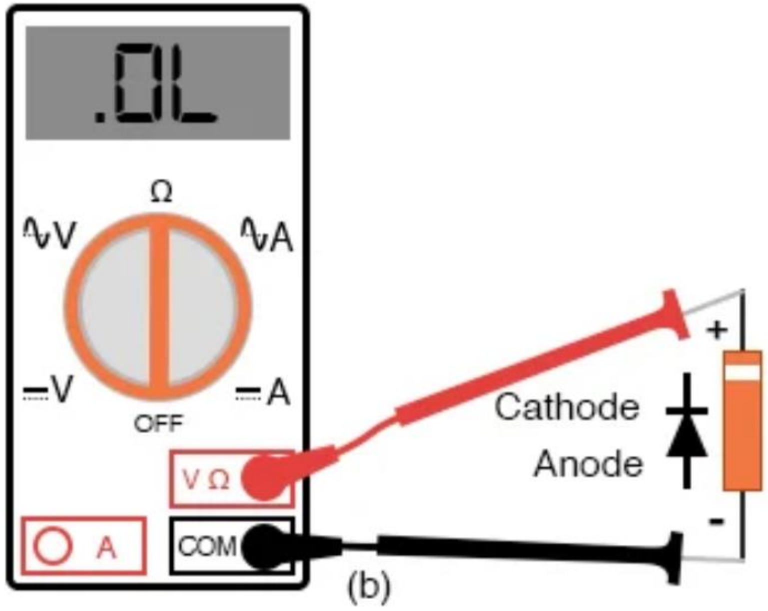
Even though the light is not visible, infrared LEDs have numerous applications where visible light is not a desirable effect. These include security systems, industrial processing, optical coupling, safety controls such as on garage door openers, and in home entertainment centers, where the infrared light of the remote control is the controlling element.

Diode



Diode polarity





(a) Low resistance indicates forward bias, black lead is cathode and red lead anode.

(b) Reversing leads shows high resistance indicating reverse bias.

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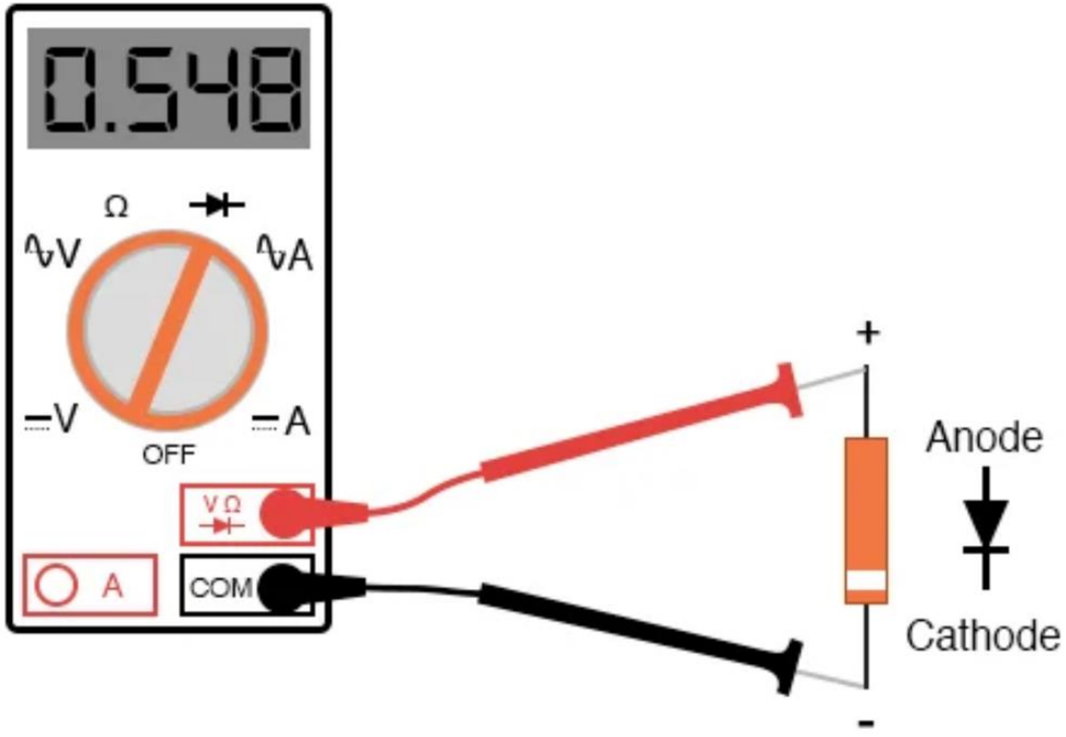
Diode polarity



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Meter with a "Diode check" function

Readings

Electronic Devices and Circuit Theory
– Robert L. Boylestad and Louis Nashelsky

Chapter 1: Semiconductor Diodes