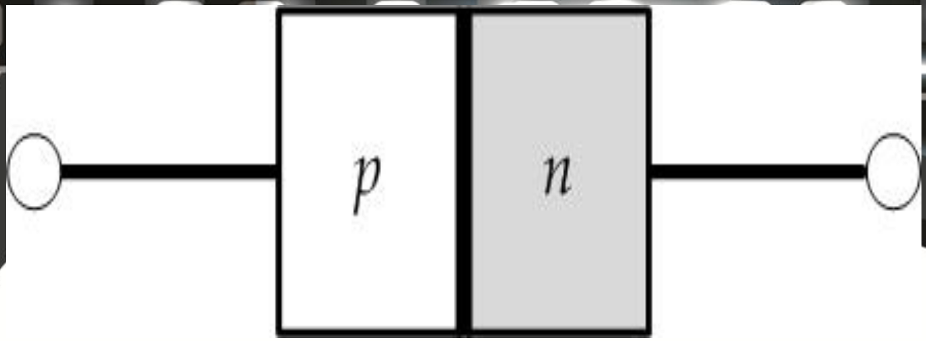
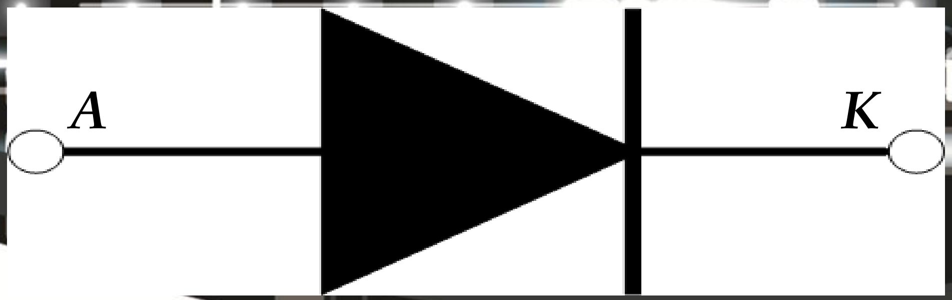
MODUL ELEKTRONIKA

Happy Nugroho, S.T., M.T.

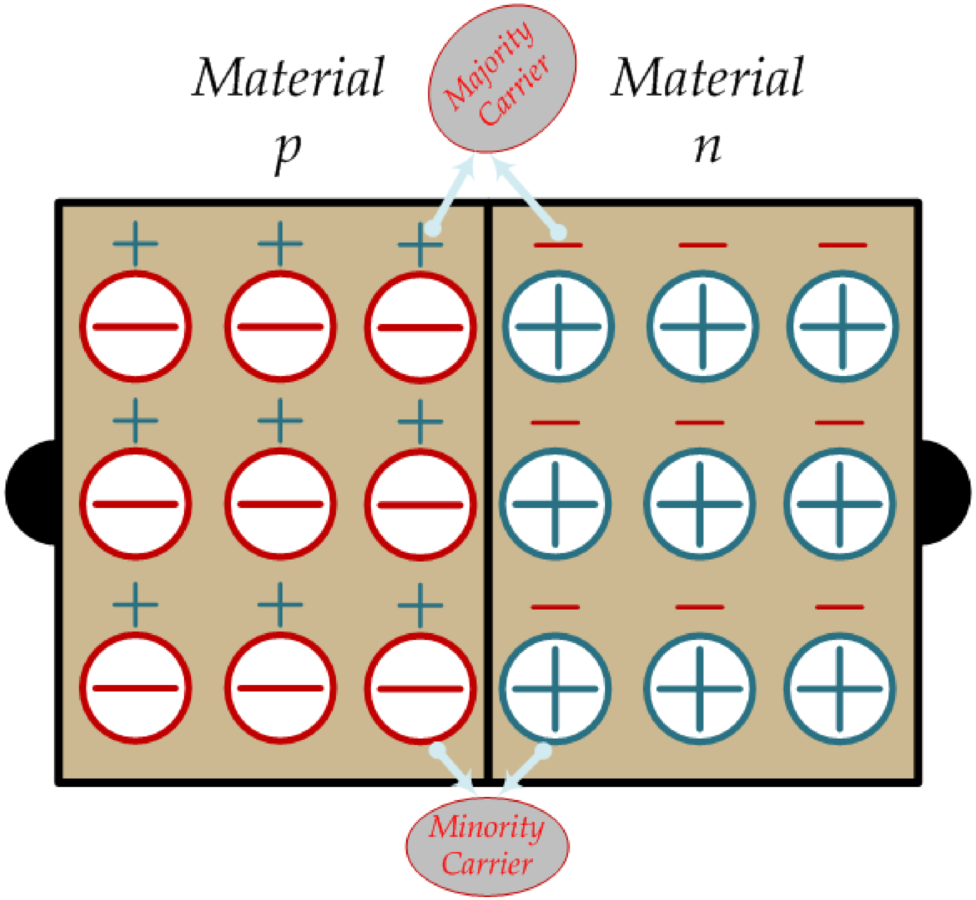
Jurusan Teknik Elektro
Universitas Mulawarman Samarinda



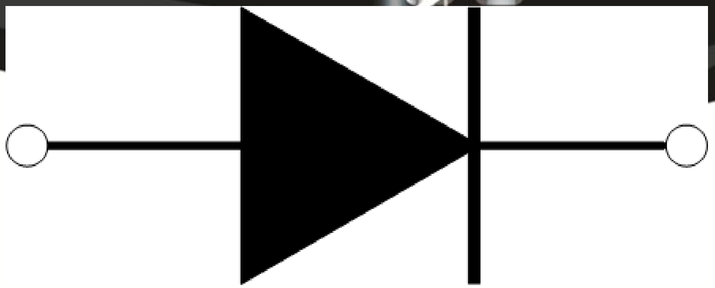


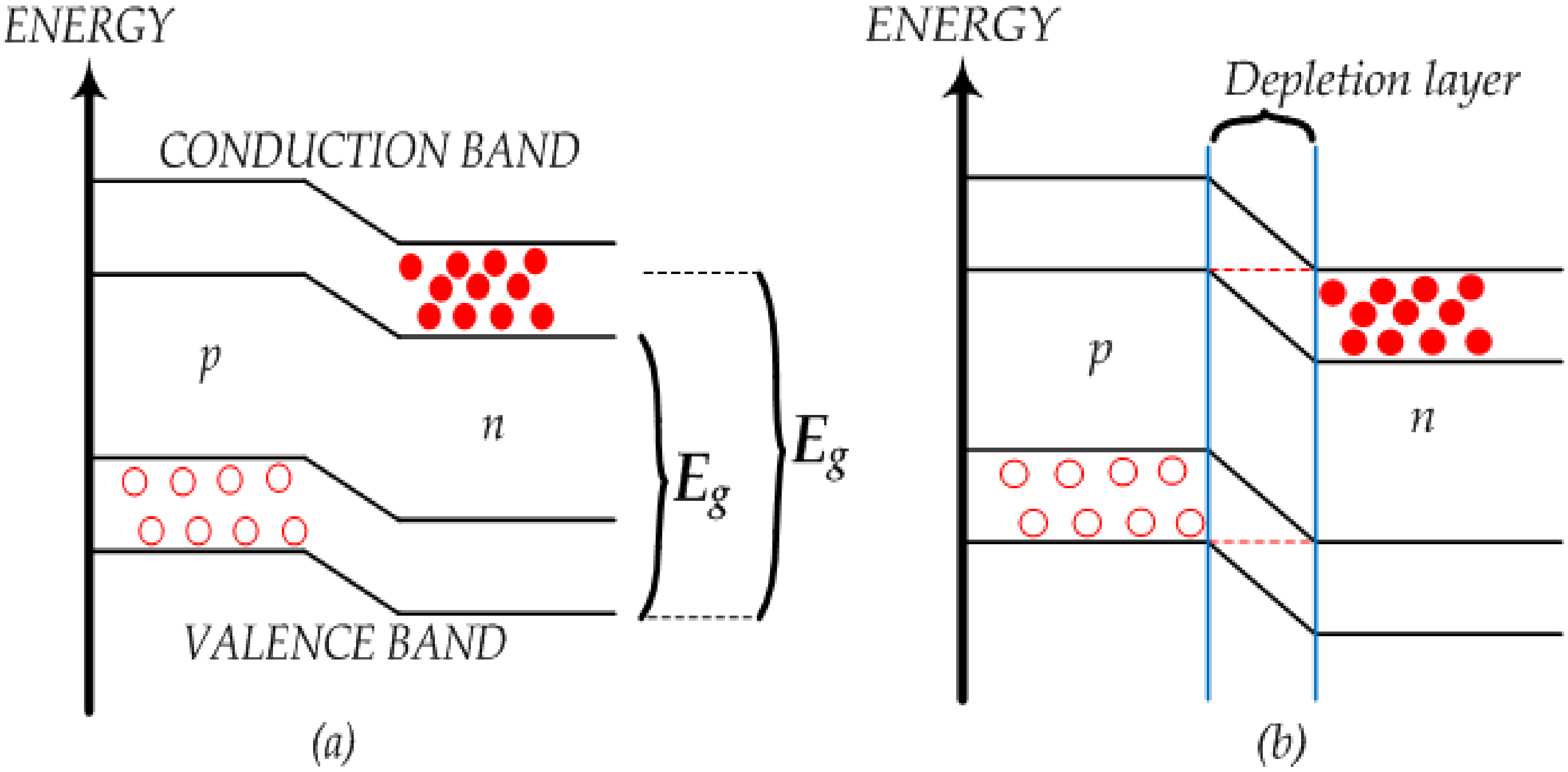
P-N Junction Diode

- The junction diode is another name for PN crystal
- The word **diode** is a contraction if two electrodes, where "*di*" stands for two
- The junction is the border where the p-type and the n-type regions meet

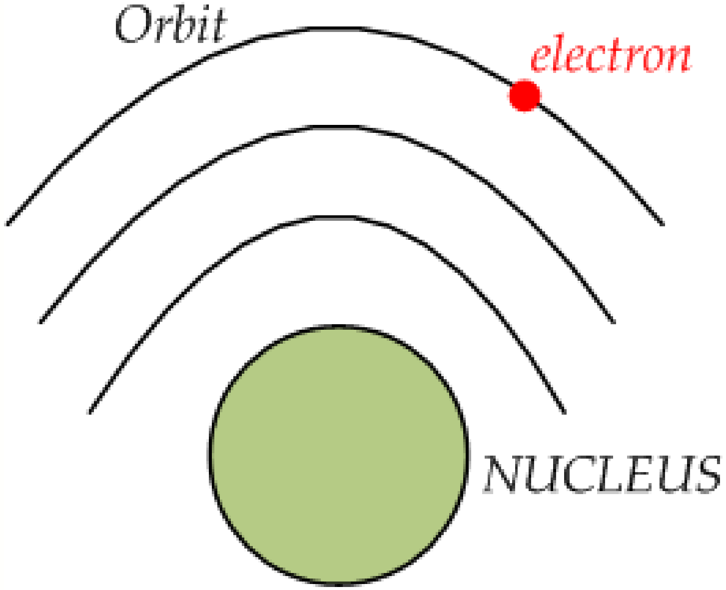


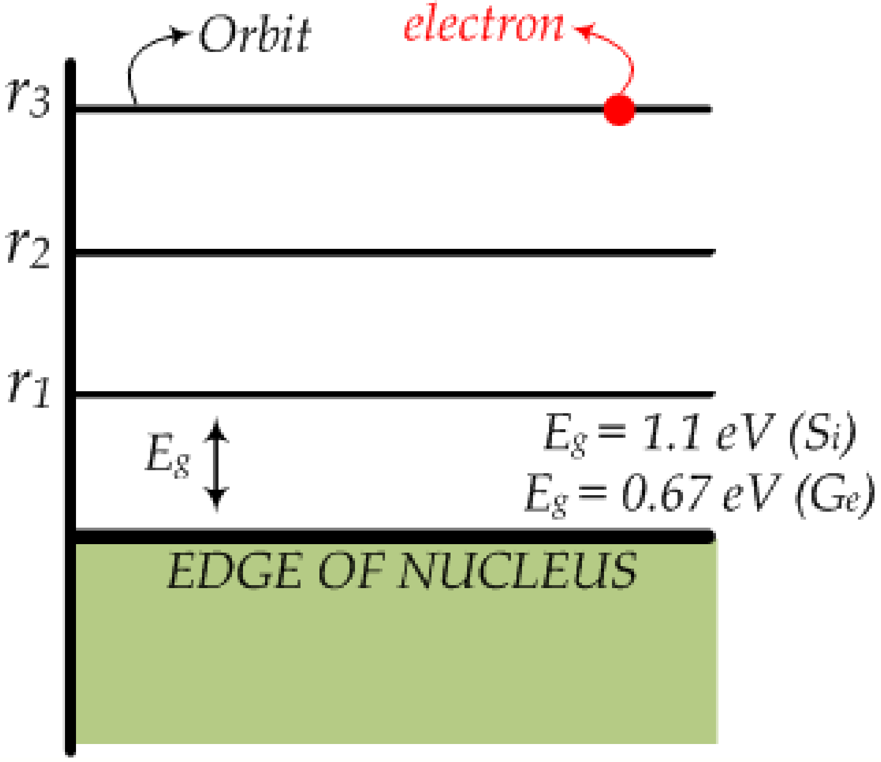
P-N JUNCTION DIODE

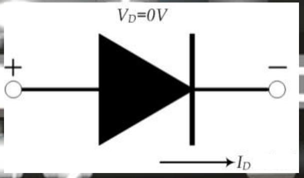




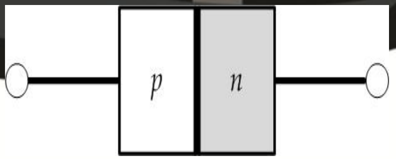
Diode Energy Levels



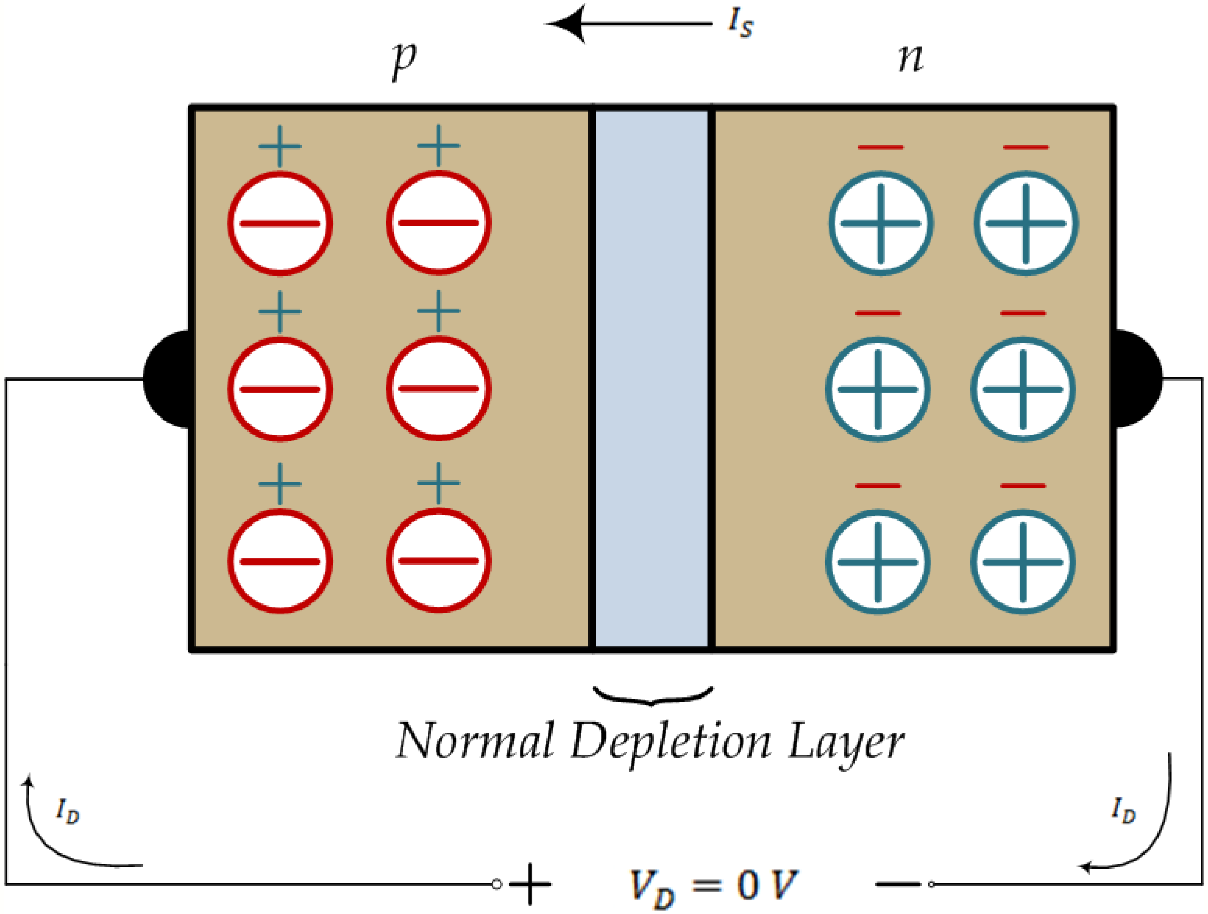




NO APPLIED BIAS CONDITION / UNBIASED DIODE ($V_D = 0\,V$)



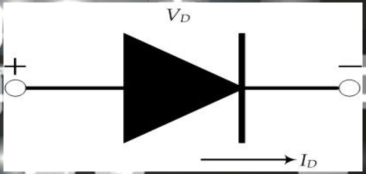
- Soon after entering the p region, the free electron recombine with a hole
- The hole disappears and the free electron becomes a valence electron



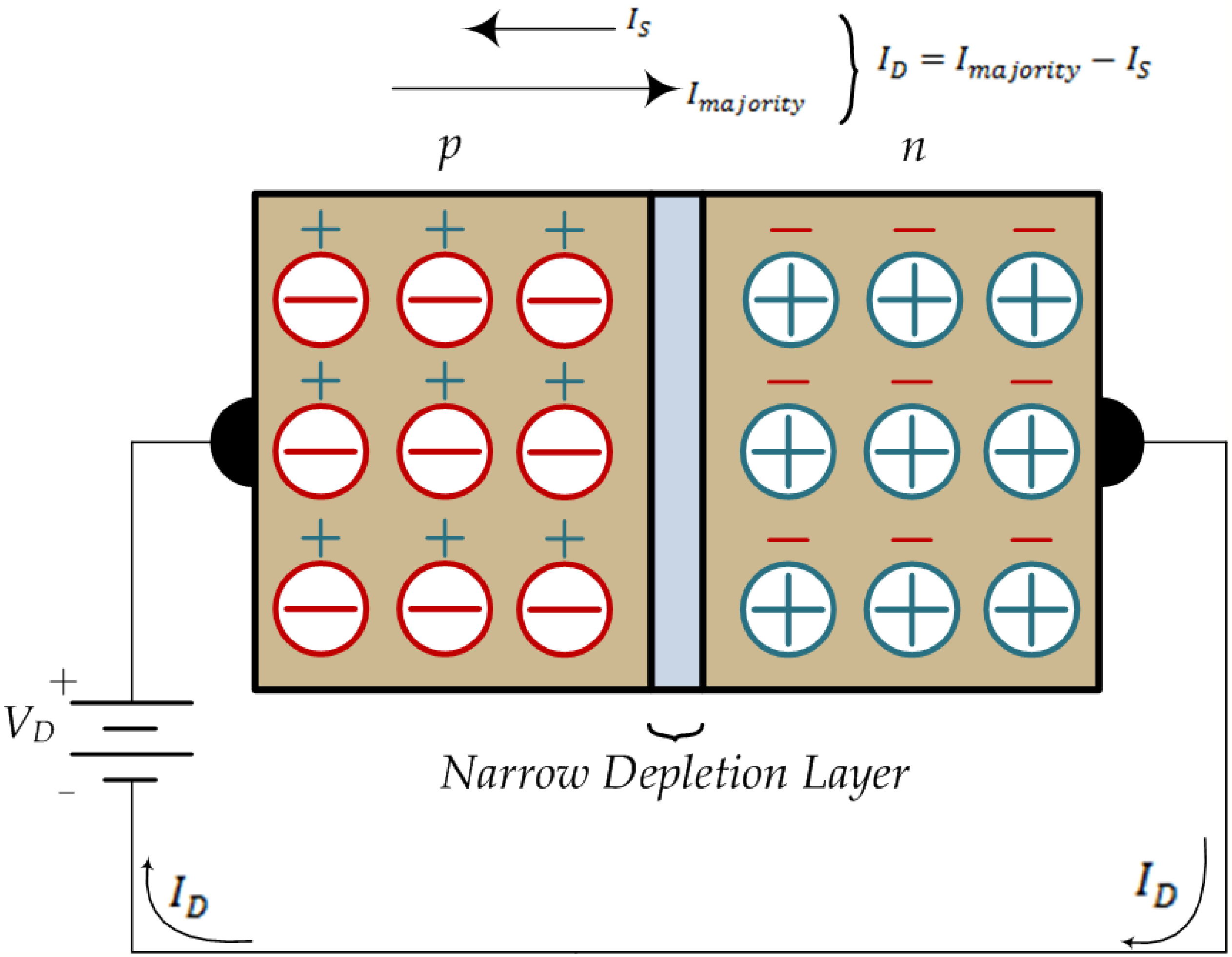
No Applied Bias Condition / Unbiased Diode ($V_D = 0\,V$)

- If additional free electrons enter the depletion layer, the electric field tries to push these electrons back into the n-side region
- The strength of the electric field increases with each crossing electron until equilibrium is reached
- At 25°C, the barrier potential equals approximately **0.3 V** for Germanium diodes and **0.7 V** for Silicon diodes

FORWARD BIAS CONDITION $(V_D > 0V)$



- The potential V_D will give "pressure" to the electron in the N-type material and holes in the p-type material to recombine with the ions near the boundary and reduce the width of the depletion area that has resulted in a heavy majority flow across the junction



FORWARD BIAS CONDITION $(V_D > 0V)$

According to Silicone semiconductor characteristics:

- $\eta = 1$ (Ge) and $\eta = 2$ (Si) for relatively low levels of diode current (at below the knee of the curve)
- $\eta = 1$ (Ge) and $\eta = 1$ (Si) for higher levels of diode current (at above the knee of the curve)

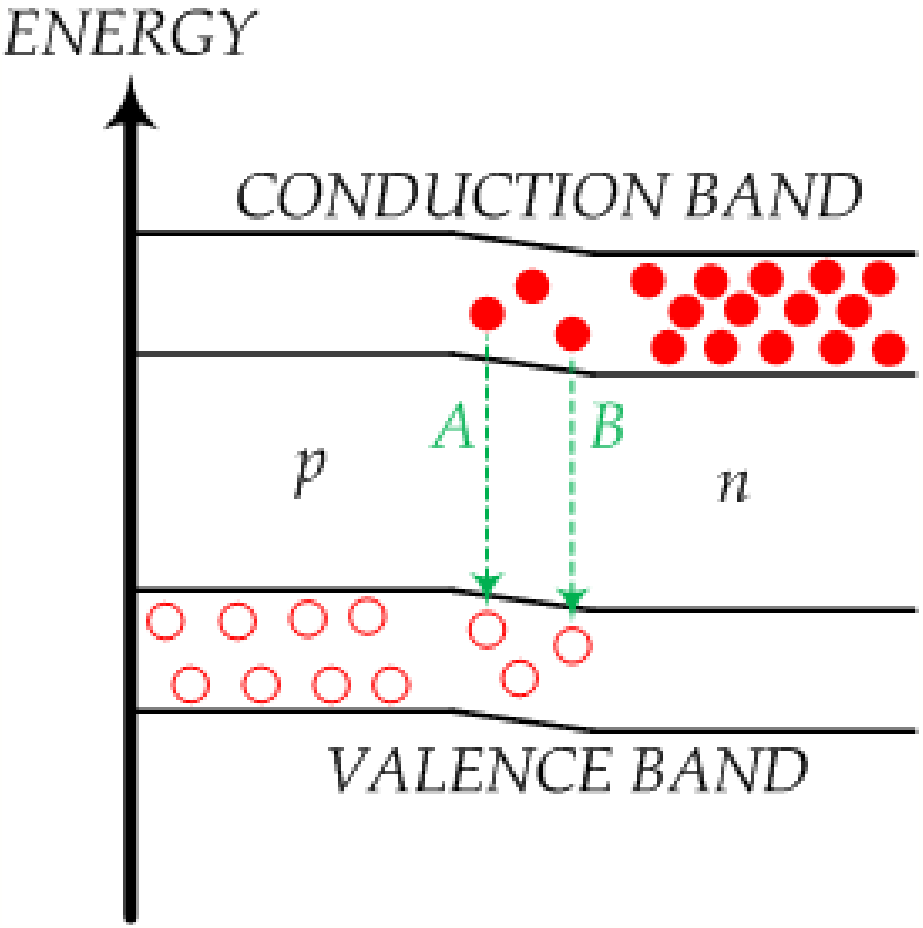
The potential at which the rise occurs is commonly referred to as the offset, firing, or **threshold potential**:

$V_T = 0.7$ V (Si)

$V_T = 0.3$ V (Ge)

Forward Bias Condition $(V_D > 0V)$

- Forward bias lower the energy band hill
- The battery increases the energy level of the free electrons so that this energy forces the band upward
- The free electrons have enough energy to enter the p-region and fall into holes (path A)
- Some holes penetrate the n-region, so that the conduction-band electrons can follow recombination (path B)



Forward Bias Condition $(V_D > 0V)$

- A steady stream of free electrons moves toward the junction and falls into holes near the junction
- The captured electrons (now valence electrons) move left in a steady stream through the holes in the p region. So that the continuous flow of electrons are occurred
- As valence electrons, they continue moving toward the left end of the crystal
- When electrons fall from the conduction band to the valence band, they radiate their excess energy in the form of heat and light
- With the ordinary diode, the radiation is heat energy. But with LED, the radiation can be light such as infrared, red, green, blue, orange, violet, or ultraviolet

FORWARD BIAS CONDITION $(V_D > 0V)$

$$I_D = I_S\left(e^{kV_D/T} - 1\right) \qquad \ldots \text{(I)}$$

where,

I_D = Diode current (Ampere)

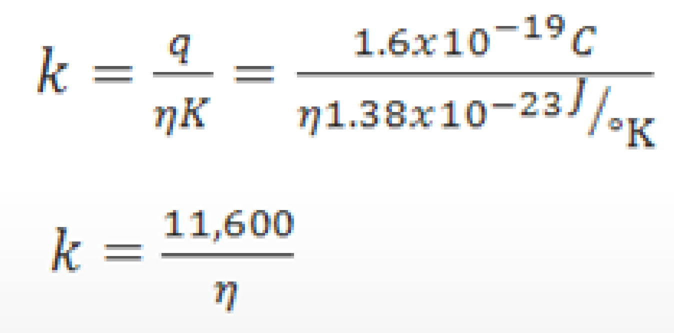
I_S = Reverse saturation current (*Ampere*)

T = temperature (°K)

V_D = Diode voltage (*Volt*)

k = constant or variable

Forward Bias Condition $(V_D > 0V)$



$$k = \frac{q}{\eta K} = \frac{1.6x10^{-19}C}{\eta 1.38x10^{-23} J/{}^{\circ}K}$$

$$k = \frac{11,600}{\eta}$$

. . . (II)

where,

k = *constant*

q = *electron charge* (C)

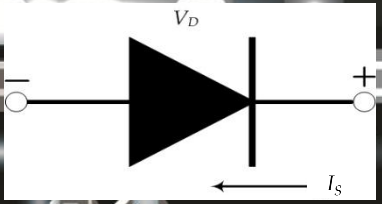
K = *Boltzmann constant* ($1.38 \cdot 10^{-23}\, J/K$)

η = *characteristic of **Si** Diode and **Ge** Diode*

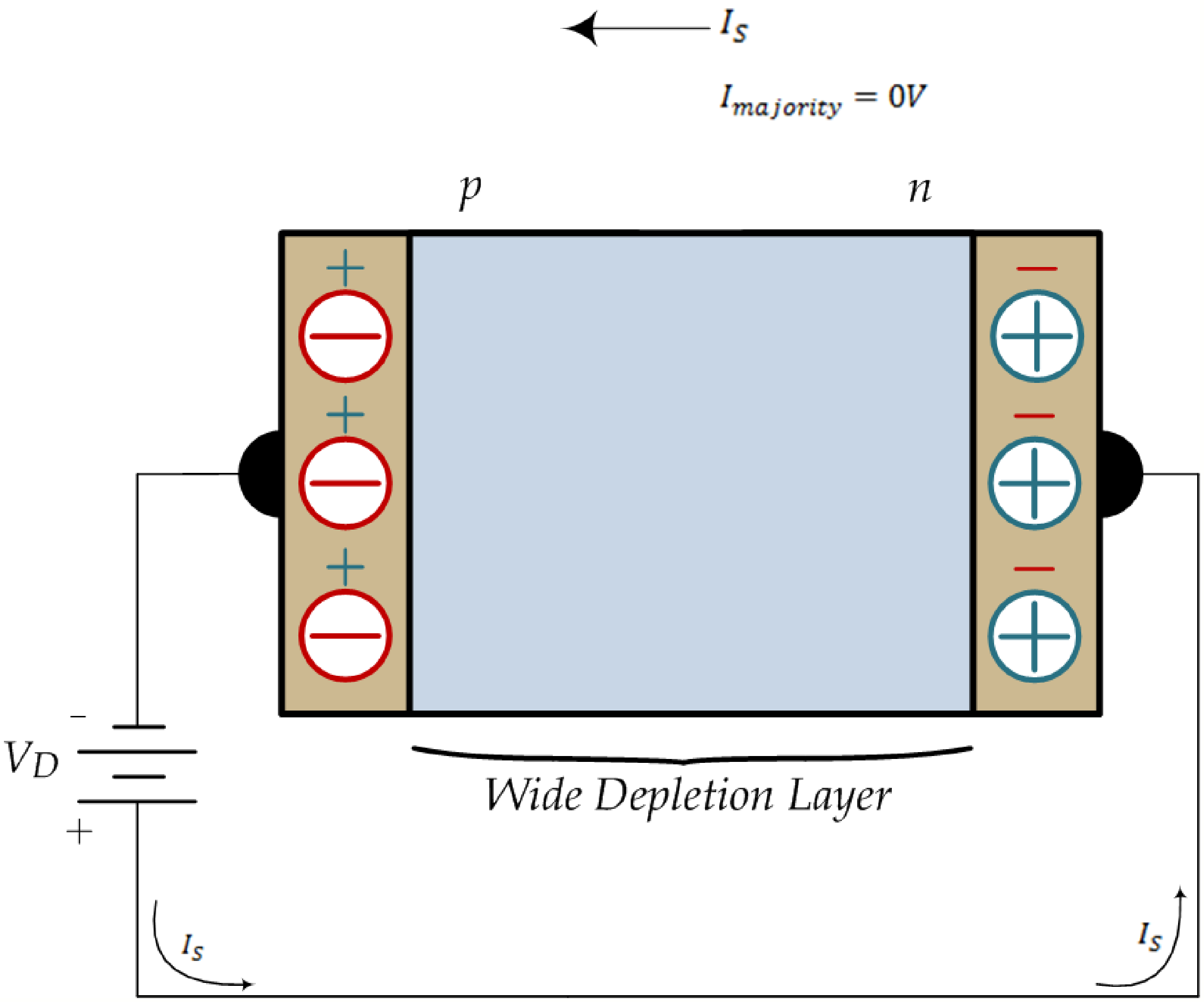
FORWARD BIAS CONDITION $(V_D > 0V)$

- Current flows easily in a forward-biased diode. As long as the applied voltage is greater than the barrier potential, there will be a large continuous current in the circuit
- If the source voltage is greater than 0.7 V, a Silicon diode allows a continuous current in the forward direction

REVERSE BIAS CONDITION ($V_D < 0V$)

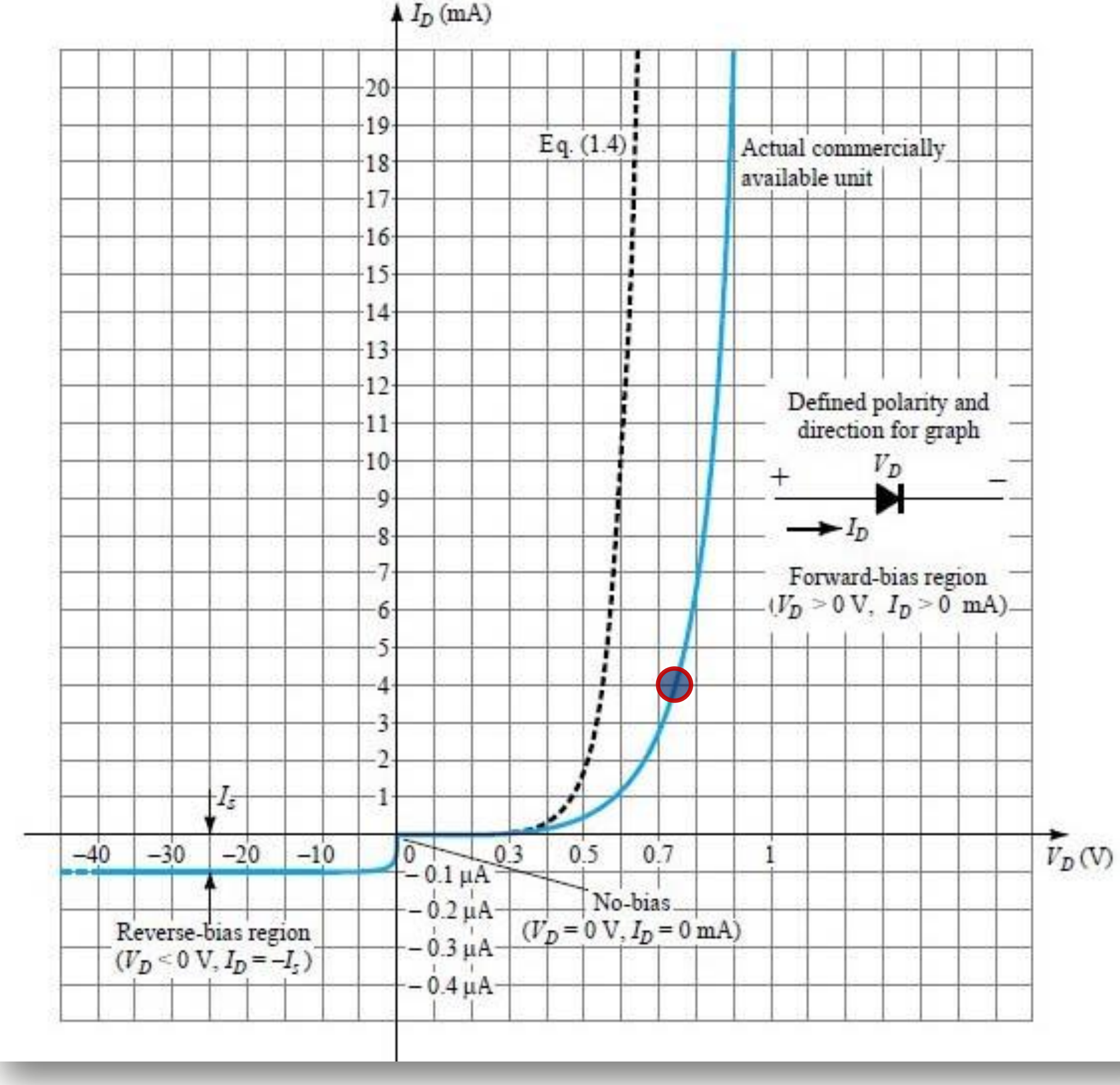


- The number of uncovered positive ions in the depletion region of the N-type will increase due to the large number of “free” electrons drawn to positive potential of applied voltage

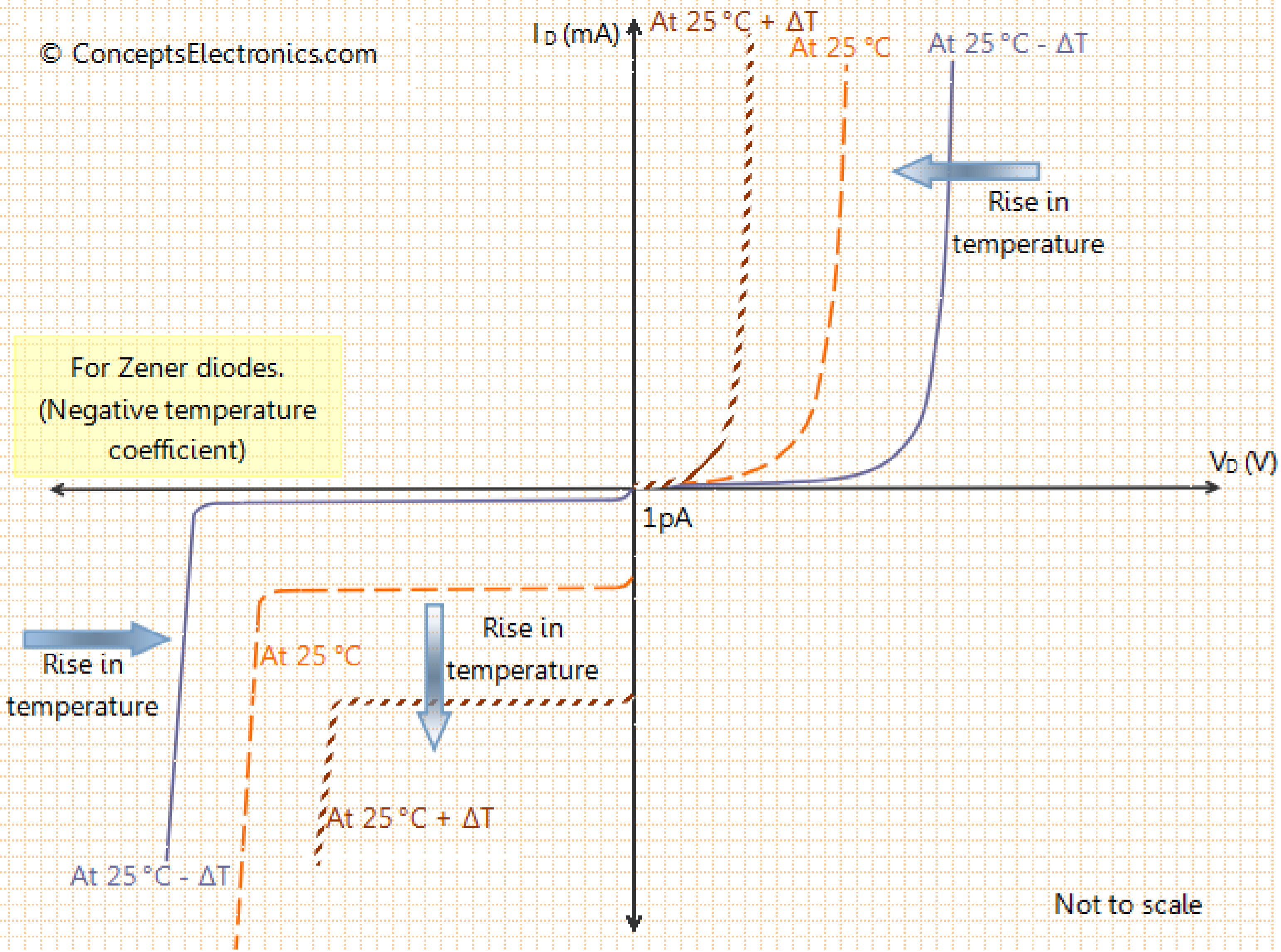


REVERSE BIAS CONDITION $(V_D < 0V)$

- For similar reasons, the number of uncovered negative ions will increase in the P-type
- This widening of the depletion region will establish too great barrier for the majority carriers to overcome, effectively reducing the majority carrier flow to zero
- The number of minority carriers, however, that find themselves entering the depletion region will not change, resulting in minority-carrier flow of the same magnitude with no applied voltage
- The reverse minority carriers I_S is seldom more than a few microamperes except for high-power devices



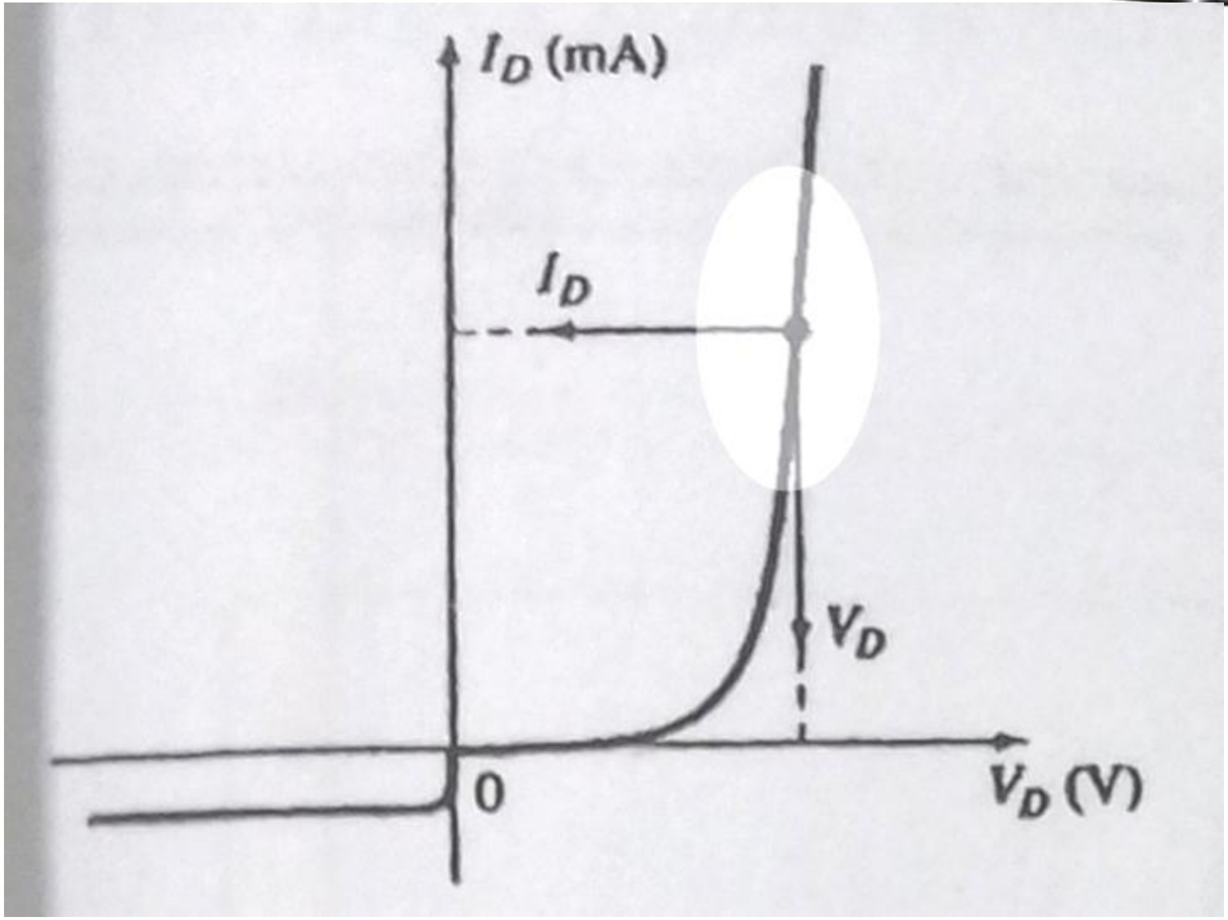
Semiconductor characteristics for Si and Ge



Effect of temperature on zener diodes

Silicone semiconductor characteristics

Resistance Level (DC Resistance)



DC Resistance or Static Resistance

RESISTANCE LEVEL (DC RESISTANCE)

DC or Static Resistance

It simply is:

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

. . . (III)

where,

R_D = *Resistance of diode* (*Ohm*)

I_D = *Current flow through diode* (*Ampere*)

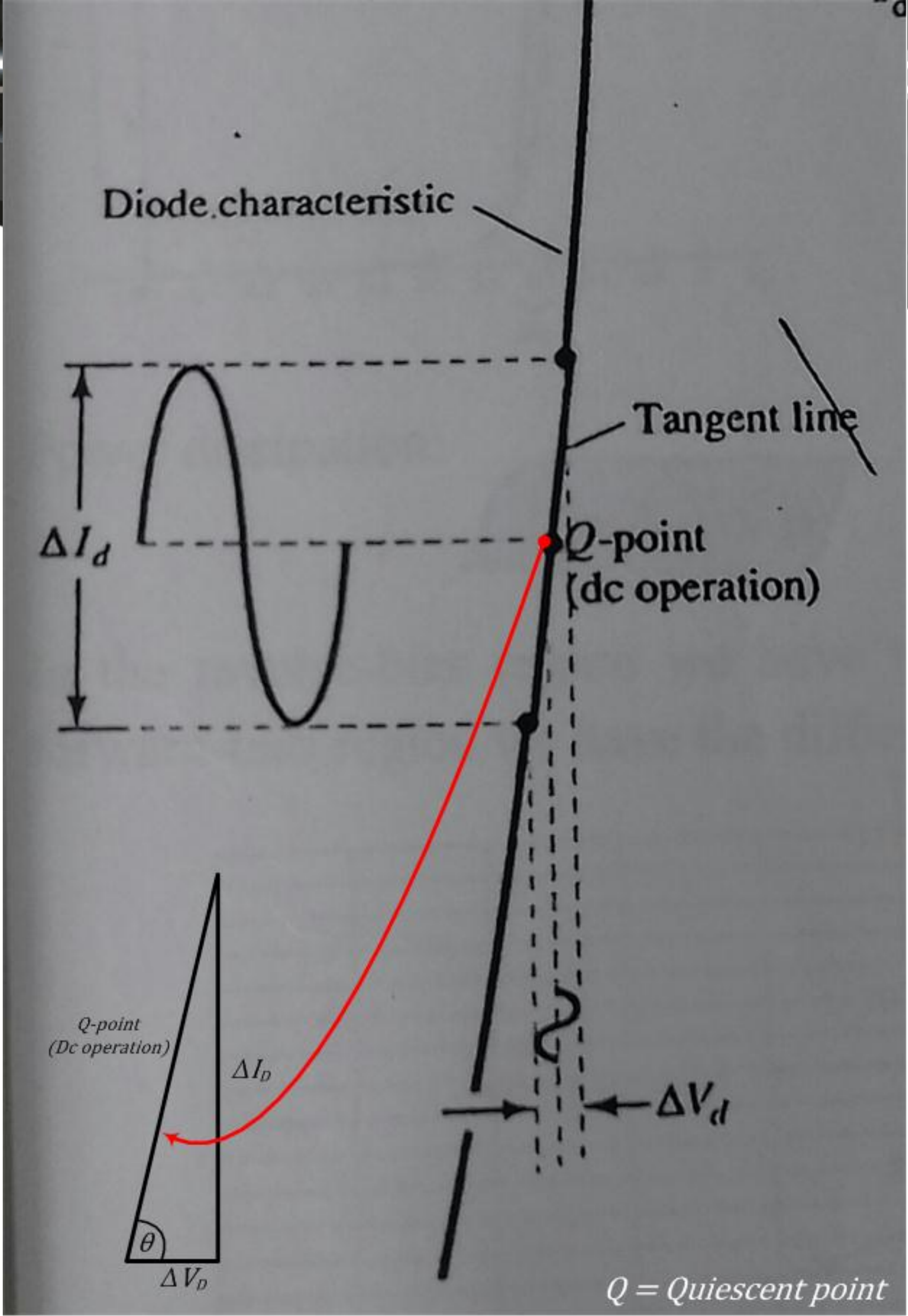
V_D = *voltage of diode* (*Volt*)

RESISTANCE LEVEL (AC RESISTANCE)

AC Resistance

Or

Dynamic Resistance



Resistance Level (AC Resistance)

$$r_d = \frac{\Delta V_D}{\Delta I_D}$$

Or the derivative of diode equation (from equation III):

$$\frac{d}{dV_D}(I_D) = \frac{d}{dV_D}\left[I_S\left(e^{kV_D/T}-1\right)\right]$$

$$\frac{dI_D}{dV_D} = \frac{k}{T} I_S\, e^{kV_D/T} = \frac{k}{T}(I_D + I_S) \cong \frac{k}{T} I_D$$

$$k = \frac{11{,}600}{\eta}$$

$$T = 25°\mathrm{C} + 273 = 298°\mathrm{K} \qquad (\textit{room temperature})$$

$$\frac{dI_D}{dV_D} = \frac{38.931 I_D}{\eta}$$

$$r_d \cong \eta \frac{0.026}{I_D}$$

So that we have: $\boxed{r_d = \eta \frac{26mV}{I_D}}$ . . . (IV)

RESISTANCE LEVEL (AC RESISTANCE)

AC or Dynamic Resistance

$$r_D = \eta \frac{26mV}{I_D}$$

. . . (V)

where,

r_D = *Resistance of diode* (*Ohm*)

η = *characteristics of diode semiconductor*

I_D = *Current flow through diode* (*Ampere*)

RESISTANCE LEVEL (AC RESISTANCE)

For I_D = 25mA (η = 1 and I_D > 4mA) on silicon semiconductor:

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.8V - 0.78V}{30mA - 20mA} = 2\Omega$$

or

$$r_d = \eta \frac{26mV}{I_D} = (1)\frac{26mV}{25mA} = 1.04\Omega$$

For I_D = 2mA (η = 2 and I_D < 4mA) on silicon semiconductor:

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.76V - 0.65V}{4mA - 0mA} = 27.5\Omega$$

or

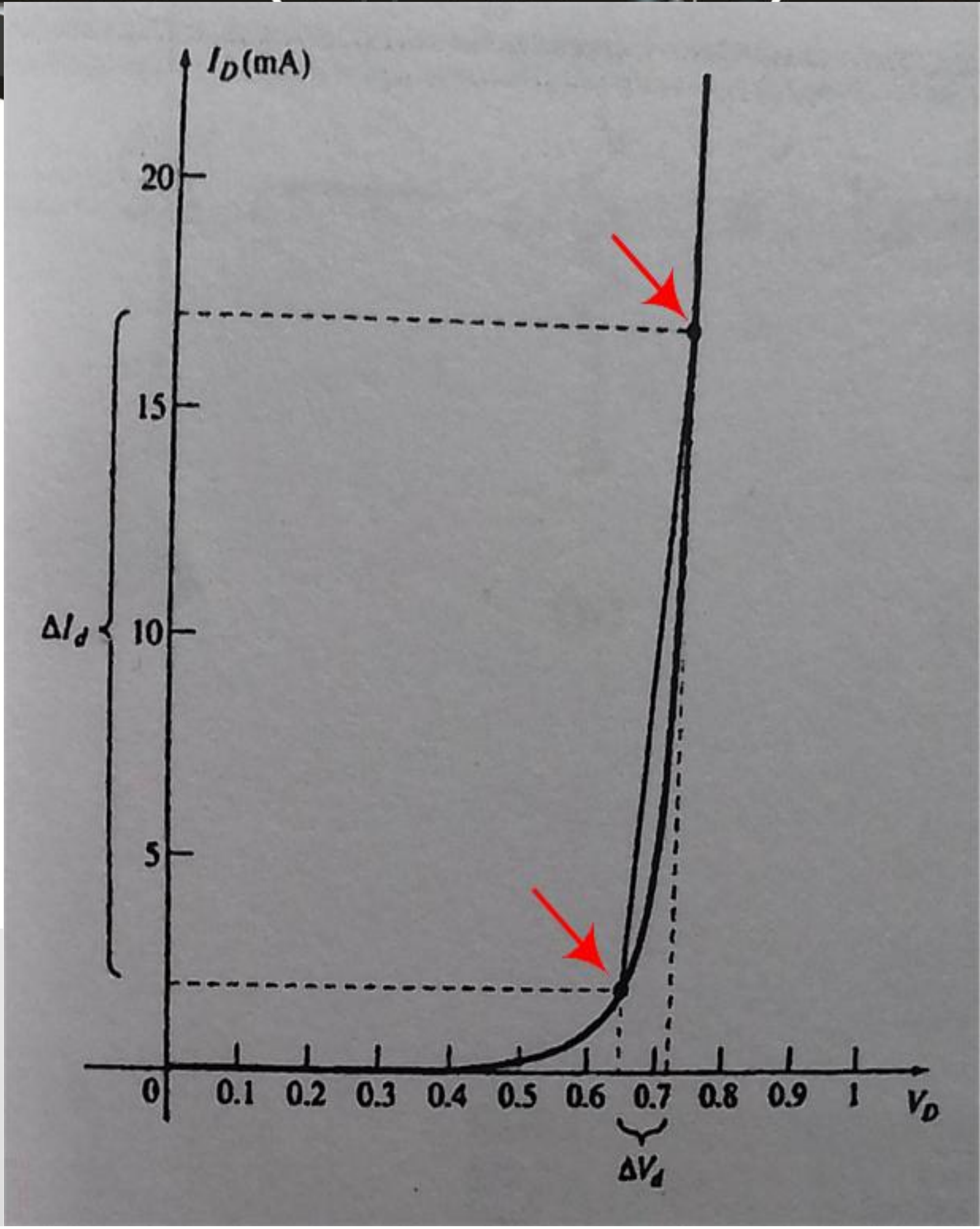
$$r_d = \eta \frac{26mV}{I_D} = (2)\frac{26mV}{2mA} = 26\Omega$$

AVERAGE AC RESISTANCE

The input signal is sufficiently large to produce a broad swing

$$r_{av} = \left.\frac{\Delta V_d}{\Delta I_d}\right|_{pt.\ to\ pt.}$$

$$r_{av} = \frac{\Delta V_d}{\Delta I_d} = \frac{0.725V-0.65V}{17mA-2mA} = 5\Omega$$



POWER DISSIPATION

$$\boxed{P_D = V_D I_D} \qquad . \quad . \quad . \quad (IV)$$

In the reverse-bias region we have the transition- or depletion- region capacitance (C_T), while in the forward-bias region we have the diffusion (C_D) or storage capacitance