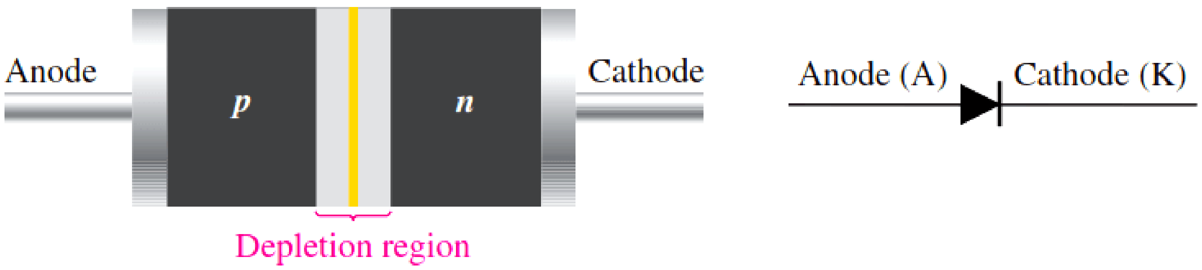
References:

1. Robert Boylestad, "Electronic Devices and Circuit Theory", Seventh Edition.

2. Thomas L. Floyd, "Electronic Devices: Electron Flow Version", Ninth Edition, 2012.

Semiconductor Diode:

A diode is made from a small piece of semiconductor material, usually silicon, in which half is doped as a **p** region and half is doped as an **n** region with a **pn** junction and depletion region in between. The **p** region is called the **anode** and is connected to a conductive terminal. The **n** region is called the **cathode** and is connected to a second conductive terminal. The basic diode structure and schematic symbol are shown in **Figure (1-1)**.



(a) Basic Structure **(b) Symbol**

Figure (1-1): The Diode.

Diode Bias:

If the external potential of V volt is applied across the P-N junction this will bias the diode. There are two type of diode bias:

1. Reverse-Bias Condition (V_D < 0V):

If an external potential of ***V*** volts is applied across the ***p-n*** junction such that the positive terminal is connected to the ***n*-type** material and the negative terminal is connected to the ***p*-type** material as shown in **Figure (1-2)**, the number of uncovered positive ions in the depletion region of the ***n*-type** material will increase due to the large number of "free" electrons drawn to the positive potential of the applied voltage. For similar reasons, the number of uncovered negative ions will increase in the ***p*-type** material. The net effect, therefore, is a widening of the depletion region. This widening of the depletion region will establish too great a barrier for the majority carriers to overcome, effectively reducing the majority carrier flow to zero as shown in **Figure (1-2)**.

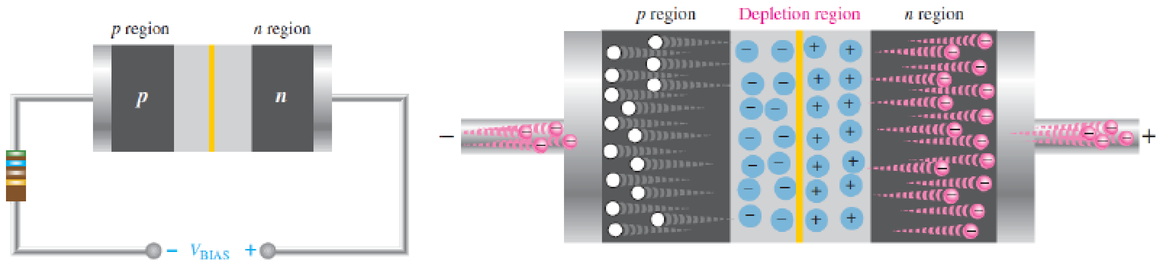


Figure (1-2): Reverse-biased p-n junction.

The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by $\mathbf{I_S}$.

2. **Forward-Bias Condition (VD > 0V):**

A semiconductor diode is forward-biased when the association ***p*-type** and positive and ***n*-type** and negative has been established, as shown in **Figure (1-3)**.

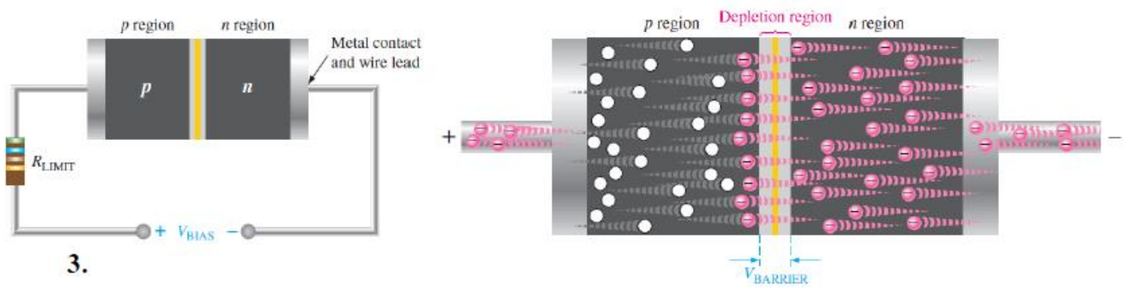


Figure (1-3): Forward-biased p-n junction.

In this case the external potential will force the carrier to cross the junction and a current will flow due to majority carrier this current depends on the external voltage, but there is a small current due to minority carrier opposing the forward carrier $\mathbf{I_S}$. The result current will be: $\mathbf{I_D = I_{majority} - I_S}$

P-N Junction Diode:

The **P-N** junction represents the bias electronic device which is the diode. It is a two-terminal device (**Anode** and **Cathode**).

The diode will be F.W. bias when $\mathbf{V_a > V_c}$ and Rev. bias when $\mathbf{V_a < V_c}$.

In general, the diode current $\mathbf{I_D}$ can be defined by the following equation for the forward- and reverse-bias regions:

$$\mathbf{I_D = I_S\,(e^{e\,V_D/KT} - 1)}$$

Where:

$\mathbf{V_D}$: applied voltage

K: Boltizman Constant. ($K = 1.38 * 10^{-23}$ J/K)

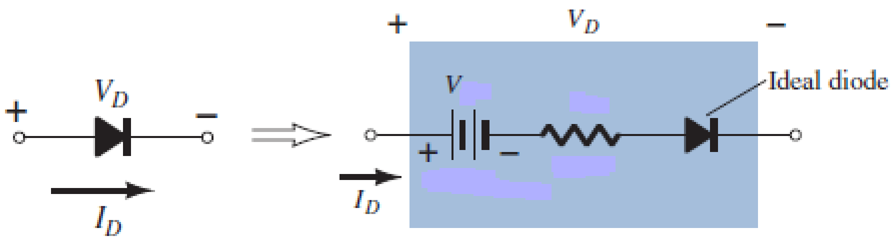
e: electron charge. ($e = 1.602 * 10^{-19}$ C)

T: Temp. in Kelvin.

$\mathbf{T_0}$: temp. in degree.

$\mathbf{T = T_0 + 273}$

Diode Equivalent Circuit:



(a) **(b)**

Figure (1-5): (a) Symbol Diode (b) Exact Equivalent Circuit.

For ideal diode at Forward it is short $\mathbf{V_D = 0}$ and Reverse it is open $\mathbf{I_D = 0}$.

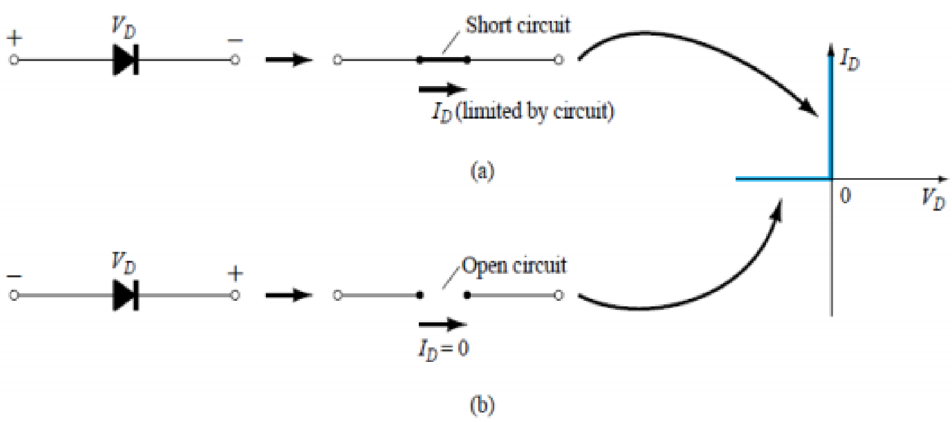


Figure (1-6): (a) Conduction (b) Non-Conduction State of Ideal Diode.

Diode equivalent circuit in both F.B and R.B shown in **Figure (1-7)**:

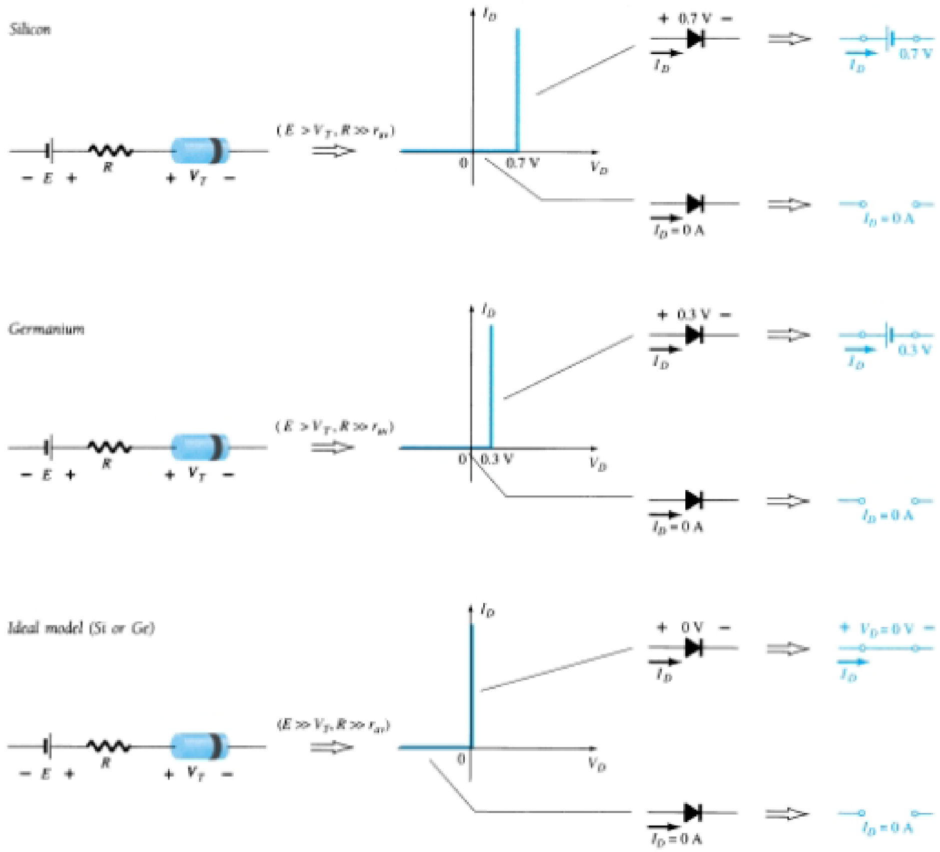
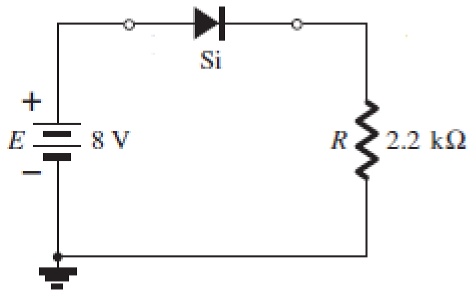
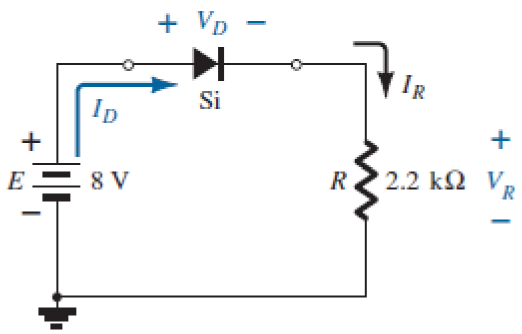


Figure (1-7): Approximate and Ideal Semiconductor Diode Models.

Example 1: **For the Figure below, Determine V_D, I_D, and V_R.**





Solution:

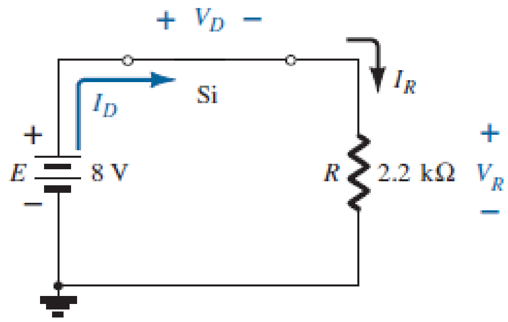
Since the applied voltage establishes a current in the clockwise direction to match the arrow of the symbol and the diode is in the "on" state,

$V_D = 0.7\ V$

$E - V_D - V_R = 0 \rightarrow E - V_D - I_D R = 0$

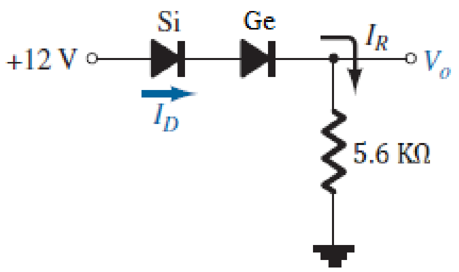
$E - V_D = I_D R$

$$I_D = \frac{E - V_D}{R} = \frac{8V - 0.7V}{2.2\ K\Omega} \cong 3.32\ mA$$

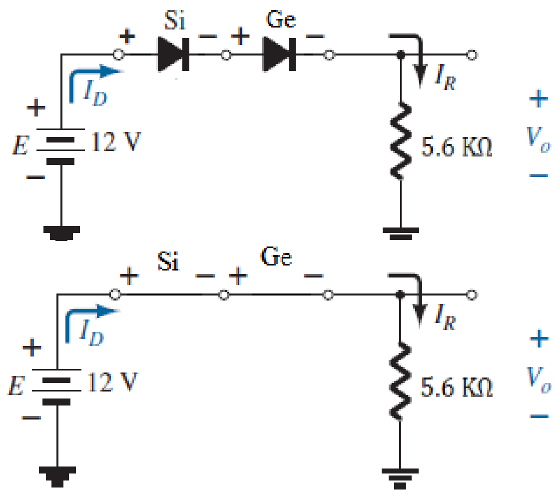


$V_R = I_R R = I_D R = 3.32\text{ mA} \times 2.2\text{ K}\Omega = 7.3\text{ V}$

Example 2: For the Figure below, Determine V_0 and I_D.



Solution:



$\mathrm{E - V_{D1} - V_{D2} - V_R = 0 \rightarrow E - V_{D1} - V_{D2} - V_o = 0}$

$\mathrm{12V - 0.7V - 0.3V - V_0 = 0}$

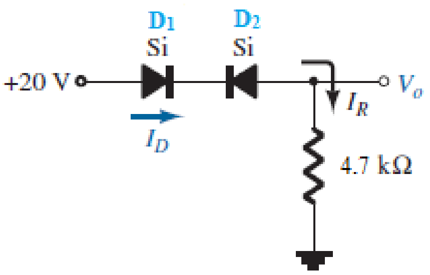
$\mathrm{V_0 = 12V - 0.7V - 0.3V = 11V}$

$\mathrm{V_0} = V_R = IR = I_D R$

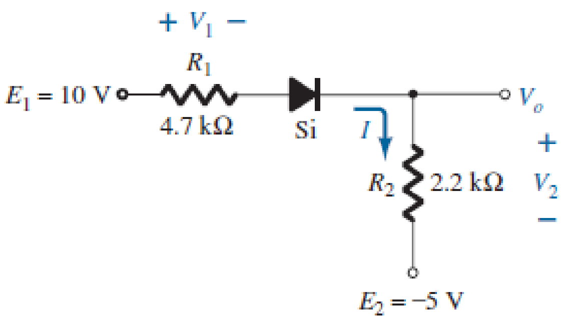
$$\mathrm{I_D = \frac{V_o}{R} = \frac{11V}{5.6\ K\Omega} \cong 1.96\ mA}$$

Homework:

1. **For the Figure below, Determine V_{D1}, V_{D2}, I_D, and V_o.**



2. **For the Figure below, Determine I, V_1, V_2 and V_o.**



V-I Diode Characteristics:

The relationship between applied voltage **V_D** and diode current **I_D** can draw as:

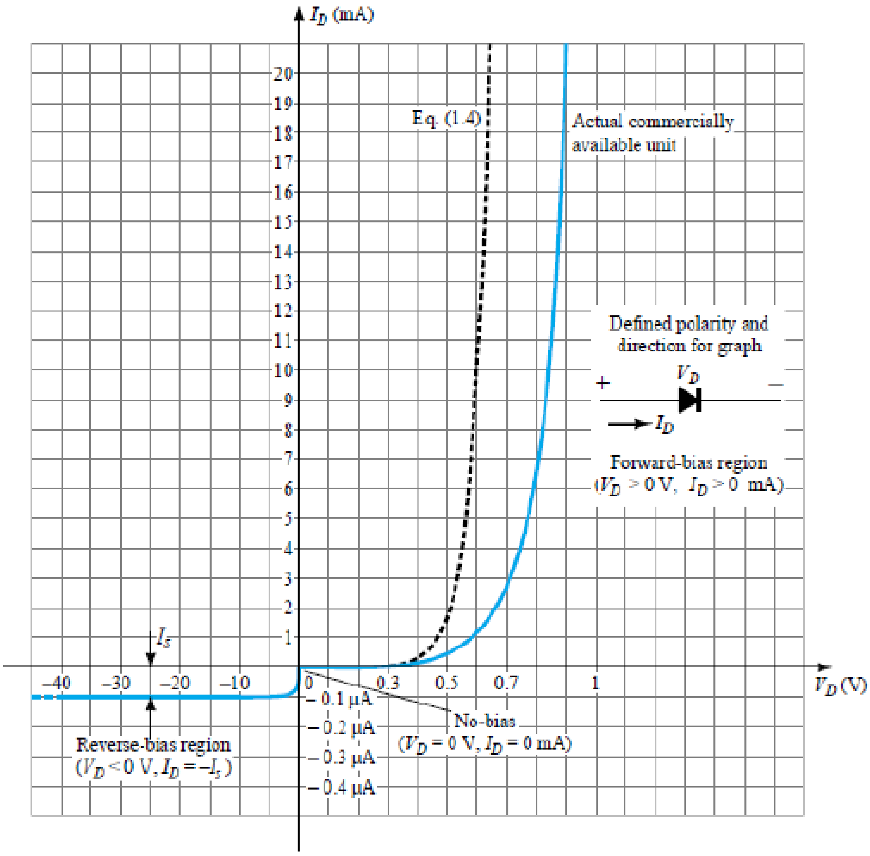


Figure (1-4): Silicon semiconductor diode characteristics.

The break down region is the reverse voltage that destroyed the reverse bias depletion region and flow current in R.B.

Diode Applications:

1. Load Line Analysis:

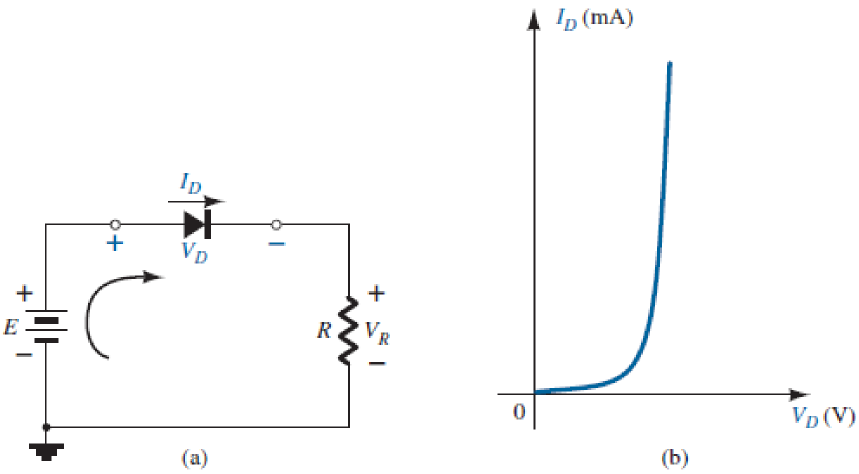


Figure (1-8): Series Diode Configuration (a) Circuit (b) Characteristics.

$$E - V_D - V_R = 0$$

$$E = V_D + I_D R$$

$$= 0\text{ V} + I_D R$$

$$I_D = \frac{E}{R}\bigg|_{V_D = 0\text{ V}}$$

$$E = V_D + I_D R$$

$$= V_D + (0\text{ A})R$$

$$V_D = E|_{I_D = 0\text{ A}}$$

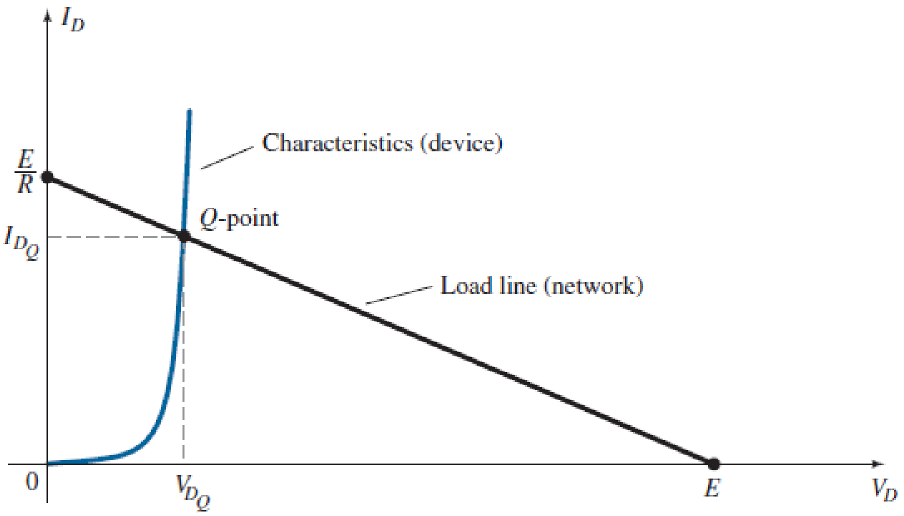
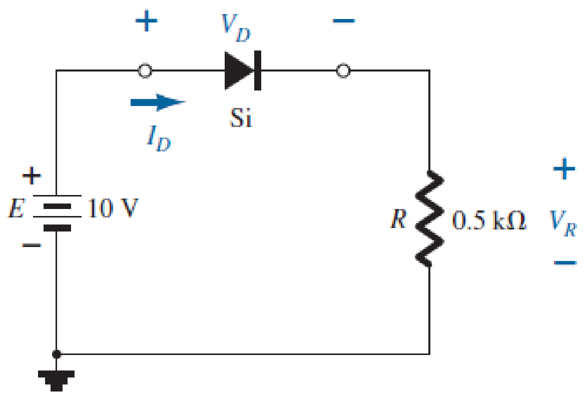
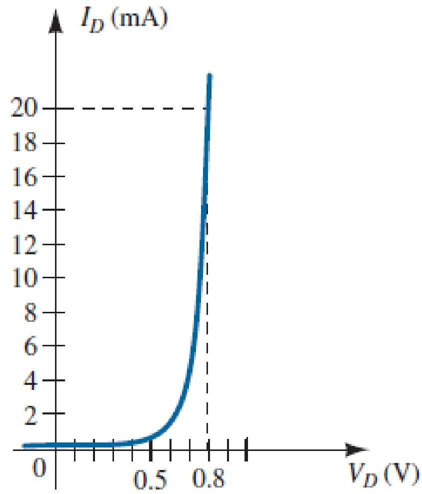


Figure (1-9): Drawing the Load Line and Finding the Point of Operating.

Example 3: For the Figure below, Determine: (a) V_{DQ} and I_{DQ}, (b) V_R.





Solution: (a)

$$I_D = \left.\frac{E}{R}\right|_{V_D=0\text{ V}} = \frac{10\text{ V}}{0.5\text{ k}\Omega} = 20\text{ mA}$$

$$V_D = E|_{I_D=0\text{ A}} = 10\text{ V}$$

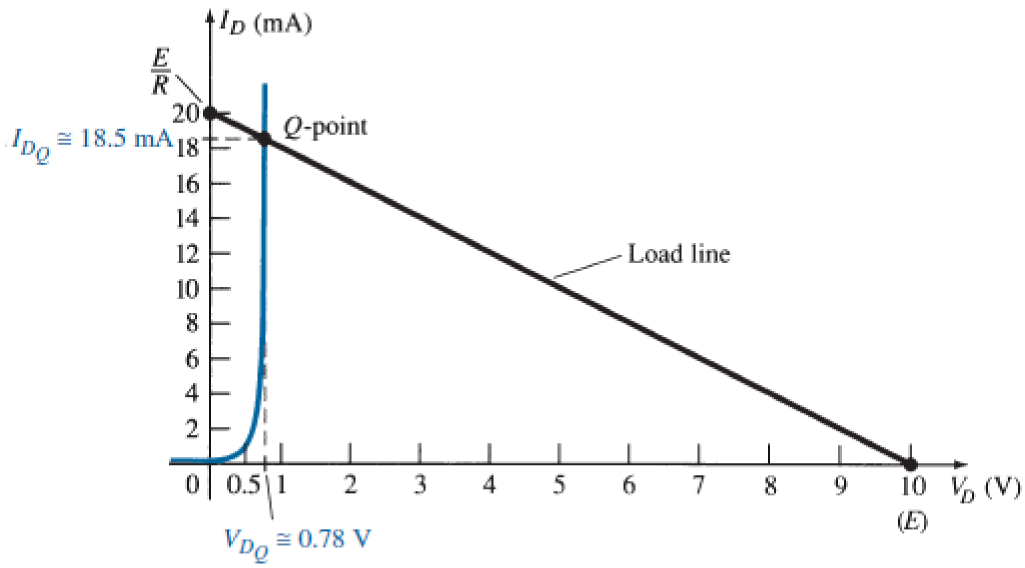
The intersection between the load line and the characteristic curve defines the Q-point as shown in Figure below:

$$V_{D_Q} \cong \mathbf{0.78\ V}$$

$$I_{D_Q} \cong \mathbf{18.5\ mA}$$

(b)

$$V_R = E - V_D = 10\text{ V} - 0.78\text{ V} = \mathbf{9.22\ V}$$



Homework: Repeat **Example 3** using the ideal diode model.