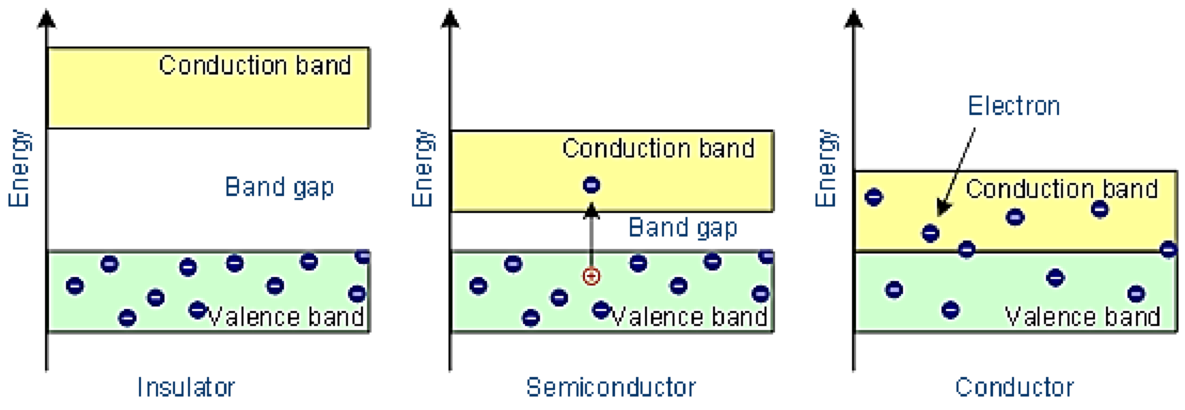
Electronics Fundamentals

Electronics: branch of physics and electrical engineering that deals with the emission, behavior, and effects of electronics and electronic devices. The science and technology of the conduction of electricity in a vacuum, a gas, of a semiconductor, and devices based on them.

We know that some solids are good conductors of electricity while others are insulators. There is also an intermediate class of semiconductors. The difference in the behavior of solids as regards their electrical conductivity can be beautifully explained in terms of energy bands. The electrons in the lower energy band are tightly bound to the nucleus and play no part in the conduction process. However, the valence and conduction bands are of particular importance in ascertaining the electrical behavior of various solids.

- **Insulators**: Insulators (e.g. wood, glass etc.) are those substances which do not allow the passage of electric current through them.
- **Conductors**: Conductors (e.g. copper, aluminum) are those substances which easily allow the passage of electric current through them. It is because there are a large number of free electrons available in a conductor.
- **Semiconductors**: Semiconductors (e.g. germanium, silicon etc.) are those substances whose electrical conductivity lies in between conductors and insulators. In terms of energy band, the valence band is almost filled and conduction band is almost empty. Further, the energy gap between valence and conduction bands is very small. Therefore, comparatively smaller electric field (smaller than insulators but much greater than conductors) is required to push the electrons from the valence band to the conduction band.



Types of semiconductors

Semiconductor
- **Intrinsic semiconductor**
- **Extrinsic semiconductor**
  - N-Type
  - P- Type

1- Intrinsic Semiconductor:

An intrinsic semiconductor is one which is made of the semiconductor material in its extremely pure form. Examples of such semiconductors are pure germanium and silicon.

2- Extrinsic semiconductor

Those intrinsic semiconductors to which some suitable impurity or doping agent or doping has been added in extremely small amount are called extrinsic or impurity semiconductors. Depending on the type of doping material used, extrinsic semiconductors can be divided into two types:

i- N-Type semiconductor

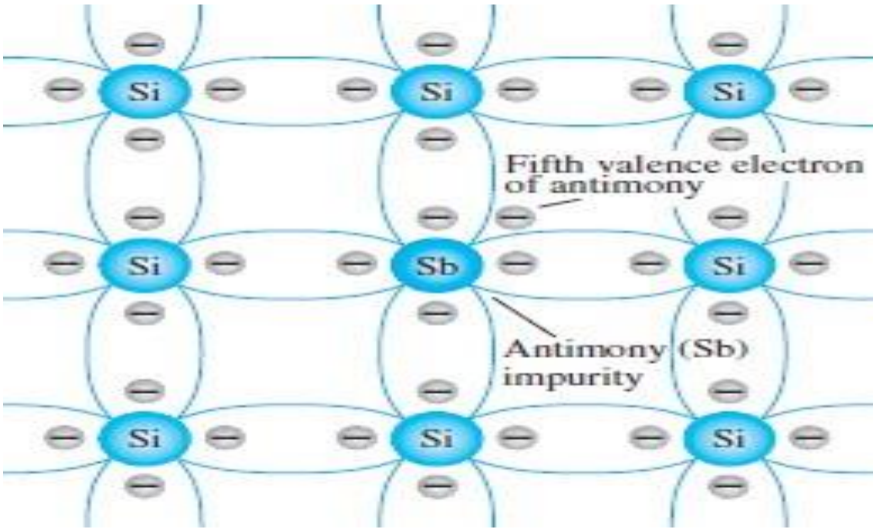
ii- P-Type semiconductor

***N*-Type semiconductor**

Both n -type and p -type materials are formed by adding a predetermined number of impurity atoms to a silicon base. An N-type material is created by introducing impurity elements that have five valence electrons (pentavalent), such as antimony, arsenic, and phosphorus.

Note that the four covalent bonds are still present. There is, however, an additional fifth electron due to the impurity atom, which is unassociated with any particular covalent bond. This remaining electron, loosely bound to its parent (antimony) atom, is relatively free to move within the newly

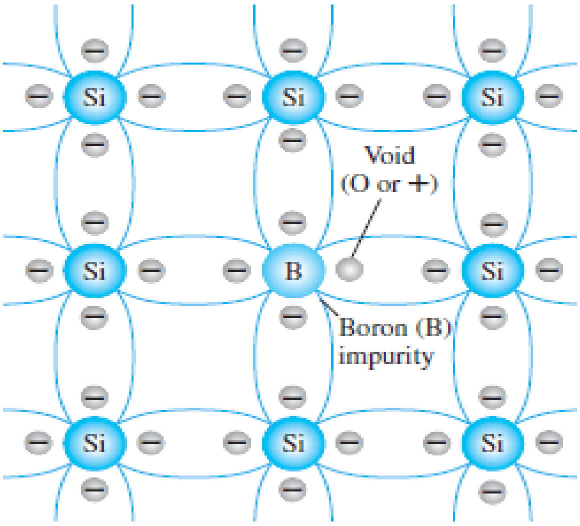
formed N-type material. Since the inserted impurity atom has donated a relatively "free" electron to the structure***: Diffused impurities with five valence electrons are called donor atoms*.**

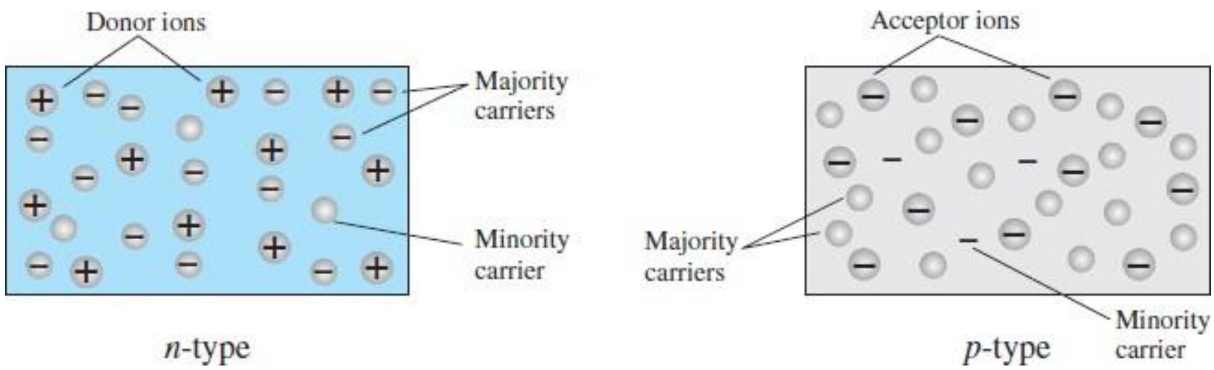


***P*-Type semiconductor**

The p -type material is formed by doping a pure germanium or silicon crystal with impurity atoms having three valence electrons. The elements most frequently used for this purpose are boron, gallium, and indium. Each is a member of a subset group of elements in the Periodic Table of Elements referred to as Group III because each has three valence electrons.

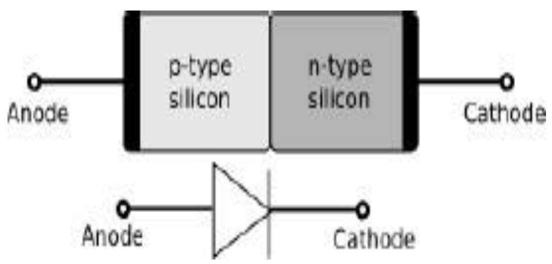
The effect of one of these elements, boron, on a base of silicon Note that there is now an insufficient number of electrons to complete the covalent bonds of the newly formed lattice. The resulting vacancy is called a hole and is represented by a small circle or a plus sign, indicating the absence of a negative charge. Since the resulting vacancy will readily accept a free electron:***The diffused impurities with three valence electrons are called acceptor atoms***.

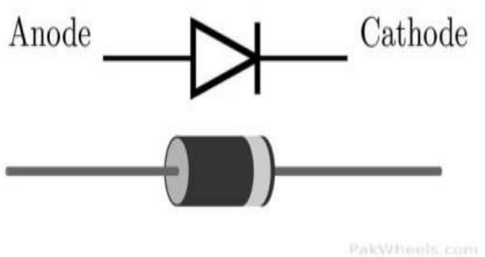




<u>P-N Junction Diode</u>

Now that both n - and p -type materials are available, we can construct our first solid-state electronic device: The semiconductor diode, with applications too numerous to mention, is created by simply joining an n -type and a p -type material together, semiconductor junction diodes are made by joining two semiconductors together. A P-N junction diode is formed by joining a P-type semiconductor to an N-type semiconductor. The basic simplicity of its construction simply reinforces the importance of the development of this solid-state era.

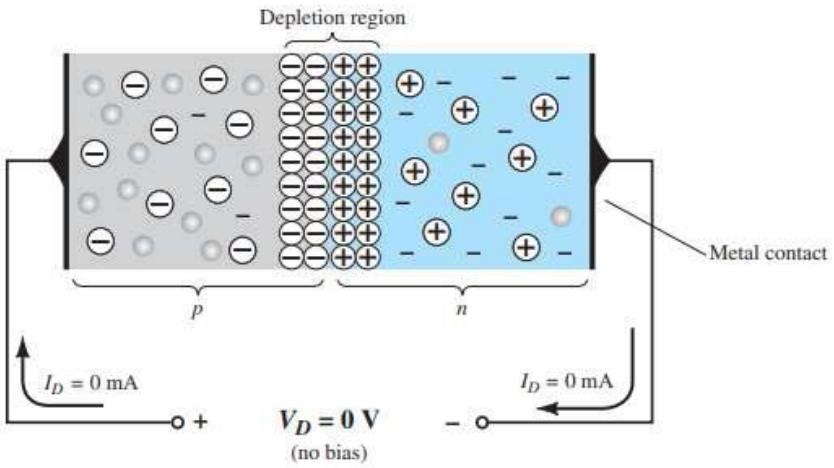




Types of Bias:

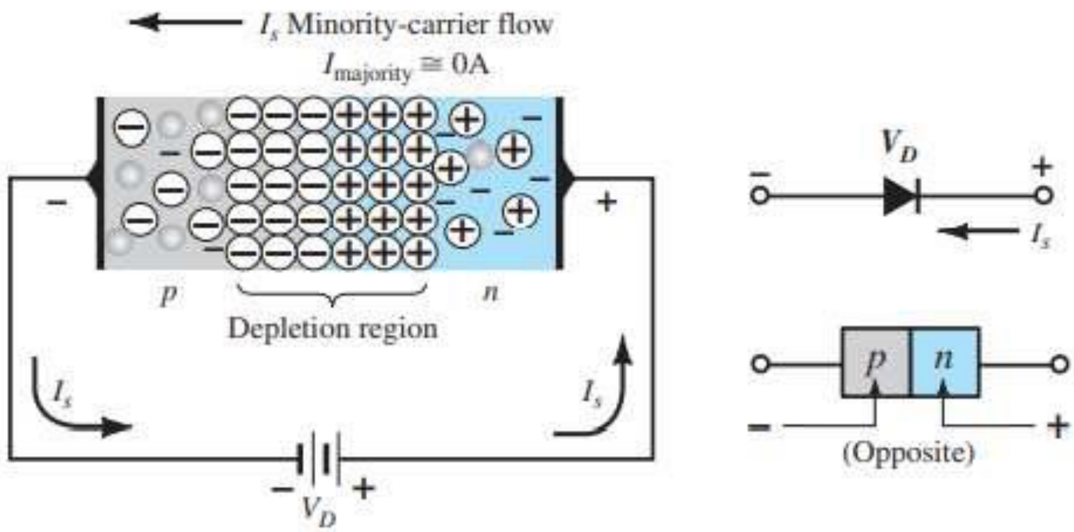
1- No Applied Bias (VD =0 V)

In the absence of an applied bias voltage, the net flow of charge in any one direction for a semiconductor diode is zero



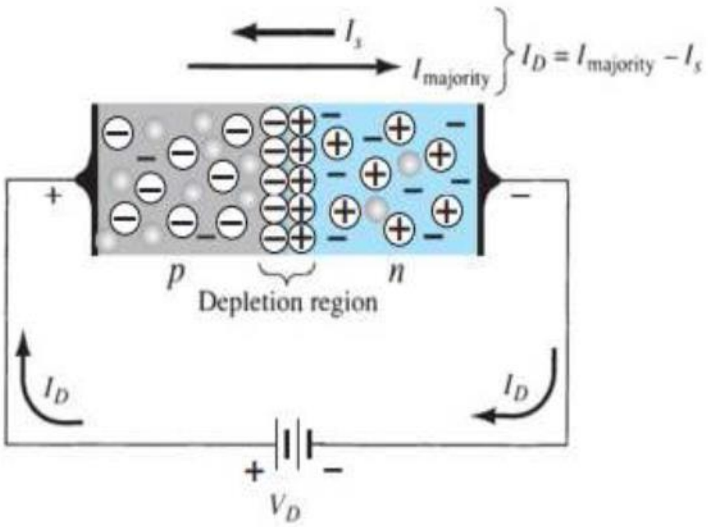
2- Reverse-Bias Condition (V D < 0 V)

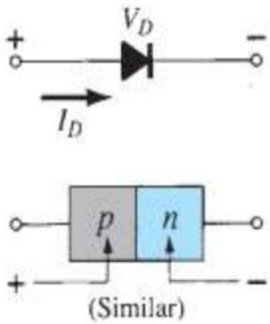
The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by Is



3- Forward-Bias Condition (V D > 0 V)

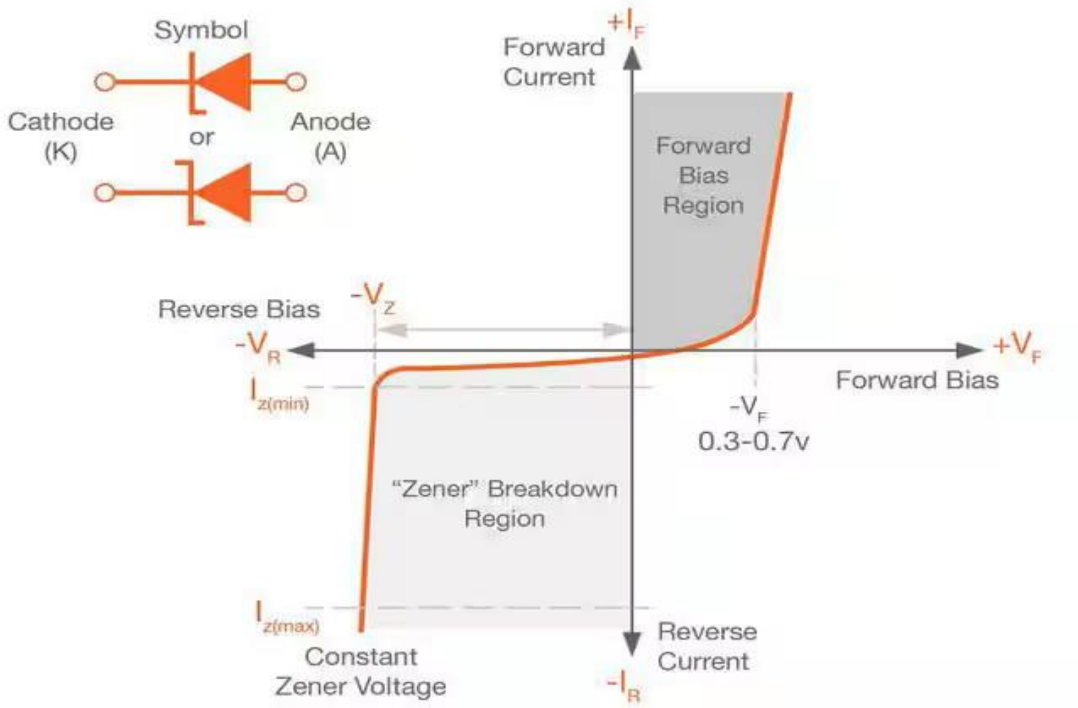
A semiconductor diode is forward-biased when the association p-type and positive and n-type and negative has been established





V/I characteristic

The figure shows the static voltage – current characteristic for the P-N junction diode.



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:

$$I_D = I_S(e^{kV_D/T_K} - 1)$$

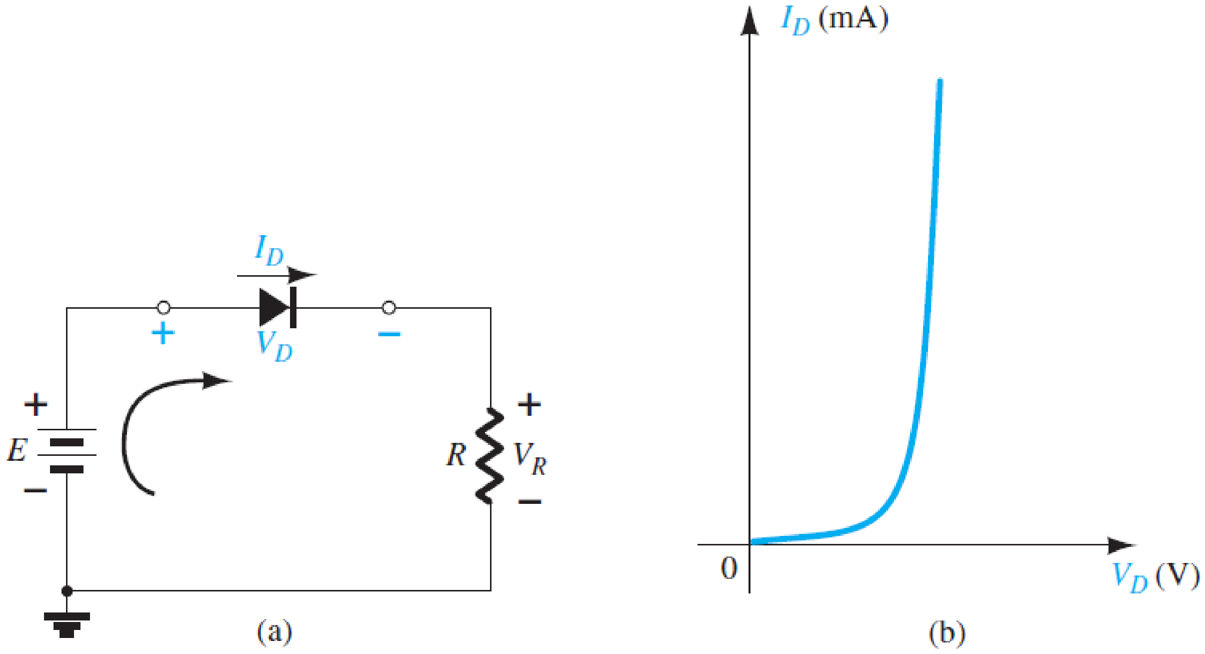
where ***Is*** is the reverse saturation current

VD is the applied forward-bias voltage across the diode where **k** is Boltzmann's constant =1.38 x 10^{-23} J/K

TK is the absolute temperature in kelvins=**273+**the temperature in °C

• Load-line analysis

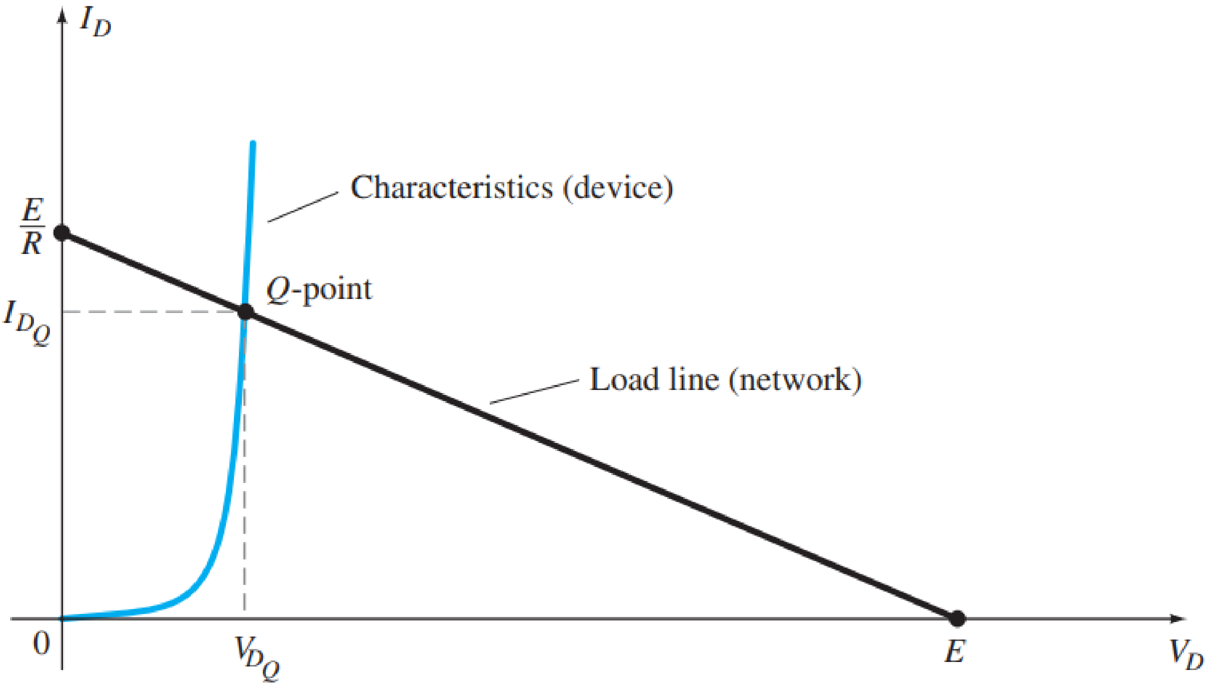
The circuit in the figure below is the simplest of diode configurations. It will be used to describe the analysis of a diode circuit using its actual characteristics.



Series diode configuration: (a) circuit; (b) characteristics.

In the figure below the diode characteristics are placed on the same set of axes as a straight line defined by the parameters of the network. The straight line is called a load line because the intersection on the vertical axis is defined by the applied load *R*. The analysis to follow is therefore called *load-line analysis*.

The intersection of the two curves will define the solution for the network and define the current and voltage levels for the network.



Drawing the load line and finding the point of operation.

The intersections of the load line on the characteristics can be determined by

first applying Kirchhoff's voltage law in the clockwise direction, which results in

$$+E-VD-VR=0$$

$$E=VD+VR$$

$$E=VD+ID\ R$$

The intersections of the load line on the characteristics can easily be determined if one simply employs the fact that anywhere on the horizontal axis $ID=0\ A$ and anywhere on the vertical axis $VD=0\ V$.

If we set $VD=0\ V$ in Eq. ($E=VD+ID\ R$) and solve for ID, we have the magnitude of ID on the vertical axis. Therefore, with $VD=0\ V$:-

$E=VD+ID\ R=0\ V+ID\ R$

$ID=\boldsymbol{E/R}|_{VD=0\ V}$

If we set $ID=0\ A$ in Eq. ($E=VD+ID\ R$) and solve for VD, we have the magnitude of VD on the horizontal axis. Therefore, with $ID=0\ V$:- $E=VD+ID\ R=VD+(0\ A)\ R$

$\boldsymbol{VD=E}|_{ID=0\ A}$

Note: Change the level of R (the load), resulting change in the slope of the load line and a different point of intersection between the load line and the diode characteristics.

We now have a load line defined by the network and a characteristic curve defined by the diode. The point of intersection between the two is the point of operation for this circuit. By simply drawing a line down to the horizontal axis, we can determine the diode voltage VDQ, whereas a horizontal line from the point of intersection to the vertical axis will provide the level of IDQ.

Using the Q-point values, the dc resistance for the diode calculate by the following equation: -

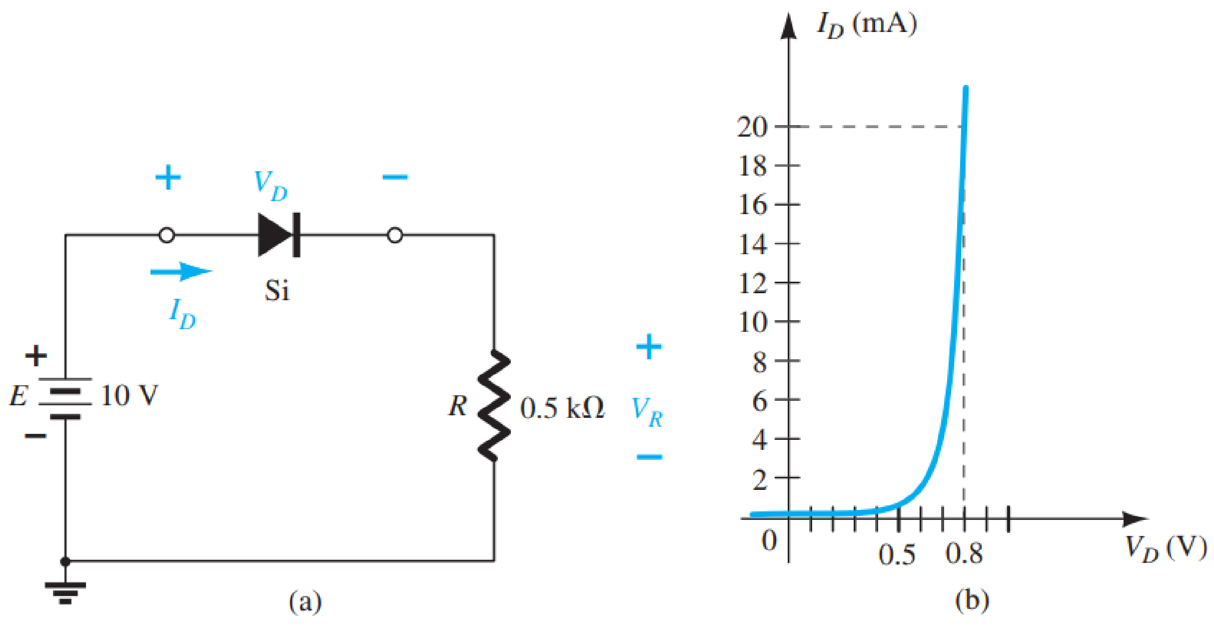
$$\boldsymbol{RD = VDQ/IDQ}$$

Example 1: For the series diode configuration in the figure below, determine:

a. VDQ and IDQ

b. RD

c. VR



(a) Circuit; (b) characteristics.

Solution:

a.

$E = V_D + I_D R$

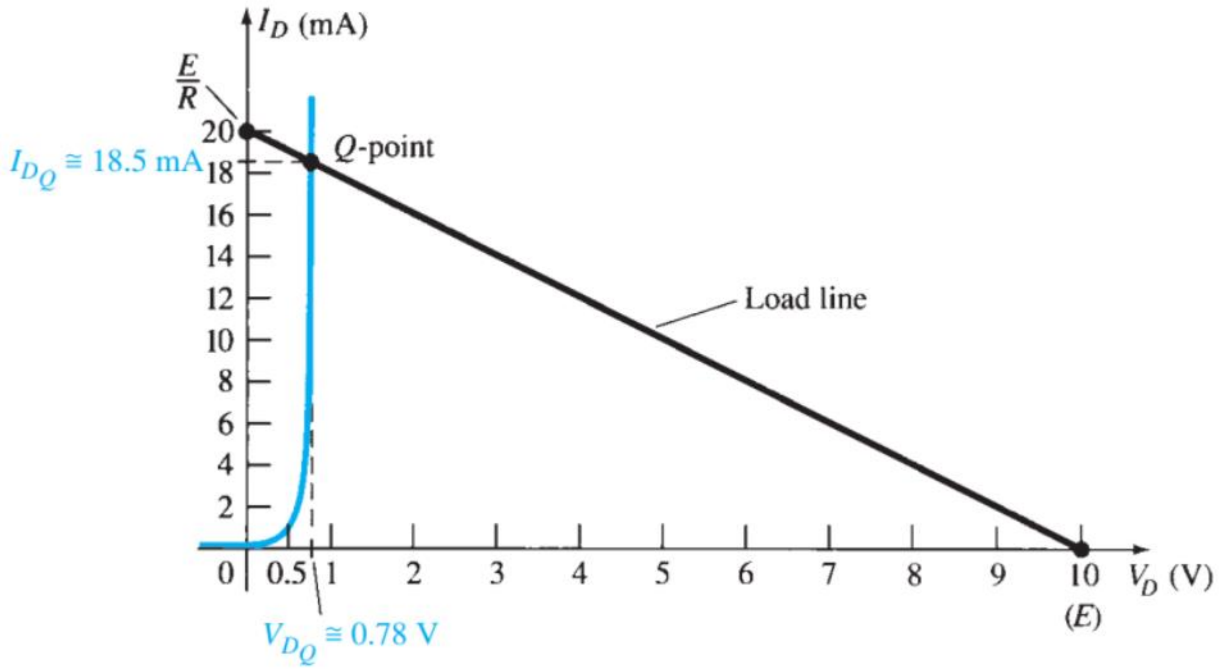
At $V_D = 0\ V$, $\boldsymbol{I_D = E/R}\,|_{V_D = 0\ V} = 10\ V/0.5\ K\Omega = 20\ mA$

At $I_D = 0\ A$, $\boldsymbol{V_D = E}|_{I_D = 0\ A} = 10\ V$

The resulting load line appears in figure below. The intersection between the load line and the characteristic curve defines the Q-point as:

$V_{DQ} \cong 0.78\ V$

$I_{DQ} \cong 18.5\ mA$



b.

$R_D = V_{DQ}/I_{DQ} = 0.78\ V/18.5\ mA = 42.16\Omega$

c.

$V_R = E - V_D = 10 - 0.78 = 9.22\ V$

Example 2: Repeat Example 1 using the approximate equivalent model for the silicon semiconductor diode.

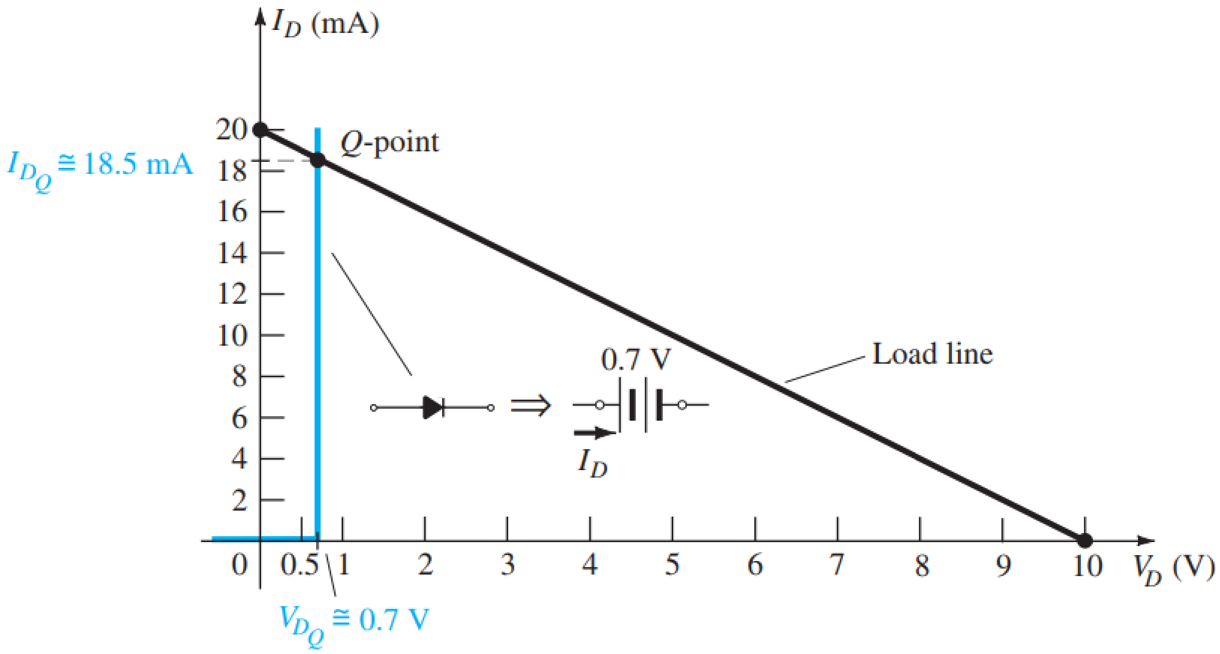
Solution:

a.

The load line is redrawn as shown below with the same intersections as defined in Example 1. The characteristics of the approximate equivalent circuit for the diode have also been sketched on the same graph. The resulting Q -point is

$VDQ = 0.7\ V$

$IDQ \cong 18.5\ \text{m}A$



Solution to Example 1 using the diode approximate model.

b.

$RD = VDQ/IDQ = 0.7\ V/18.5\ \text{m}A = 37.84\ \Omega$

c.

$VR = E - VD = 10 - 0.7 = 9.3\ V$

Example 3: Repeat Example 1 using the ideal diode model

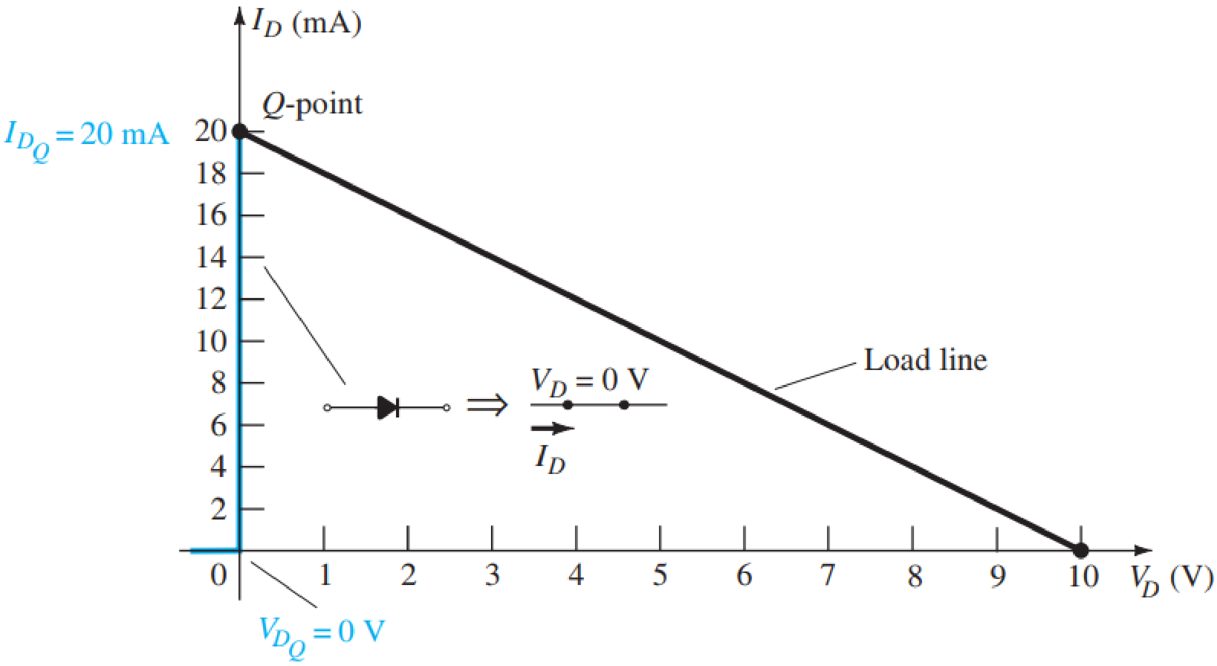
Solution:

a.

As shown below the load line is the same, but the ideal characteristics now intersect the load line on the vertical axis. The Q -point is therefore defined by

$V_{DQ} = 0\ V$

$I_{DQ} = 20\ mA$



Solution to Example 1 using the ideal diode model.

b.

$R_D = V_{DQ}/I_{DQ} = 0\ V/20\ mA = 0\ \Omega$ (or a short-circuit equivalent)

c.

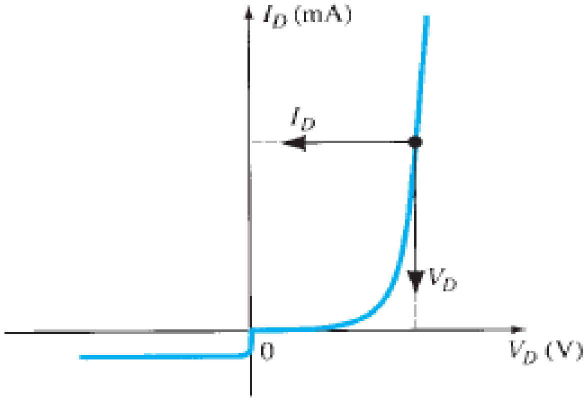
$V_R = E - V_D = 10 - 0 = 10\ V$

Resistance Levels

1- DC or Static Resistance:

The application of a dc voltage to a circuit containing a p-n junction diode will result in an operating point on the characteristic carve that will not change with time. The resistance of the diode at the operating point can found simply by finding the corresponding levels of VD and ID as shown in Fig. and applying the following equation:

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

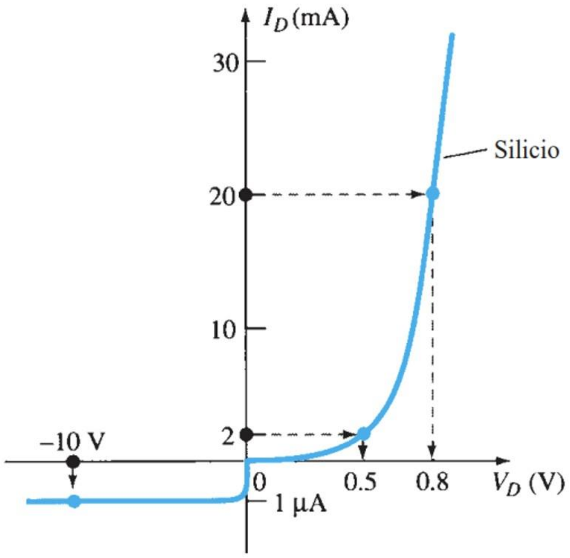


Example 4: Determine the dc resistance levels for the diode of Figure below

a) ID = 2 mA

b) ID = 20 mA

c) VD = -10 V



Solution:

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

=0.5 V/2 mA = **250 Ω**

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

=0.8 V/20 mA = **40 Ω**

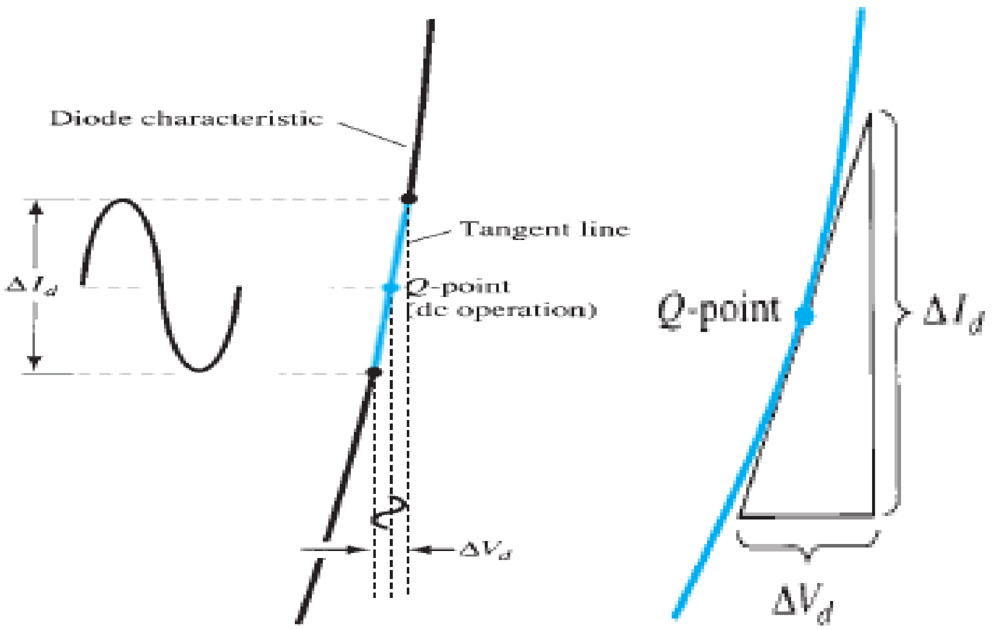
c. At V_D=-10 V, $I_D = I_s$ =-1 mA (from the curve) and $R_D = V_D/I_D$

=-10 V/-1 mA = **10 MΩ**

2. AC or Dynamic Resistance

If a sinusoidal rather than a dc input is applied, the situation will change completely. The varying input will move the instantaneous operating point up and down a region of the characteristics and thus defines a specific change in current and voltage as shown in Figure. With no applied varying signal, the point of operation would be the Q -point appearing on Figure, determined by the applied dc levels. The designation Q-point is derived from the word quiescent, which means “still or unvarying”.

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



Example 5: For the characteristics of Fig. 5:

a. Determine the ac resistance at I_D =2 mA.

b. Determine the ac resistance at I_D= 25 mA.

c. Compare the results of parts (a) and (b) to the dc resistances at each current level.

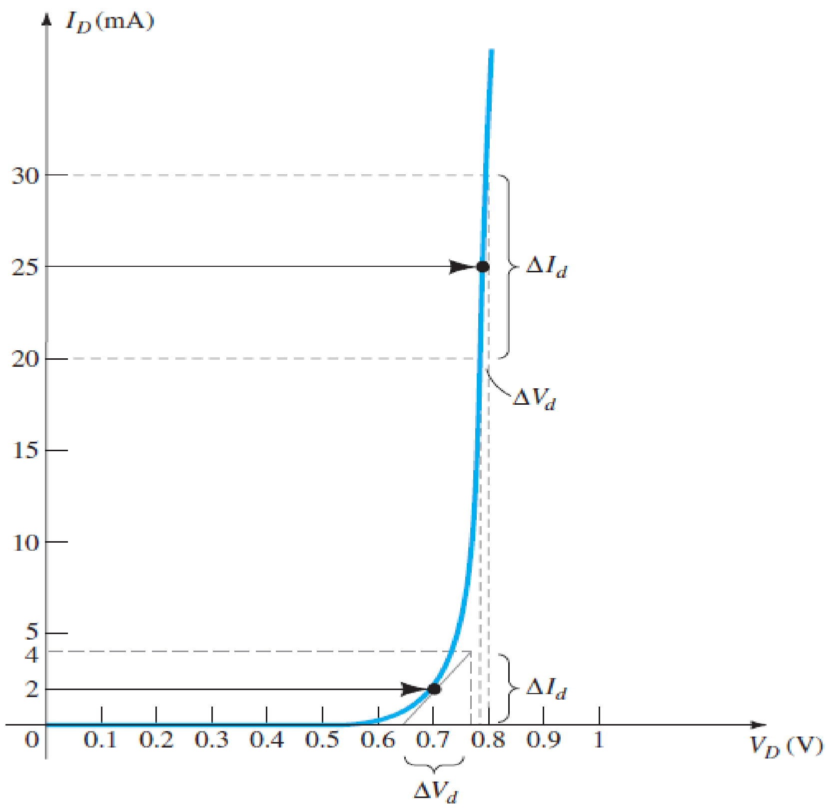


Fig. 5

Solution:

a. For I_D= 2 mA, the tangent line at I_D = 2 mA was drawn as shown in Fig. 1.2 and a swing of 2 mA above and below the specified diode current was chosen. At I_D= 4 mA,

V_D= 0.76 V, and at I_D = 0 mA, V_D = 0.65 V. The resulting changes in current and voltage are, respectively,

ΔI_d = 4 mA - 0 mA = 4 mA

and ΔV_d = 0.76 V - 0.65 V = 0.11 V

and the ac resistance is

$r_d = \Delta V_d / \Delta I_d$ =0.11 V/4 mA = **27.5Ω**

b. For I_D = 25 mA, the tangent line at I_D= 25 mA was drawn as shown in Fig. 5 and a swing of 5 mA above and below the specified diode current was chosen. At I_D = 30 mA,V_D= 0.8 V, and at I_D = 20 mA, V_D =0.78 V. The resulting changes in current and voltage are, respectively,

ΔI_d = 30 mA - 20 mA = 10 mA

and ΔV_d = 0.8 V - 0.78 V = 0.02 V

and the ac resistance is

$r_d = \Delta V_d / \Delta I_d$

=0.02 V/10 mA = **2 Ω**

c. For I_D = 2 mA, V_D = 0.7 V and

$R_D = V_D / I_D$

=0.7 V/2 mA = **350 Ω**

which far exceeds the r_d of 27.5 **Ω**.

For I_D = 25 mA, V_D = 0.79 V and

$R_D = V_D / I_D$

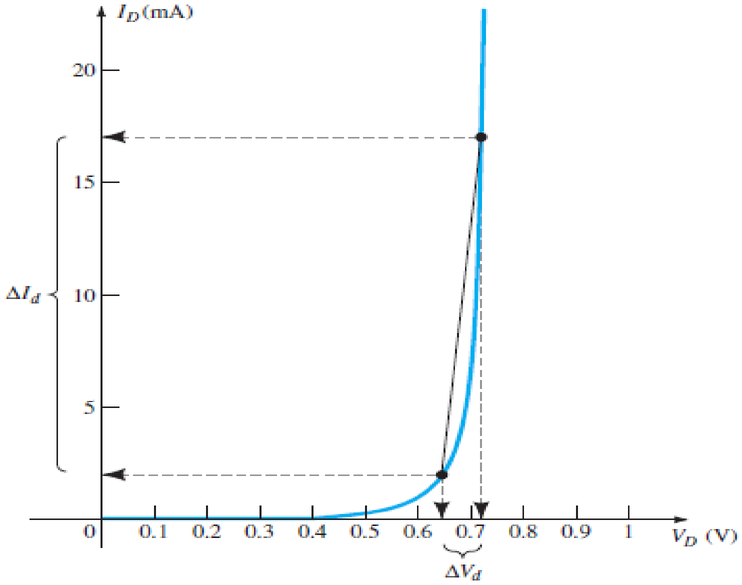
=0.79 V/25 mA = **31.62 Ω**

which far exceeds the r_d of 2 **Ω**.

Average AC Resistance

If the input signal is sufficiently large to produce a broad swing such as indicated in Figure, the resistance associated with the device for this region is called the average ac resistance. The average ac resistance is, by definition, the resistance determined by a straight line drawn between the two intersections established by the maximum and minimum values of input voltage. In equation form

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



and $=\Delta V_d = 0.725\text{ V} - 0.65\text{ V} = 0.075\text{ V}$

with $r_{av} = \Delta V_d / \Delta I_d$

$=0.075\text{ V}/15\text{ mA} = \mathbf{5\ \Omega}$

If the ac resistance (r_d) were determined at I_D= 2 mA, its value would be more than 5 Ω,and if determined at 17 mA, it would be less. In between, the ac resistance would make the transition from the high value at 2 mA to the lower value at 17 mA. a value that is considered the average of the ac values from 2 mA to 17 mA. The fact that one resistance level can be used for such a wide range of the characteristics will prove quite useful in the definition of equivalent circuits for a diode in a later section.

As with the dc and ac resistance levels, the lower the level of currents used to determine the average resistance, the higher is the resistance level.