BFF1303: ELECTRICAL / ELECTRONICS ENGINEERING

Analog Electronics

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Semiconductor Diodes & Circuits

BFF1303 ELECTRICAL/ELECTRONICS ENGINEERING

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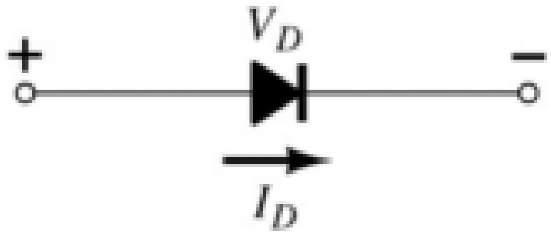
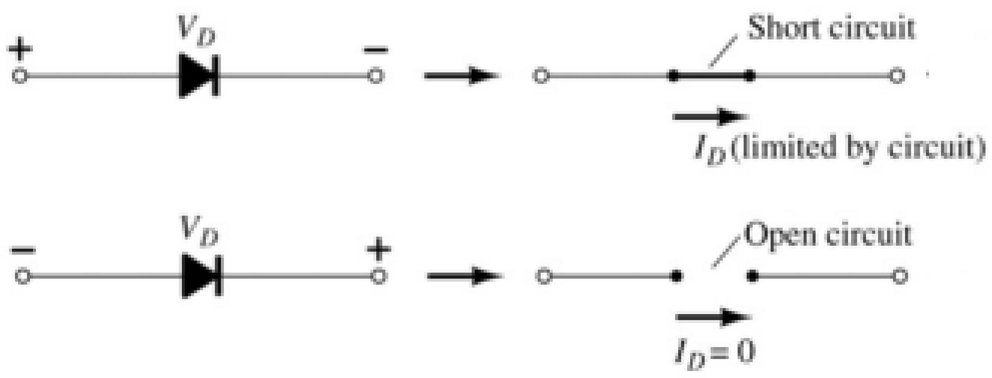
Outcomes

1. Understand the diode characteristics and its model
2. Learn the types of diodes
3. Learn the series and parallel operation of diodes
4. Analyze and design simple voltage-regulator circuits.
5. Understand various rectifiers and wave-shaping circuits

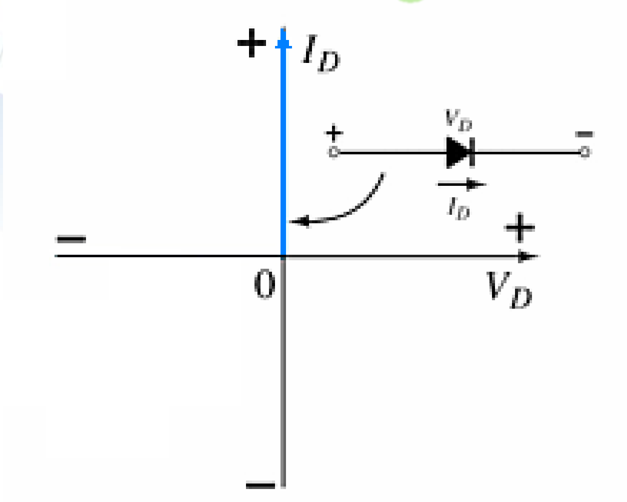
The diode is a 2-terminal device.



A diode ideally conducts in only one direction.

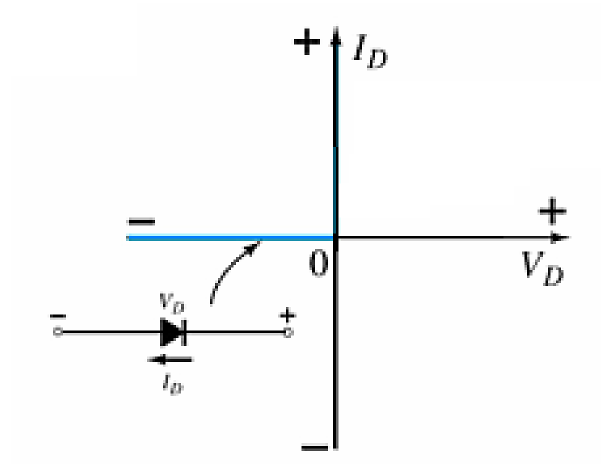


Conduction Region



- The voltage across the diode is 0 V
- The current is infinite
- The forward resistance is defined as $R_F = V_F / I_F$
- The diode acts like a short

Non-Conduction Region



- All of the voltage is across the diode
- The current is 0 A
- The reverse resistance is defined as $R_R = V_R / I_R$
- The diode acts like open

- Materials commonly used in the development of semiconductor devices:
  - Silicon (Si)
  - Germanium (Ge)
  - Gallium Arsenide (GaAs)

Doping

- The electrical characteristics of silicon and germanium are improved by adding materials in a process called doping.

- There are just two types of doped semiconductor materials:

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n-type

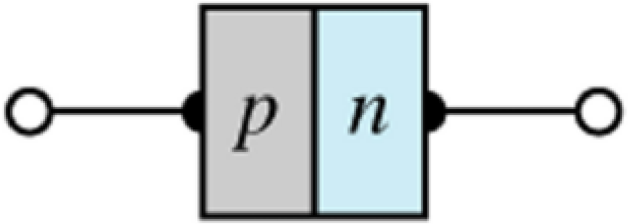
- n-type materials contain an excess of conduction band electrons.

p-type

- p-type materials contain an excess of valence band holes.

P-N Junction

- One end of a silicon or germanium crystal can be doped as a p-type material and the other end as an n-type material.



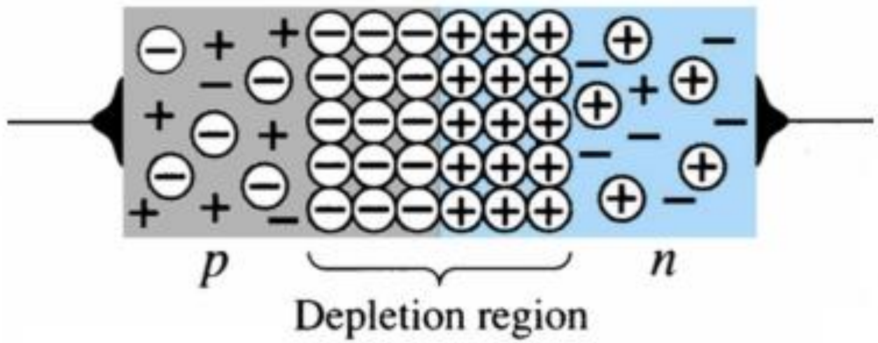
- At the p-n junction, the excess conduction-band electrons on the n-type side are attracted to the valence-band holes on the p-type side.

- The electrons in the n-type material migrate across the junction to the p-type material (electron flow).

P-N Junction

- The electron migration results in a negative charge on the p-type side of the junction and a positive charge on the n-type side of the junction.

- The electron migration results in a negative charge on the p-type side of the junction and a positive charge on the n-type side of the junction.



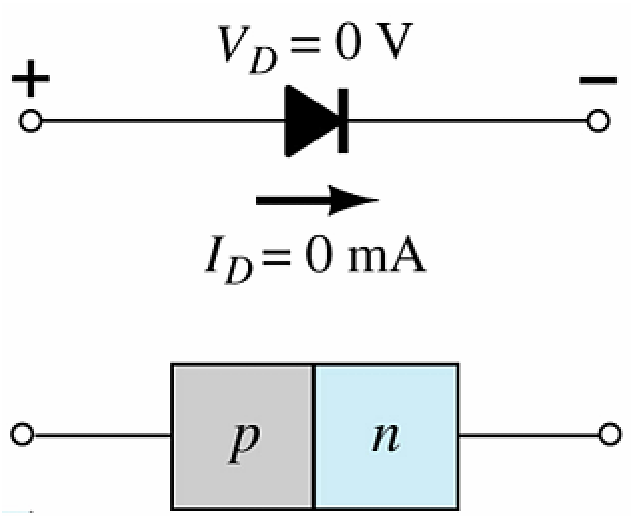
- The result is the formation of a depletion region around the junction.

Diode Operating Conditions

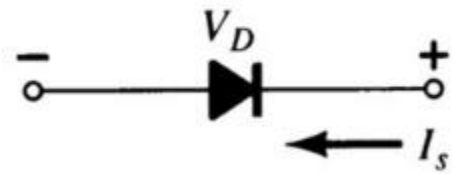
- A diode has three operating conditions:
  - No bias
  - Forward bias
  - Reverse bias

No Bias

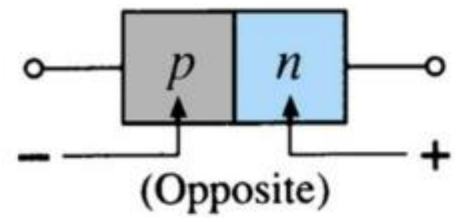
- No external voltage is applied: $V_D = 0$ V
- No current is flowing: $I_D = 0$ A
- Only a modest depletion region exists

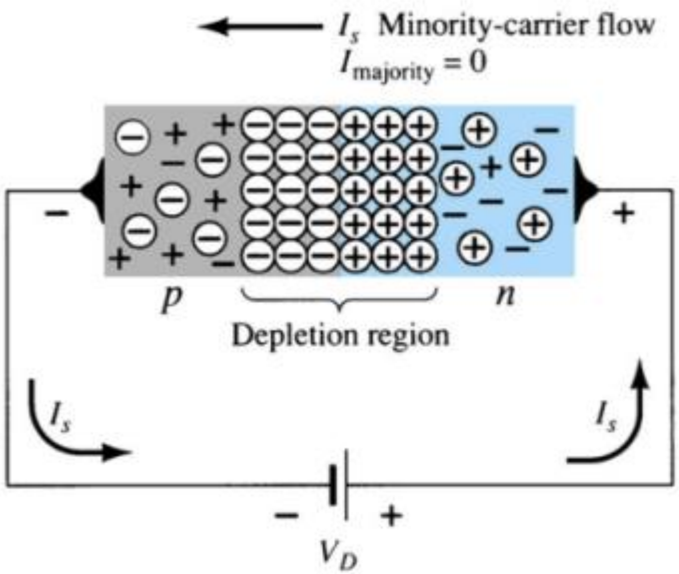


Reverse Bias



- External voltage is applied across the p-n junction in the opposite polarity of the p- and n-type materials.





- The reverse voltage causes the depletion region to widen.
- The electrons in the n-type material are attracted toward the positive terminal of the voltage source.
- The holes in the p-type material are attracted toward the negative terminal of the voltage source.

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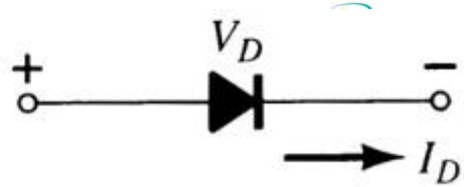
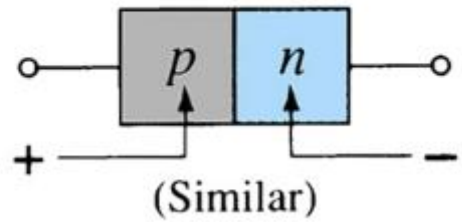
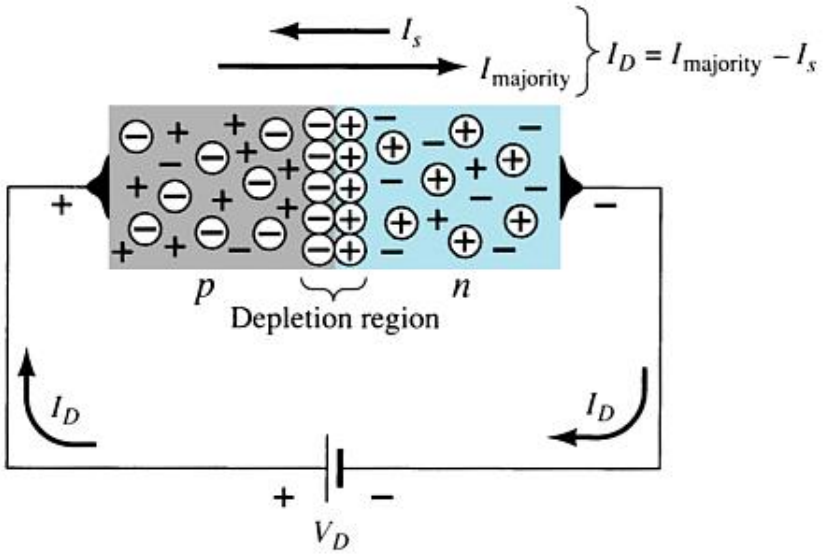
Forward Bias





- External voltage is applied across the p-n junction in the same polarity as the p- and n-type materials.



- The forward voltage causes the depletion region to narrow.
- The electrons and holes are pushed toward the p-n junction.
- The electrons and holes have sufficient energy to cross the p-n junction.

Majority Carriers

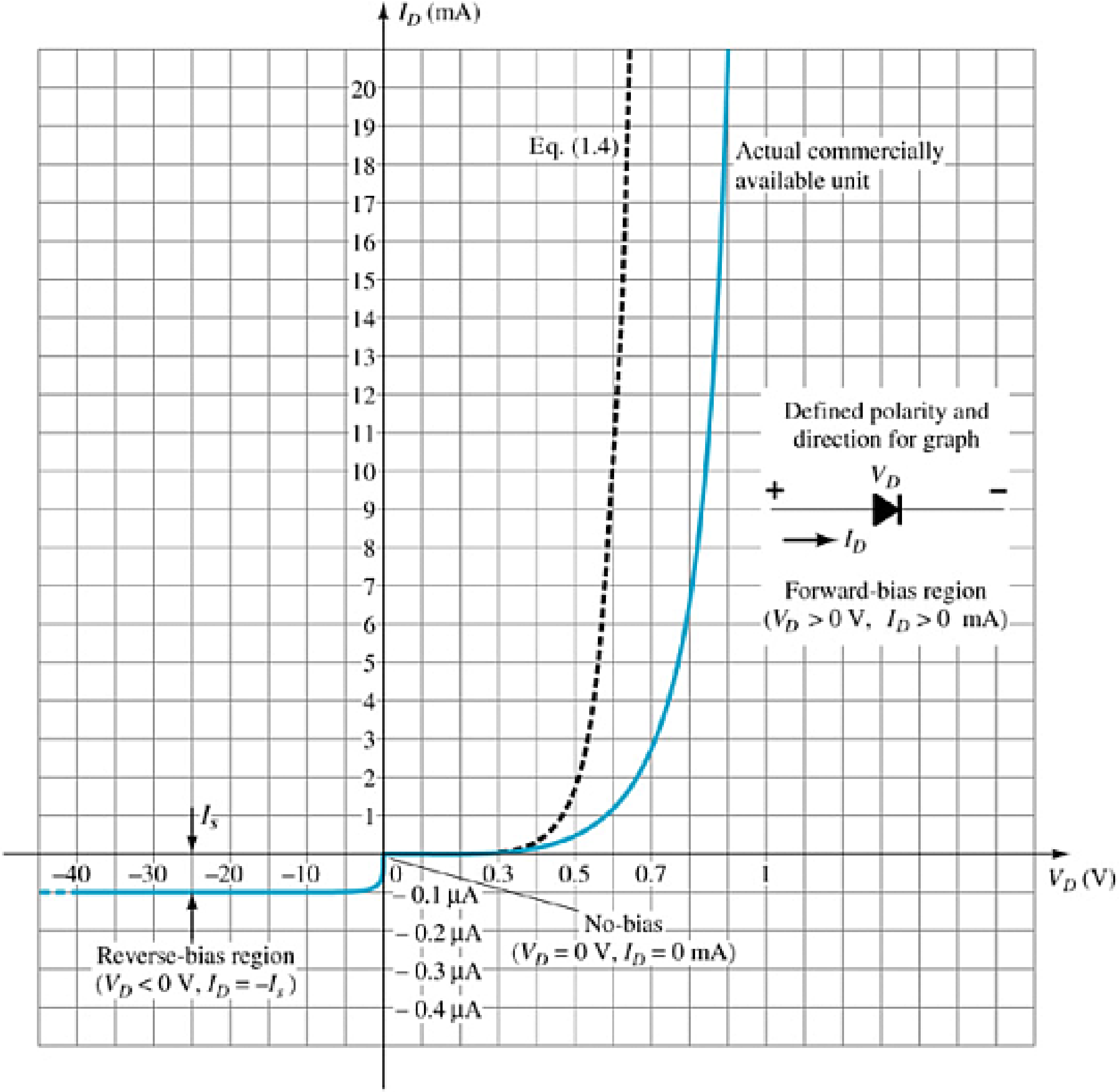
- The majority carriers in n-type materials are electrons.
- The majority carriers in p-type materials are holes.

Minority Carriers

- The minority carriers in n-type materials are holes.
- The minority carriers in p-type materials are electrons.

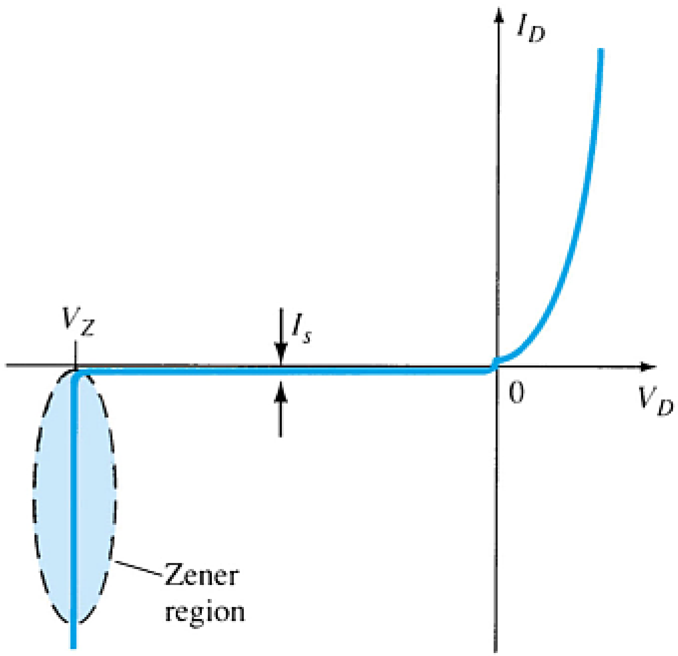
Actual Diode Characteristics

- Note the regions for no bias, reverse bias, and forward bias conditions.
- Carefully note the scale for each of these conditions.



Zener Region

- The Zener region is in the diode's reverse-bias region.
- At some point the reverse bias voltage is so large the diode breaks down and the reverse current increases dramatically.
  - The maximum reverse voltage that won't take a diode into the zener region is called the peak inverse voltage or peak reverse voltage.
  - The voltage that causes a diode to enter the zener region of operation is called the zener voltage (V_Z).



Forward Bias Region

- The point at which the diode changes from no-bias condition to forward-bias condition occurs when the electrons and holes are given sufficient energy to cross the *p-n* junction. This energy comes from the external voltage applied across the diode.

- The forward bias voltage required for a:

  - gallium arsenide diode ≅ 1.2 V
  - silicon diode ≅ 0.7 V
  - germanium diode ≅ 0.3 V

Temperature Effects

- As temperature increases it adds energy to the diode.
  - It reduces the required forward bias voltage for forward-bias conduction.
  - It increases the amount of reverse current in the reverse-bias condition.
  - It increases maximum reverse bias avalanche voltage.
- Germanium diodes are more sensitive to temperature variations than silicon or gallium arsenide diodes.

Resistance Levels

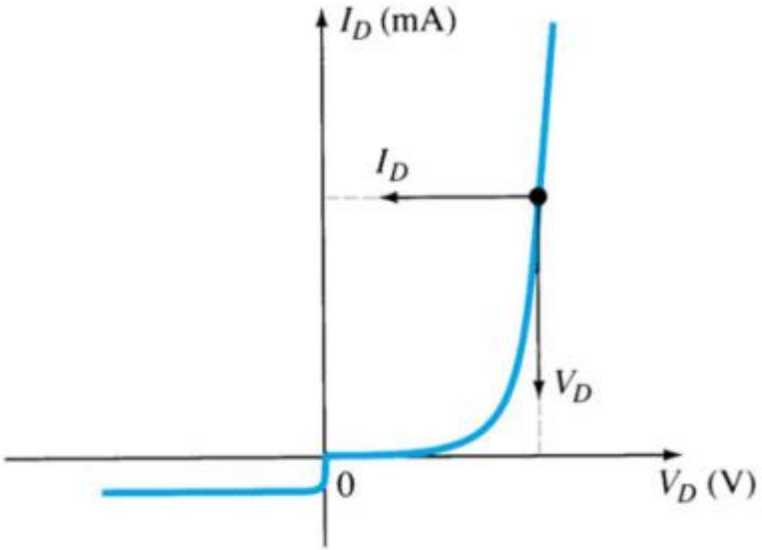
- Semiconductors react differently to DC and AC currents.

- There are three types of resistance:
  - DC (static) resistance.
  - AC (dynamic) resistance.
  - Average AC resistance.

DC (static) resistance

For a specific applied DC voltage V_D, the diode has a specific current I_D, and a specific resistance R_D.

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



AC (Dynamic) resistance

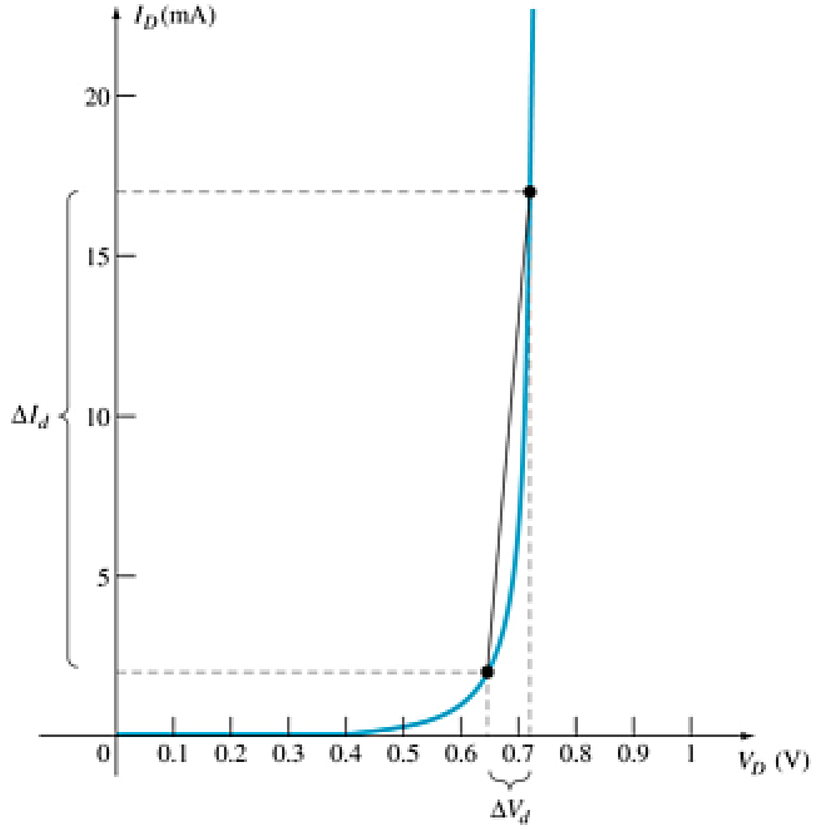
- In the forward bias region: $r'_d = \frac{26\text{ mV}}{I_D} + r_B$
  - The resistance depends on the amount of current (I_D) in the diode.
  - The voltage across the diode is fairly constant (26 mV for 25°C).
  - r_B ranges from a typical 0.1 Ω for high power devices to 2 Ω for low power, general purpose diodes. In some cases r_B can be ignored.
- In the reverse bias region: $r'_d = \infty$
- The resistance is effectively infinite. The diode acts like an open.

Resistance Levels

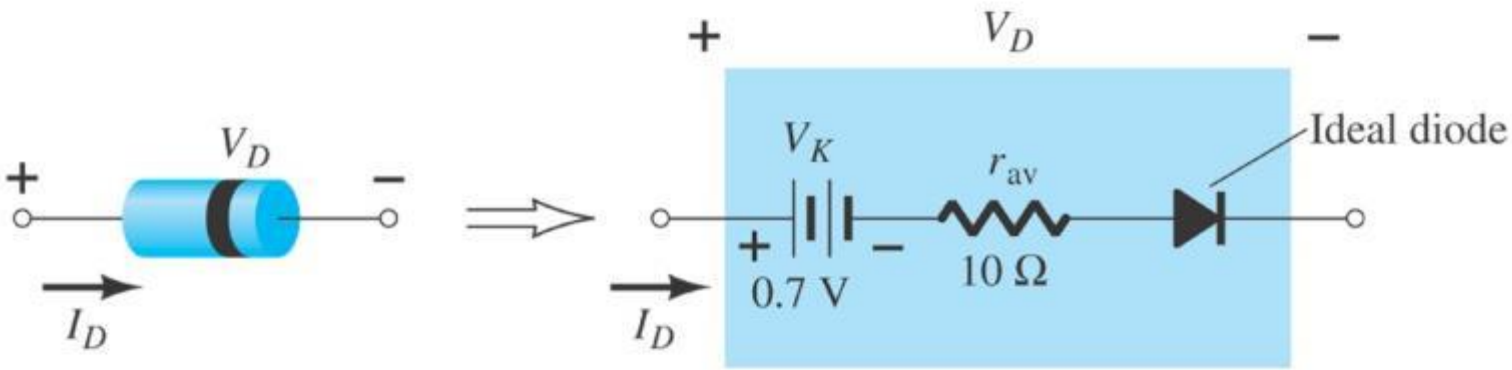
Average AC resistance

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

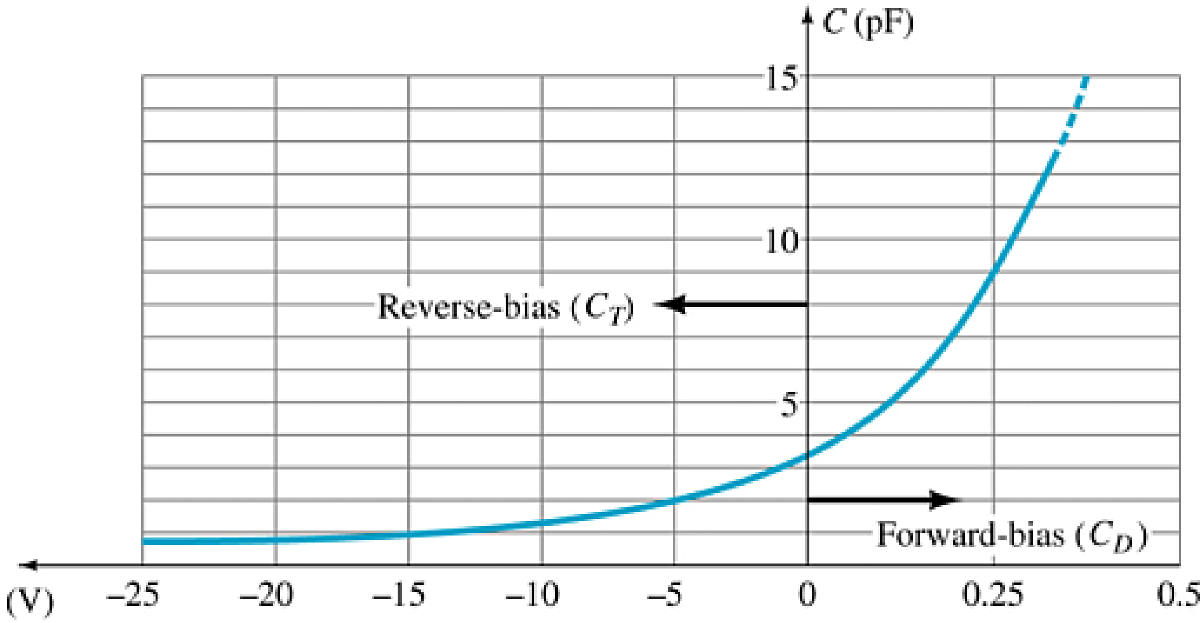
AC resistance can be calculated using the current and voltage values for two points on the diode characteristic curve.



Diode Equivalent Circuit



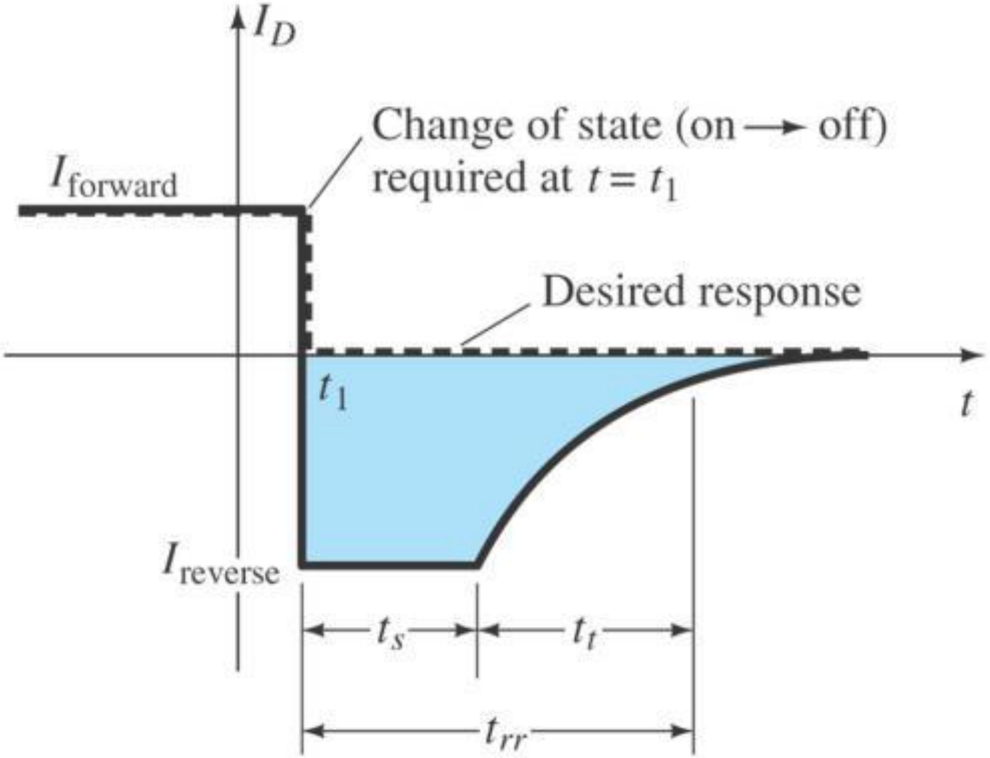
Diode Capacitance



- In reverse bias, the depletion layer is very large. The diode's strong positive and negative polarities create capacitance, C_T. The amount of capacitance depends on the reverse voltage applied.
- In forward bias storage capacitance or diffusion capacitance (C_D) exists as the diode voltage increases.

Reverse Recovery Time (t_{rr})

- Reverse recovery time is the time required for a diode to stop conducting once it is switched from forward bias to reverse bias.

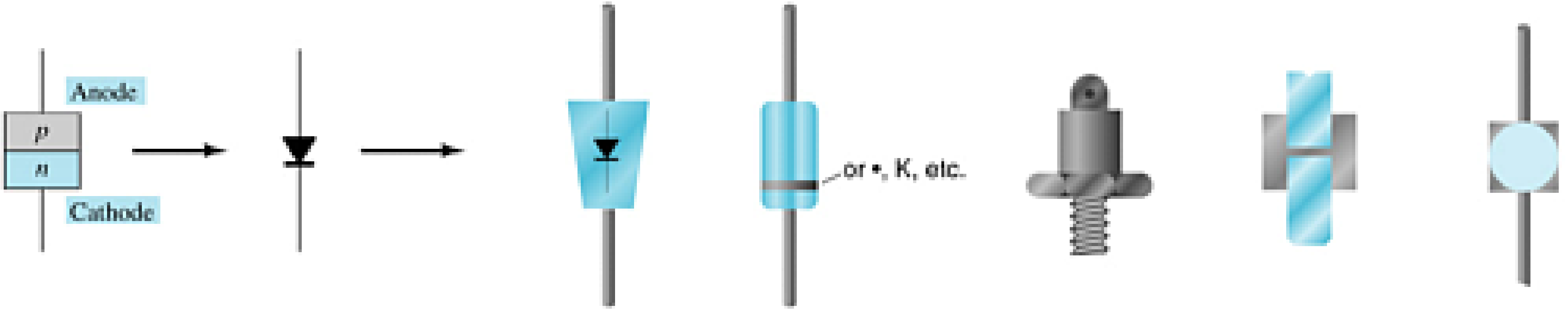


Diode Specification Sheet

- Data about a diode is presented uniformly for many different diodes. This makes cross-matching of diodes for replacement or design easier.

1. Forward Voltage (V_F) at a specified current and temperature
2. Maximum forward current (I_F) at a specified temperature
3. Reverse saturation current (I_R) at a specified voltage and temperature
4. Reverse voltage rating, PIV or PRV or V(BR), at a specified temperature
5. Maximum power dissipation at a specified temperature
6. Capacitance levels
7. Reverse recovery time, t_{rr}
8. Operating temperature range

Diode Symbol & Packaging

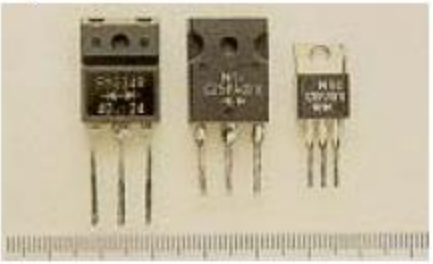


The anode is abbreviated A
The cathode is abbreviated K

Various Diode

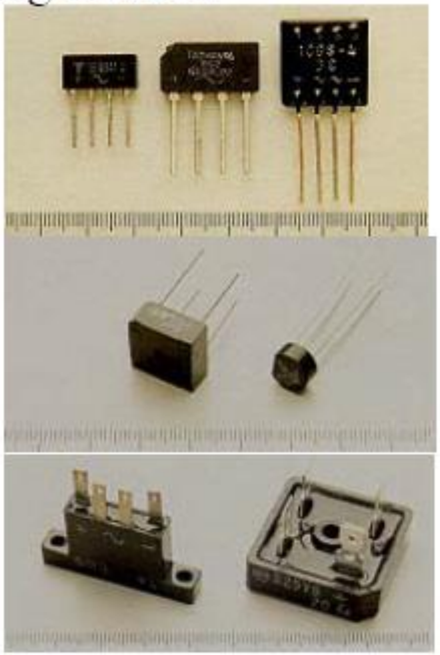
Normal Diode (Small Signal)

Array Diode

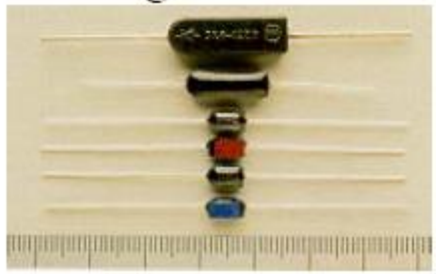


High Current Diode

Bridge Diode



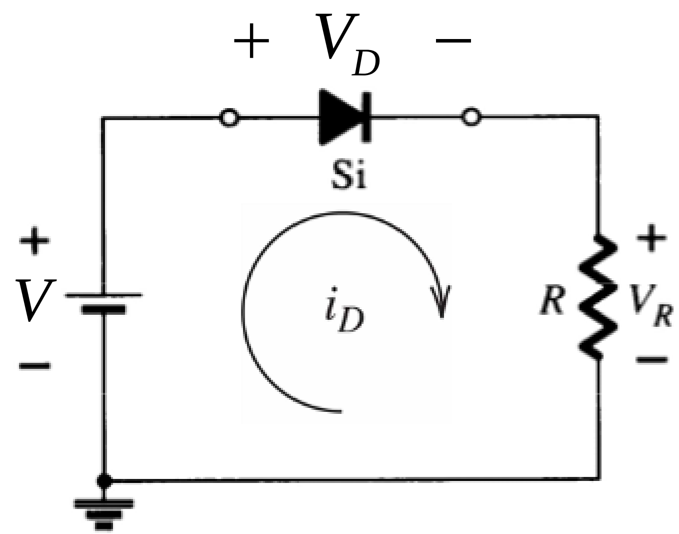
High Voltage Diode



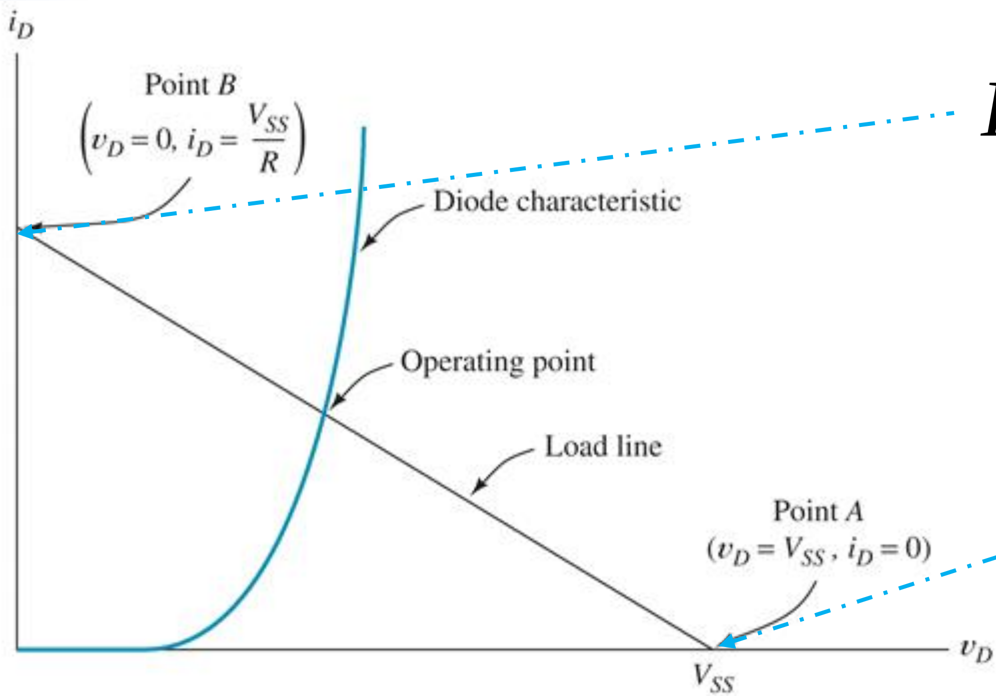
Load-Line Analysis

- The load line plots all possible combinations of diode current (I_D) and voltage (V_D) for a given circuit. The maximum I_D equals V/R, and the maximum V_D equals V.
- The point where the load line and the characteristic curve intersect is the Q-point, which identifies I_D and V_D for a particular diode in a given circuit.

Load-Line Analysis



$$-V + V_D + I_D R$$



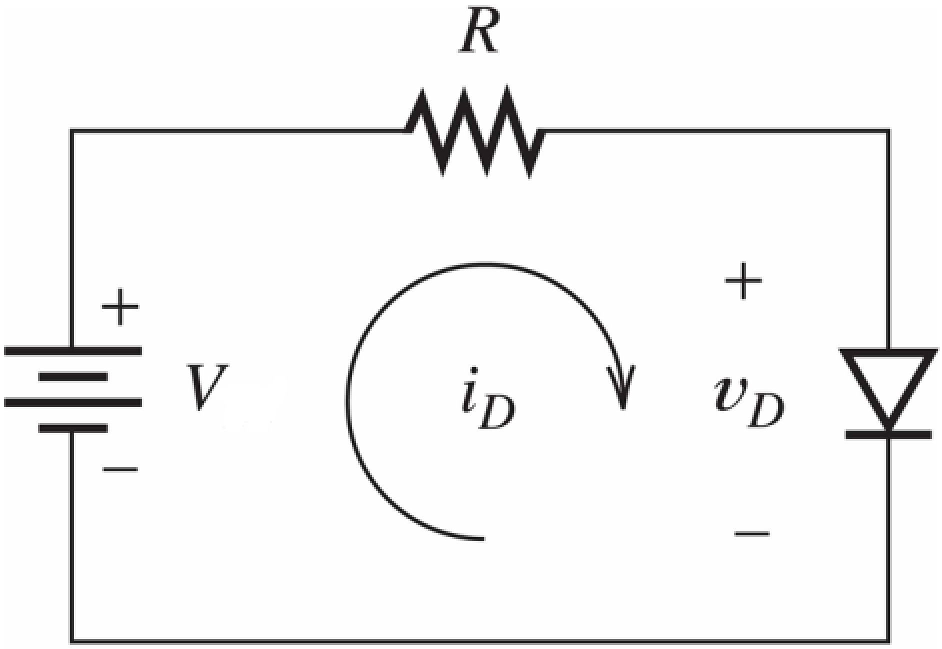
$$I_D = \frac{V}{R}\bigg|_{V_D=0}$$

$$V_D = V\big|_{I_D=0}$$

Example #1

Find the diode voltage and current operating point when

$$V = 2\,\text{V}, R = 1\,\text{k}\Omega$$



Example #1

Solution

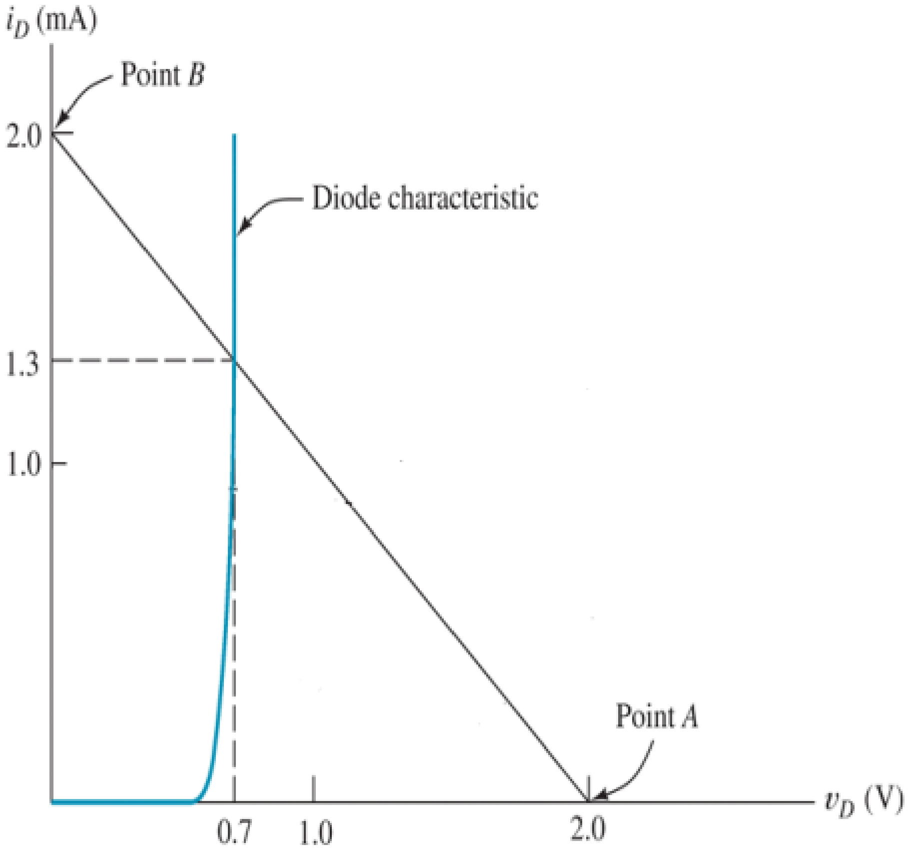
Substituting $V_D = 0$ and the value of V, R into $V = Ri_D + V_D$

then $i_D = 2\ \text{mA}$

Substituting $i_D = 0 \quad V_D = 2\,\text{V}$

$$I_{DQ} \cong 1.3\,\text{mA}$$

$$V_{DQ} \cong 0.7\,\text{V}$$



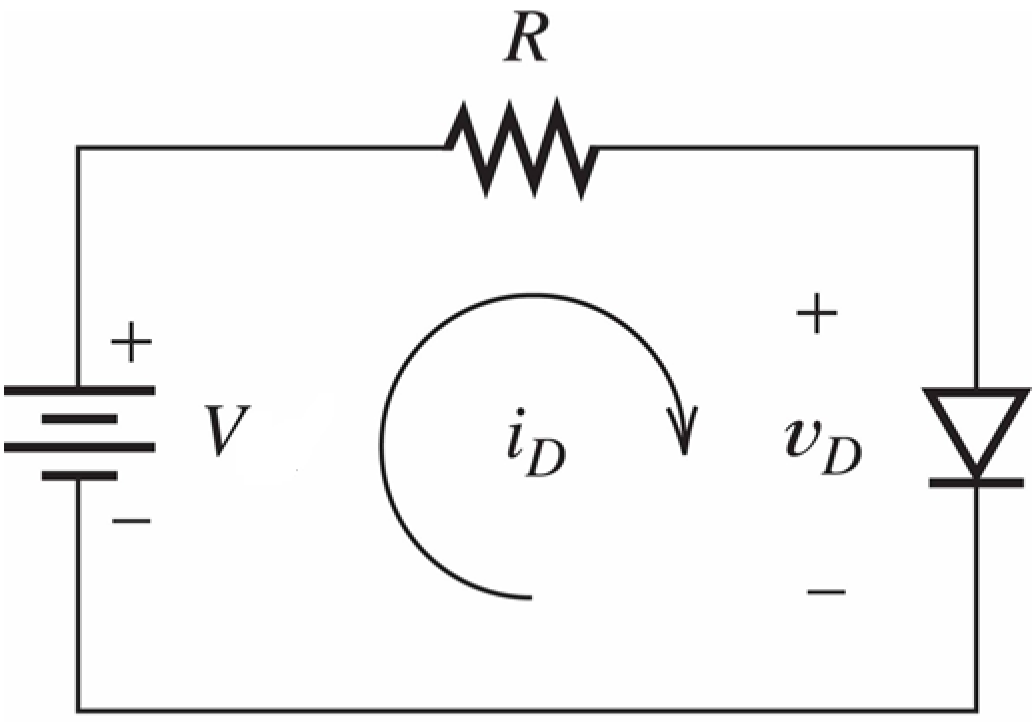
Example #2

Find the diode voltage and current operating point when

$$V = 2\,\text{V}, R = 100\,\Omega$$

$$V = 15\,\text{V}, R = 1\,\text{k}\Omega$$

$$V = 1\,\text{V}, R = 20\,\Omega$$

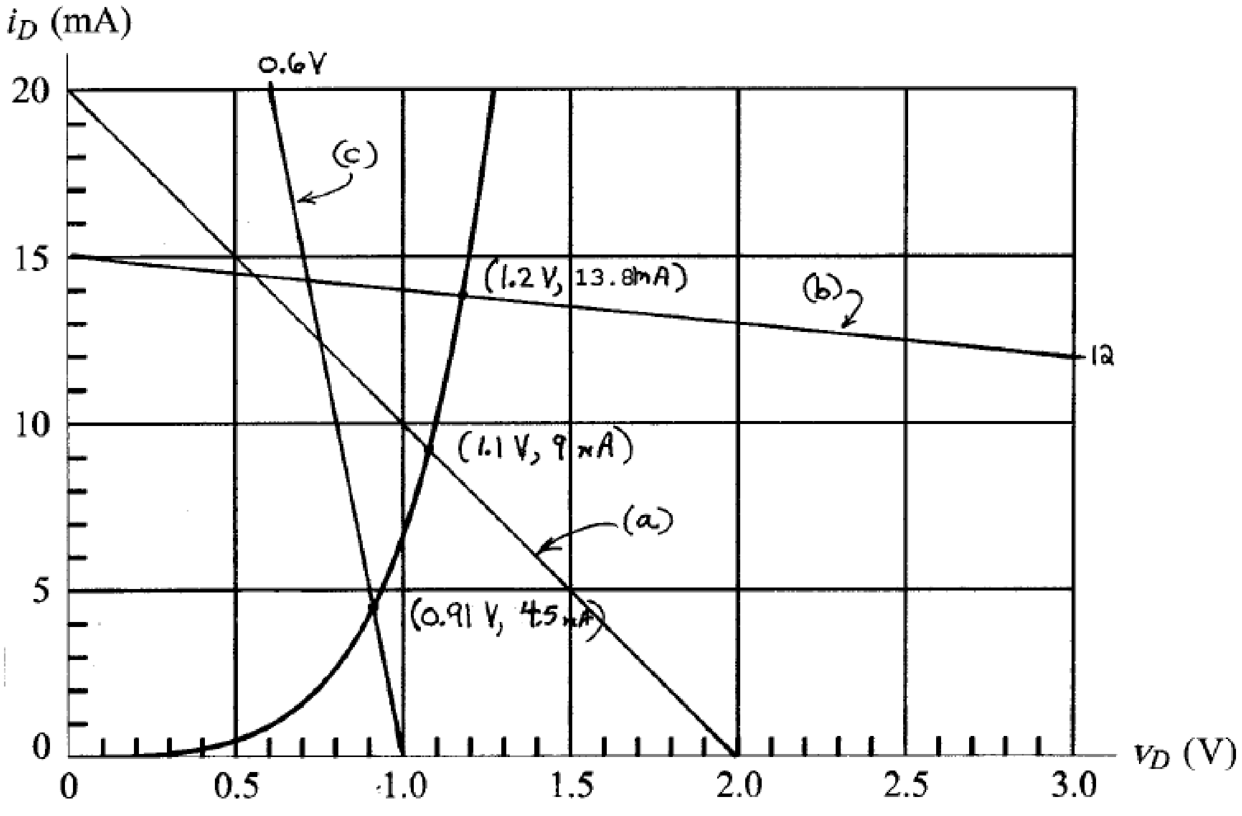


Example #2

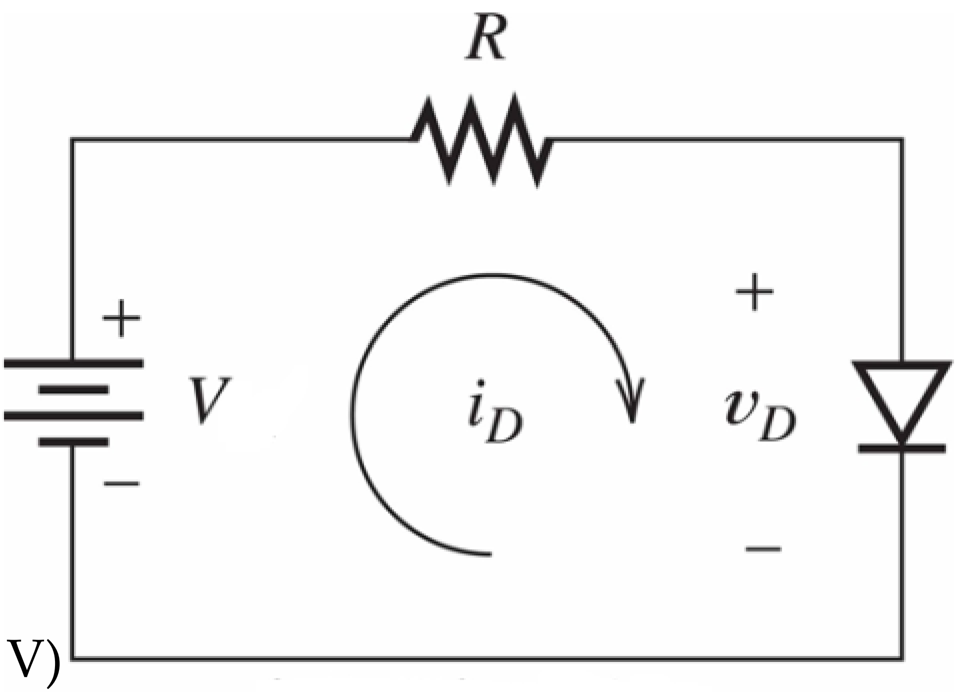
$$V_{DQ} \cong 1.1\,\text{V};\, I_{DQ} \cong 9\,\text{mA}$$

$$V_{DQ} \cong 1.2\,\text{V};\, I_{DQ} \cong 13.8\,\text{mA}$$

$$V_{DQ} \cong 0.91\,\text{V};\, I_{DQ} \cong 4.5\,\text{mA}$$



Forward Bias



Constants

- Silicon Diode: $V_D = 0.7$ V
- Germanium Diode: $V_D = 0.3$ V

Analysis (for silicon)

- $V_D = 0.7$ V (or $V_D = V$ if $V < 0.7$ V)
- $V_R = V - V_D$
- $I_D = I_R = I_T = V_R / R$

Reverse Bias

Diodes ideally behave as open circuits

Analysis (for silicon)

- $V_D = V$
- $V_R = 0$ V
- $I_D = 0$ A

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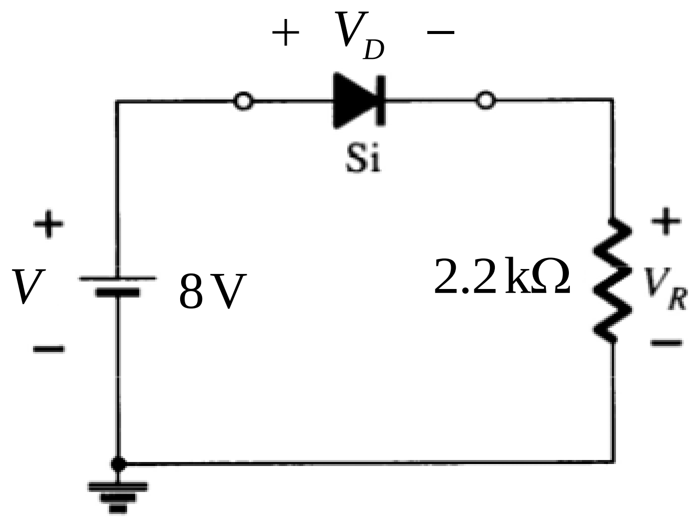
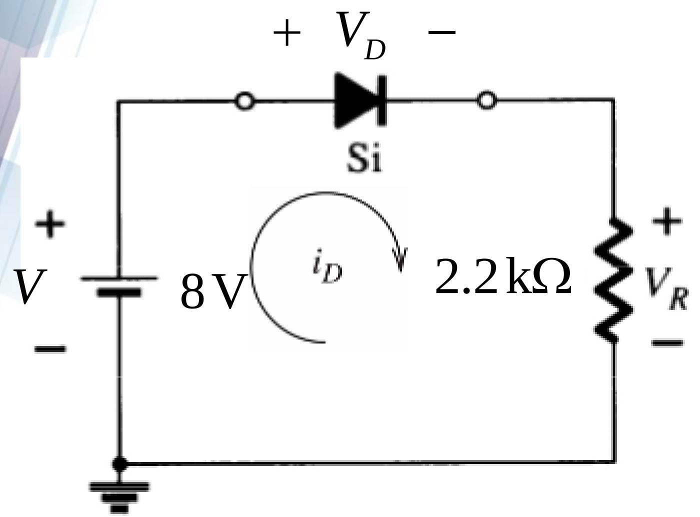
Example #2

For the series diode configuration, determine V_D, V_R, and I_D



Example #2

Solution



Since the input voltage *V* establish a current in the clockwise direction to match the arrow of the symbol, so the diode is operating in forward bias and is in the on state

Then $V_D = 0.7\,\text{V}$

$$V_R = V - V_D$$

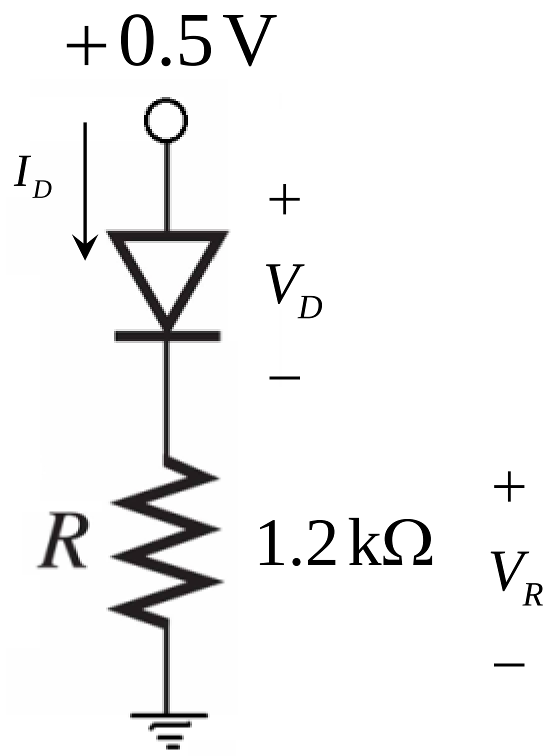
$$V_R = 8 - 0.7 = 7.3\,\text{V}$$

$$I_D = I_R = \frac{V_R}{R}$$

$$I_D = \frac{7.3}{2.2\text{k}} = 3.32\,\text{mA}$$

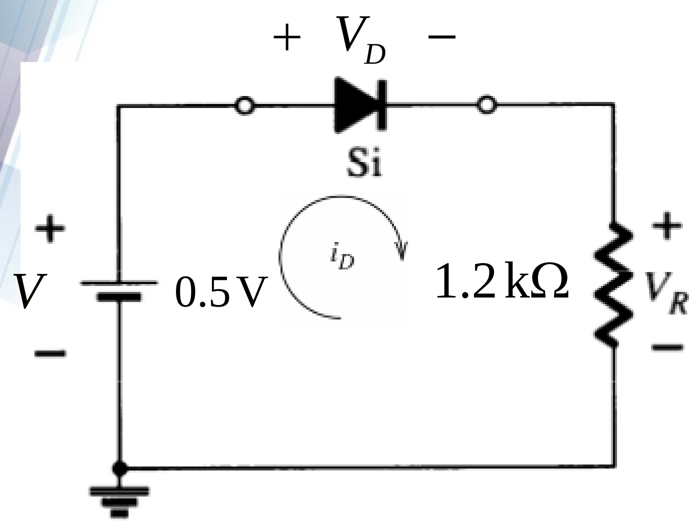
Example #3

For the series diode configuration, determine V_D, V_R, and I_D



Example #3

Solution



Since the input voltage V establish a current in the clockwise direction to match the arrow of the symbol, but the value of applied voltage is insufficient to turn the diode on.

Then $V_D = V = 0.5\,\text{V}$

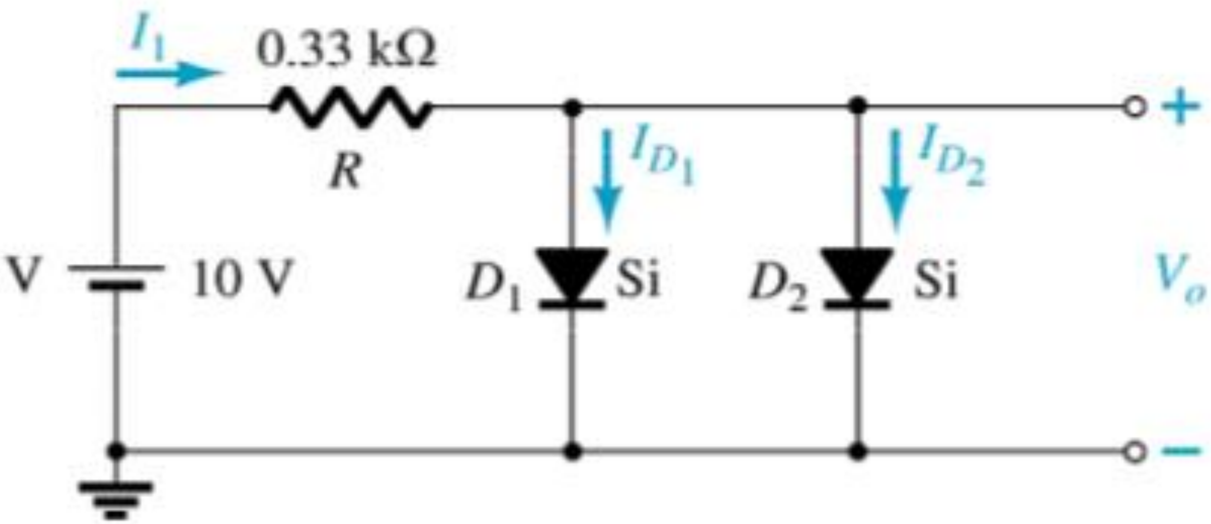
$$I_D = 0\text{A}$$

$$V_R = I_D R$$

$$V_R = 0\,\text{V}$$

Example #4

Determine V_D, I_1, I_{D_1}, and I_{D_2} for the parallel diode configuration



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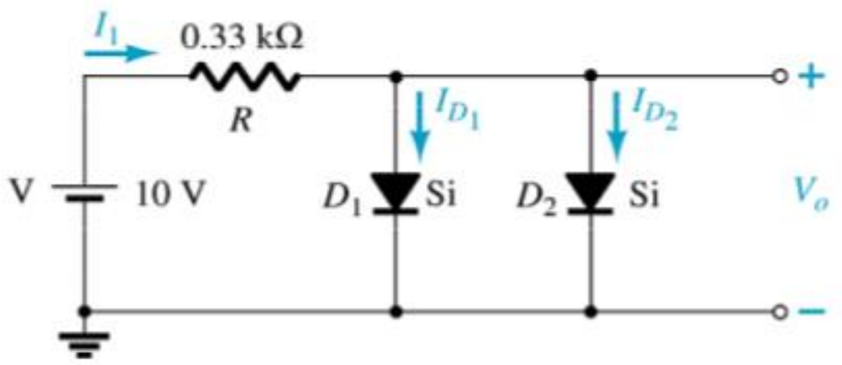
Parallel Diode Configuration

Solution



$$V_D = 0.7\text{ V}$$

$$V_{D_1} = V_{D_2} = V_o = 0.7\text{ V}$$

$$V_R = 9.3\text{ V}$$

$$I_R = \frac{V - V_D}{R} = \frac{10\text{ V} - 0.7\text{ V}}{0.33\text{k}\Omega} = 28\text{ mA}$$

$$I_{D_1} = I_{D_2} = \frac{28\text{ mA}}{2} = 14\text{ mA}$$