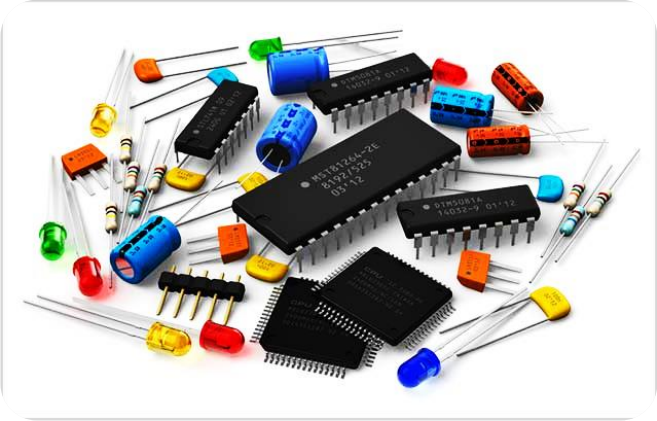
New Mansoura Univeristy

Electronic Circuits

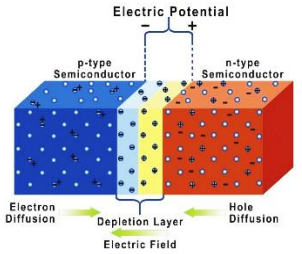
Basic Diode Behavior

CSE 113



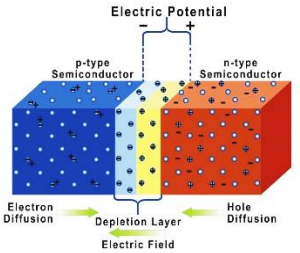
22/04/2024

OUTLINES



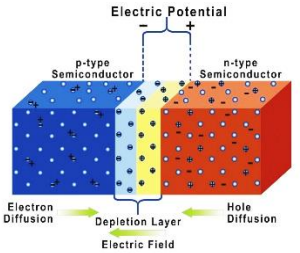
- Electronics Circuits
- Semiconductor Material
- Diode
  - P-N Junction
  - Forward/Reverse Bias
- Diode Applications
  - Rectifiers,
  - Ripple,
  - Clipping,
  - clamping,
  - voltage multipliers,
  - voltage doublers,
  - Simple smoothing,
  - regulators,
  - zener diode.

Electronics Circuits

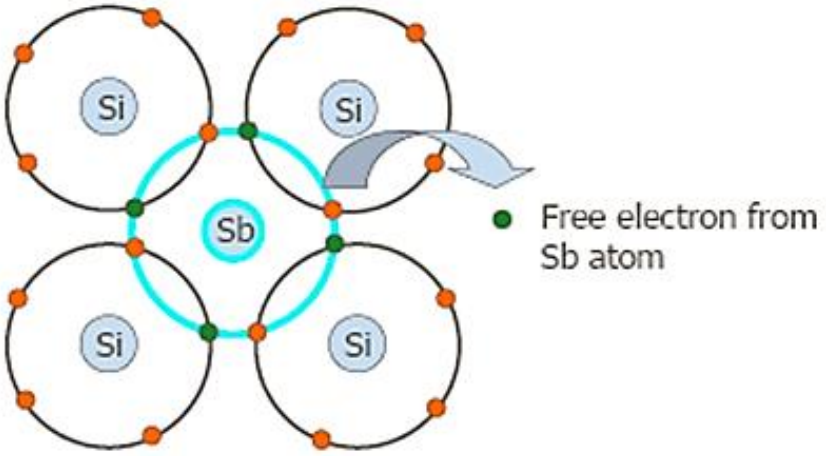


- The branch of physics that deals with the emission and effects of electrons ; and the use of electronic devices.
- Science of the motion of charges in a gas, vacuum or semiconductor.
- An electronic building block packaged in a discrete form with two or more connecting leads or metallic pads.
- Components are connected together to create an electronic circuit with a particular function.
  - E.g.: an amplifier, radio receiver, or oscillator.

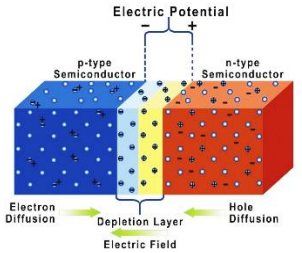
N-type Semiconductor



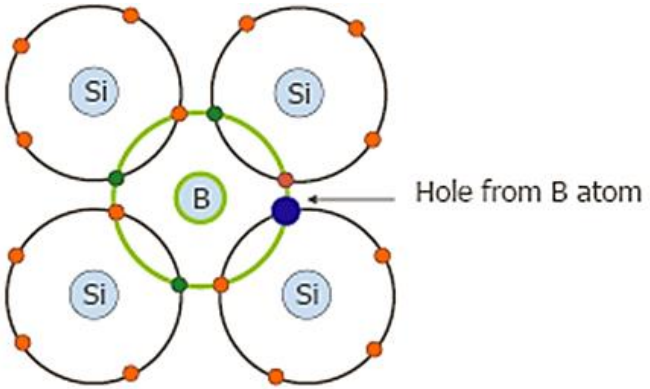
- Pentavalent impurity atoms are added – Arsenic (As), phosphorus (P),bismuth (Bi),
- Pentavalent also known as a donor atoms since they donate electrons. When a pentavalent atom is added to an intrinsic semiconductor, it'll readily donate it's 5^{th} electron, as a result – becomes n-type extrinsic semiconductor.
- In n-type material electrons are majority carrier, and holes the minority carrier



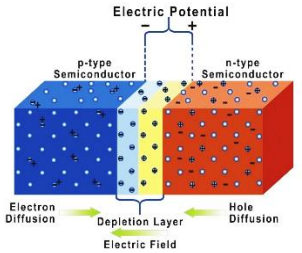
P-type Semiconductor

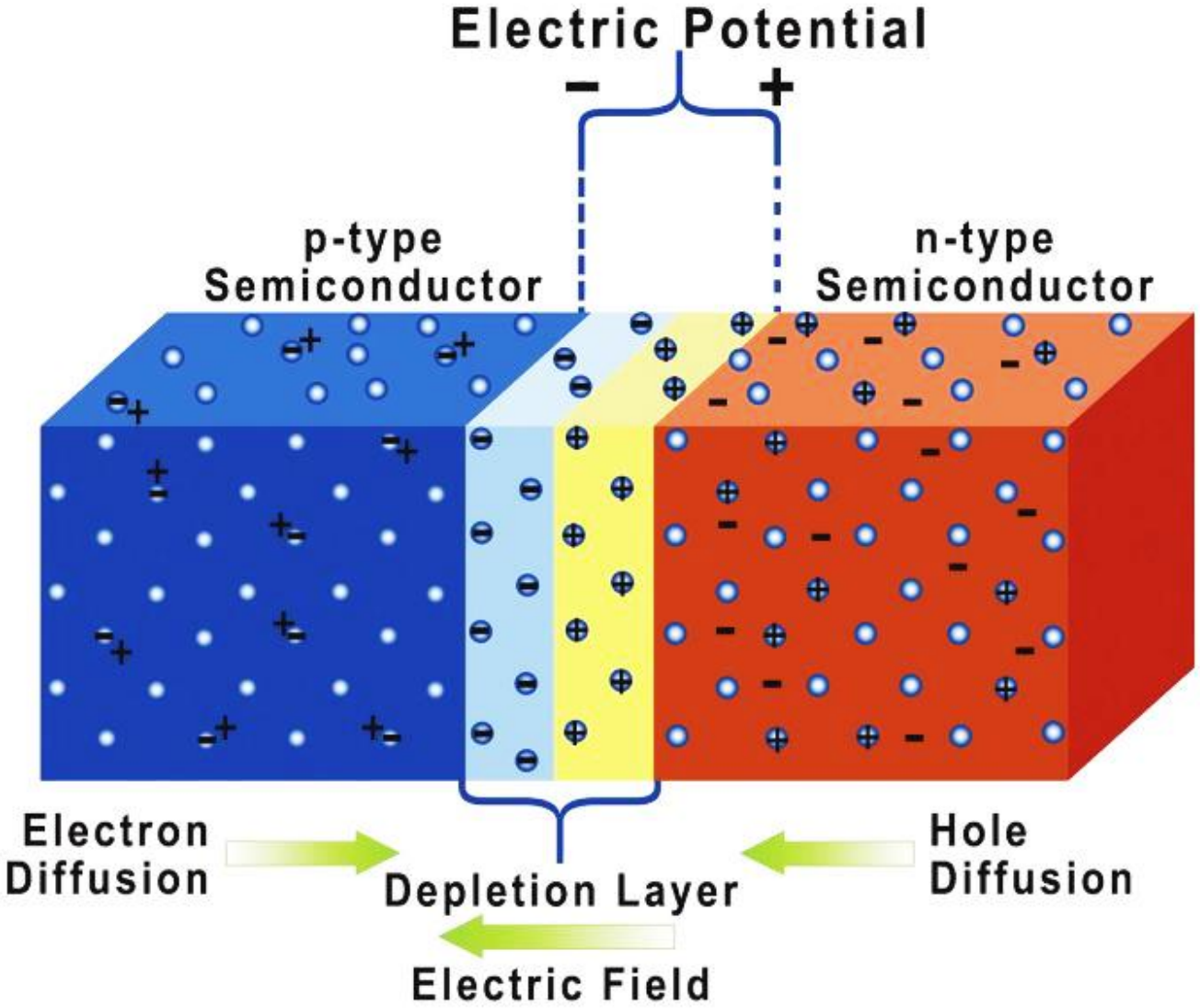


- Trivalent (with 3 valence electrons) impurity atoms are added – Aluminum (Al), boron (B), indium (In), gallium (Ga)
- Trivalent also known as a acceptor atom since they accept electrons. When a trivalent atom is added to an intrinsic semiconductor, it'll readily accept free electron, as a result – becomes p-type extrinsic semiconductor.
- In p-type material holes are majority carrier, and electron the minority carrier

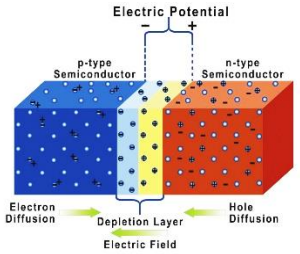


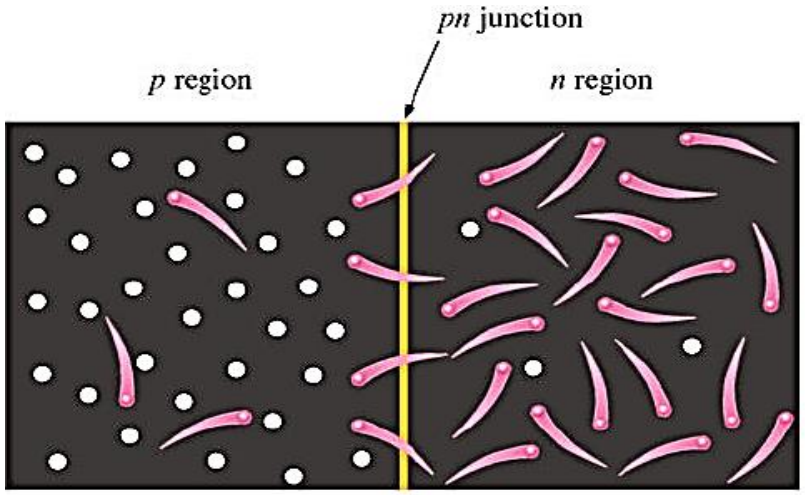
Semiconductor Diode

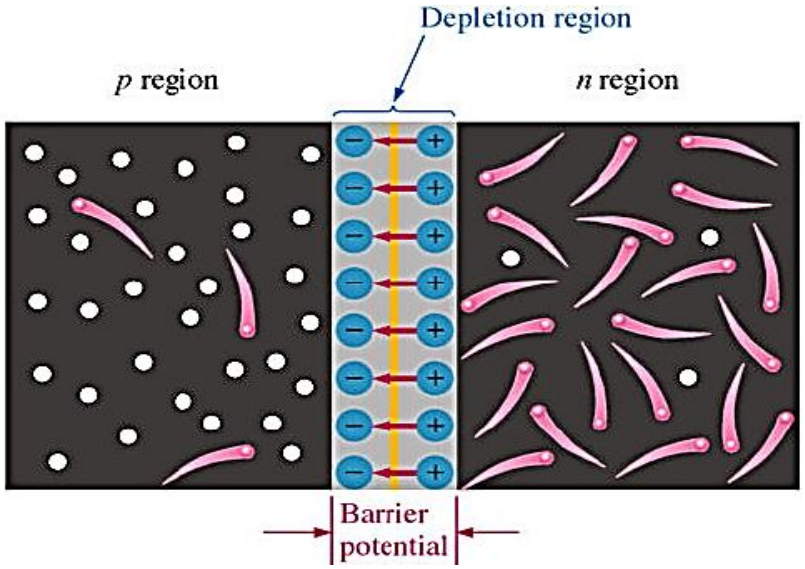




P-N Junction

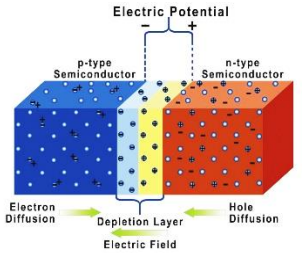




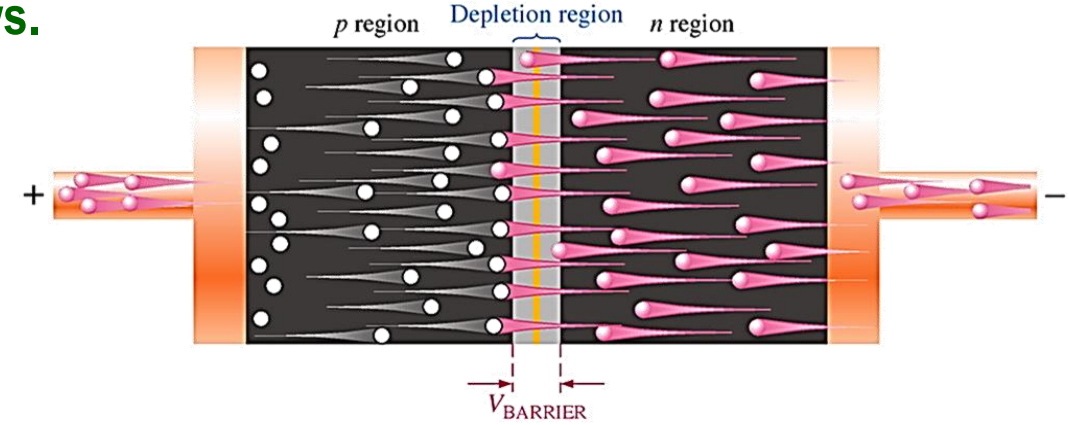


- With the formation of the p and n materials combination of electrons and holes at the junction takes place.
- This creates the depletion region and has a barrier potential. This potential cannot be measured with a voltmeter, but it will cause a small voltage drop.

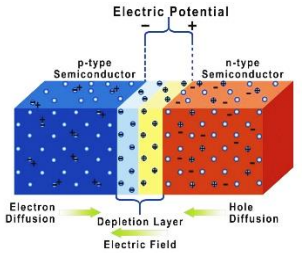
Forward Bias



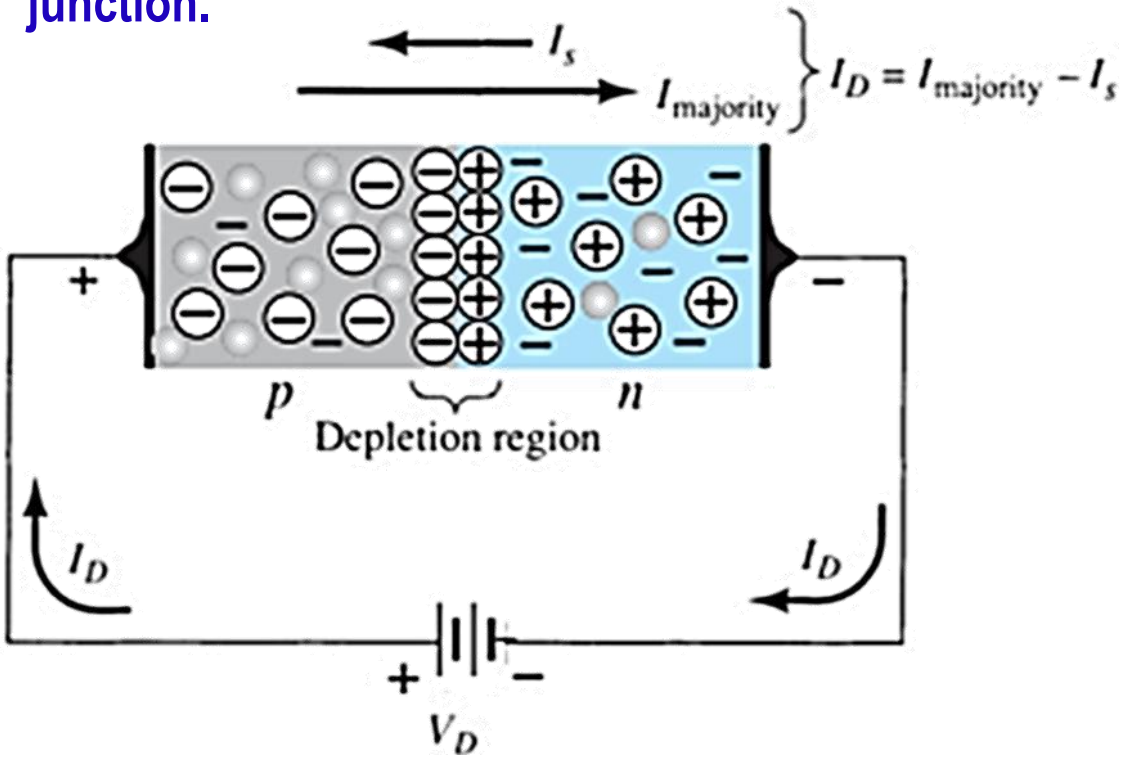
- A forward-bias or "on" condition is established by applying the positive potential to the p-type material and the negative potential to the n-type material
- Bias must be greater than 0.3 V for Germanium or 0.7 V for Silicon diodes.
- The electrons moves to the external circuit becoming conducting electrons in metal.
- As more electrons move into the depletion region, the number of + ions is reduced.
- As more holes move into the depletion region on the other side, the number of - ions is also reduced. The depletion region narrows.

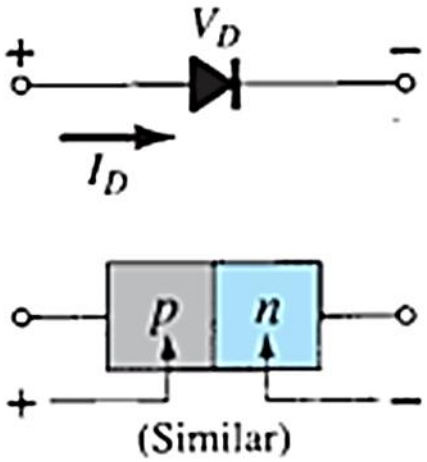


Forward-Bias Condition (VD > 0 V)

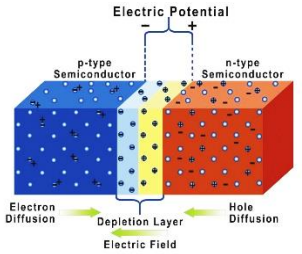


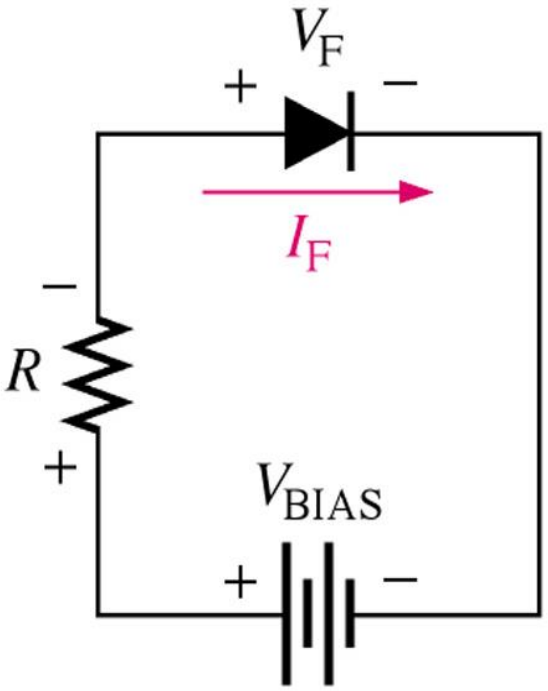
- External voltage is applied across the p-n junction in the same polarity as the p-type and n-type materials.
- The forward voltage causes the depletion layer to narrow.
- The electrons and holes are pushed toward the p-n junction.
- The electrons and holes have sufficient energy to cross the p-n junction.



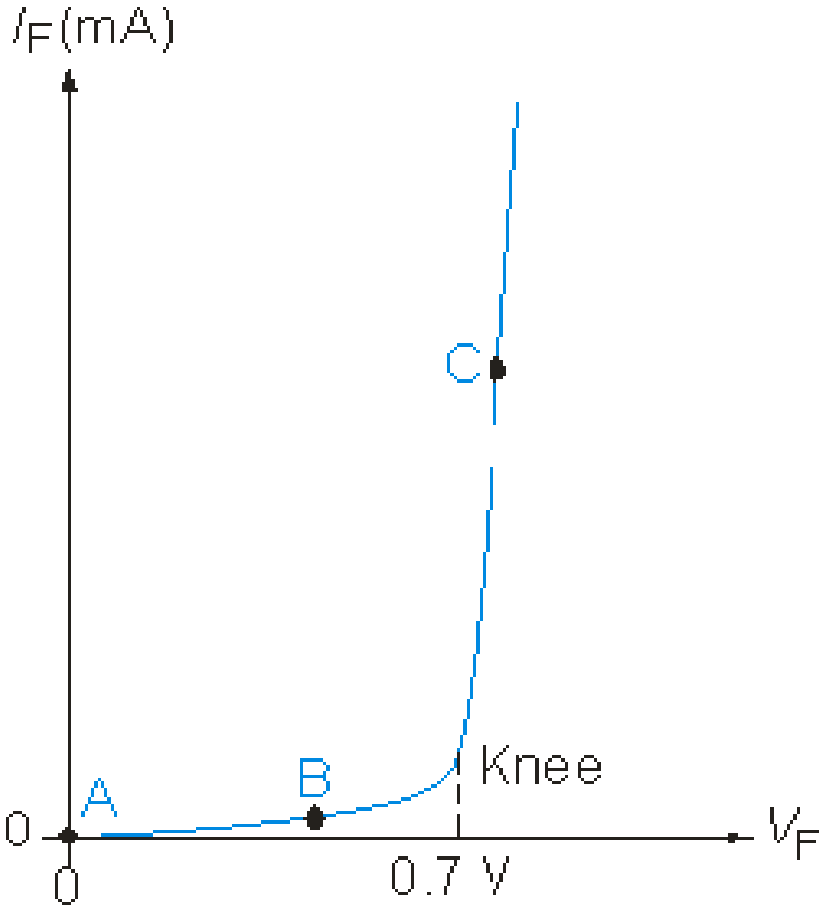


Forward Bias Characteristic Curve



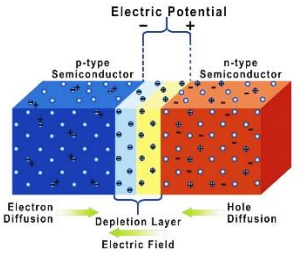


a) Circuit connections showing the diode symbol.

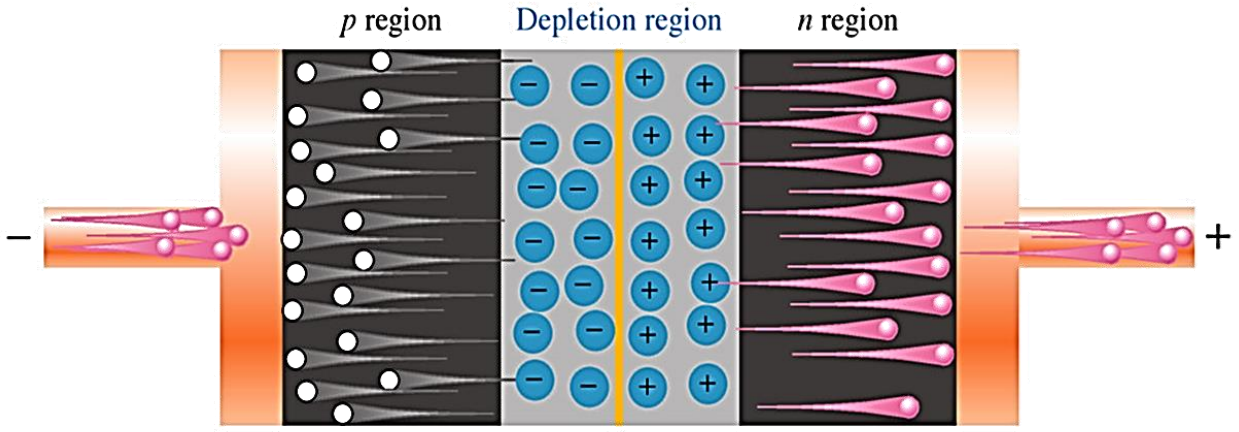


b) V-I characteristic

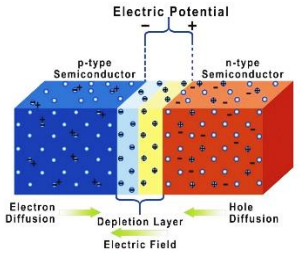
Reverse Bias



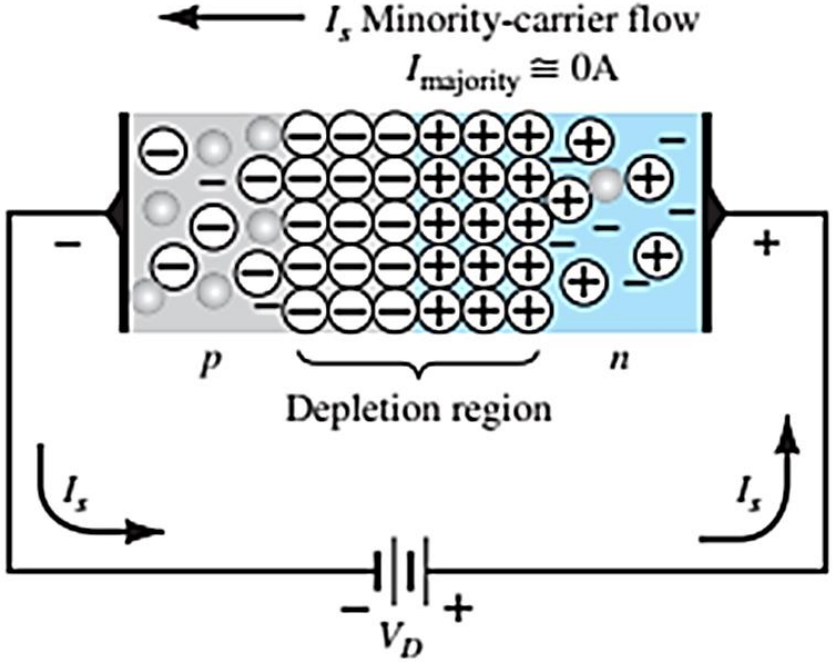
- Voltage source or bias connections are – to the p material and + to the n material.
- Bias must be less than the breakdown voltage.
- Positive side of battery pulls the free electrons, (majority in n) away from the junction. As electrons move away from junction, more positive are created.
- The depletion region widens.
- The electric field increases in strength until the potential across depletion region equals the bias voltage.
- Only a very small reverse current Exist.

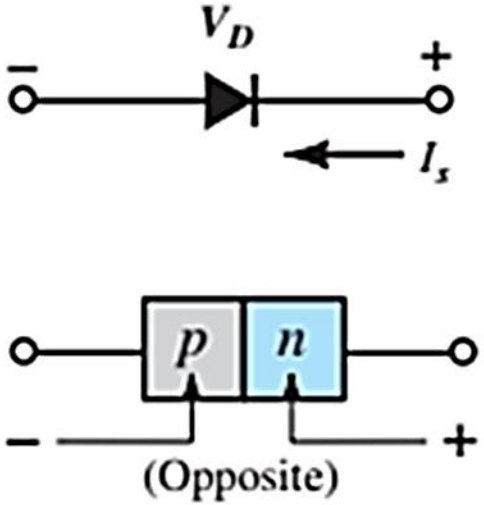


Reverse- Bias Condition (VD < 0 V)

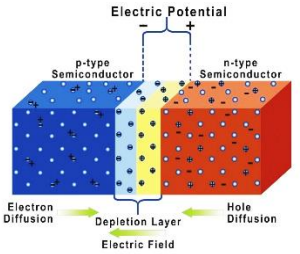


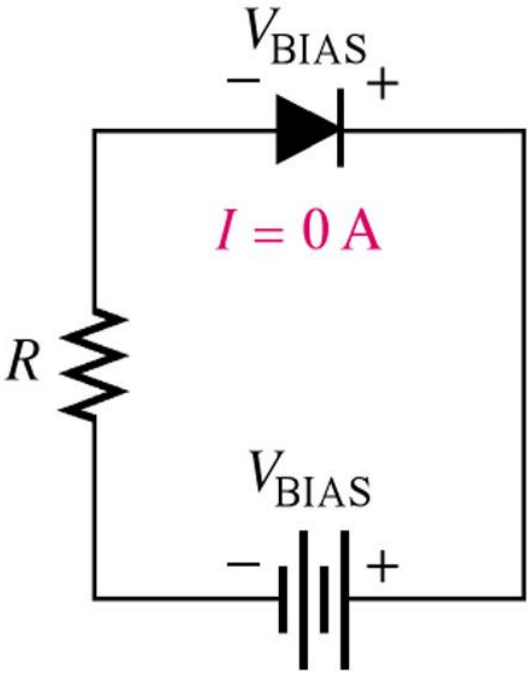
- External voltage is applied across the p-n junction in the opposite polarity of the p-type and n-type materials.
- The reverse voltage causes the depletion layer to widen.
- The electrons in the n-type material are attracted toward the positive terminal.
- The holes in the p-type material are attracted toward the negative terminal.



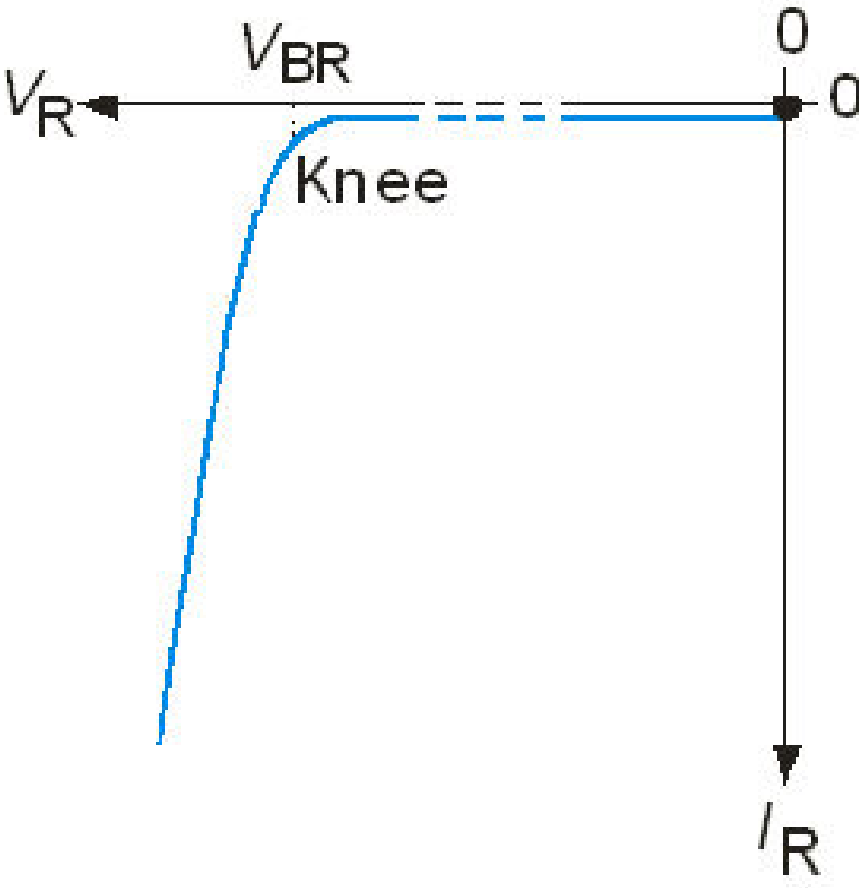


Revesre Bias Characteristic Curve



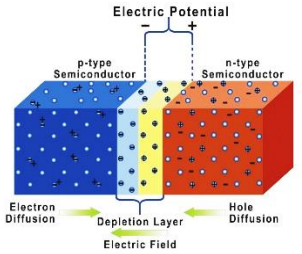


a) Circuit connections showing the diode symbol.

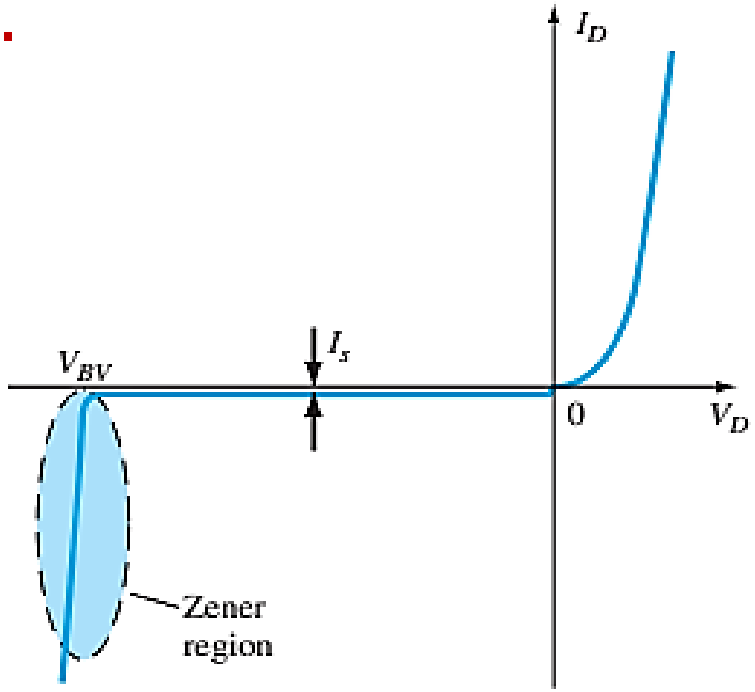


b) V-I characteristic

Breakdown Region

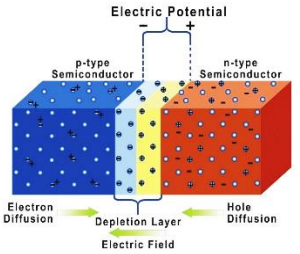


- The maximum reverse-bias potential that can be applied before entering the breakdown region is called the peak inverse voltage (referred to simply as the PIV rating) or the peak reverse voltage (denoted the PRV rating).

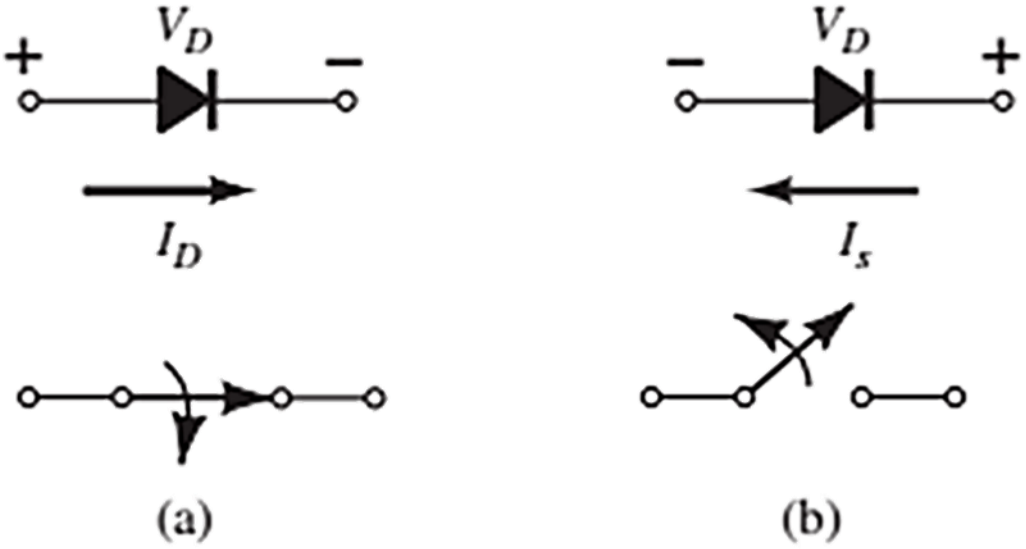


Breakdown region.

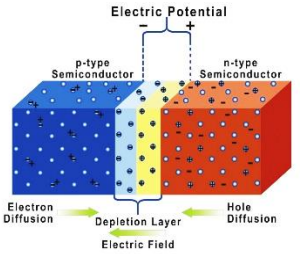
Summery



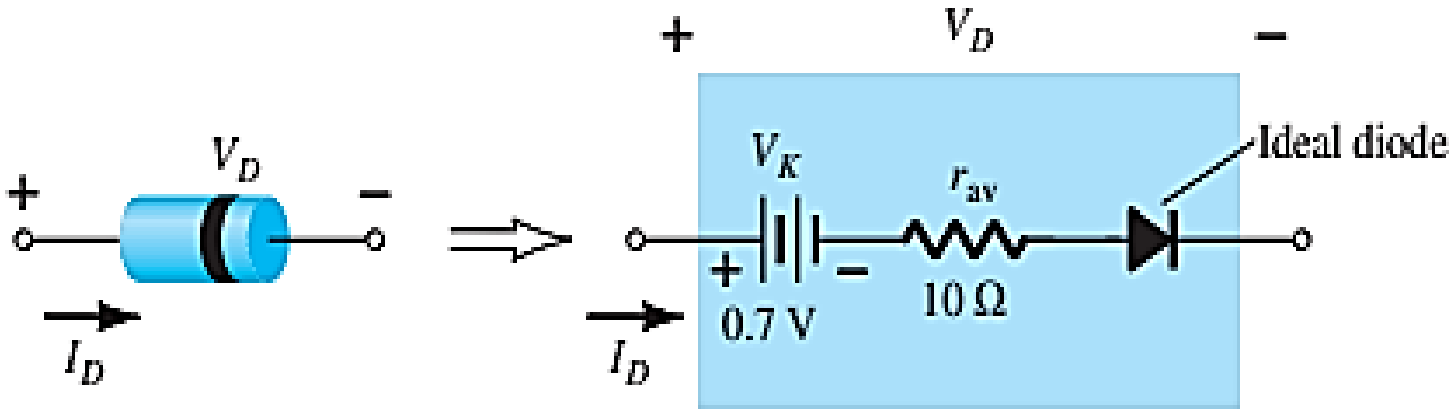
- The semiconductor diode behaves in a manner similar to a mechanical switch in that it can control whether current will flow between its two terminals.
- *The semiconductor diode is different from a mechanical switch in the sense that when the switch is closed it will only permit current to flow in one direction.*



Diode Equivalent Circuits

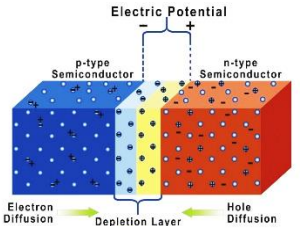


- An equivalent circuit is a combination of elements properly chosen to best represent the actual terminal characteristics of a device or system in a particular operating region.

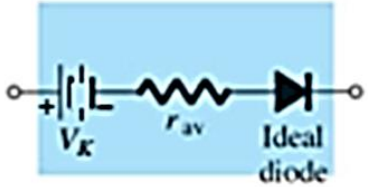
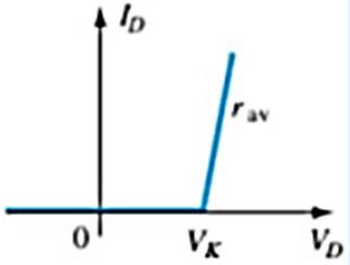
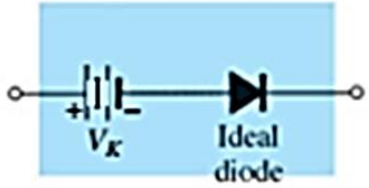
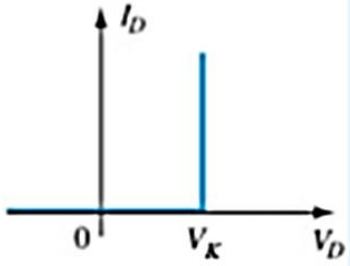
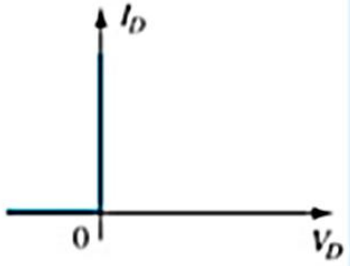


Components of the piecewise-linear equivalent circuit.

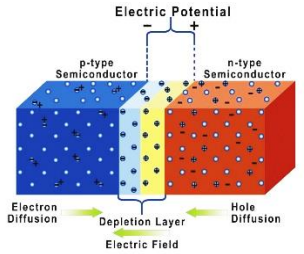
Diode Equivalent Circuits



Diode Equivalent Circuits (Models)

Type	Conditions	Model	Characteristics
Piecewise-linear model			
Simplified model	$R_{network} \gg r_{av}$		
Ideal device	$R_{network} \gg r_{av}$ $E_{network} \gg V_K$		

Diodes Applications



Rectifiers

HALF-WAVE RECTIFICATION

Full-WAVE RECTIFICATION

Clippers

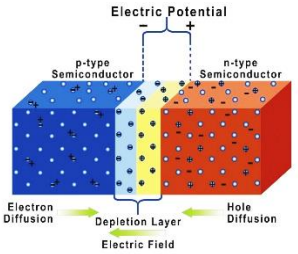
Clampers

Voltage multipliers

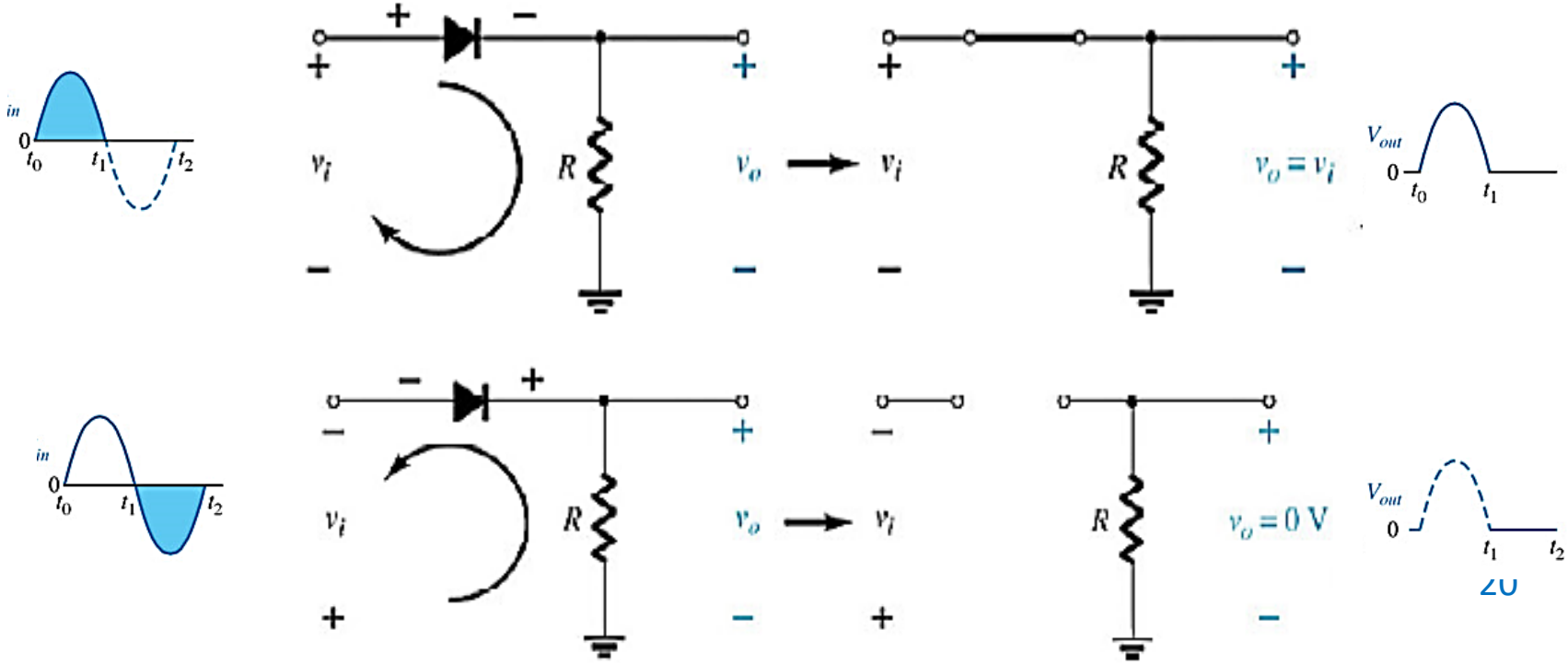
Zener diode

Essay assignment

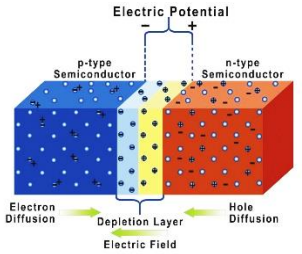
The AC Power Supply



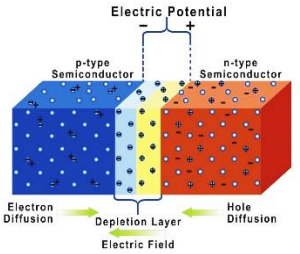
- The diode only conducts when it is in forward bias, hence only half of the AC cycle passes through the diode.
- The diode is OFF during the negative cycle.
- Diode is reverse biased and is therefore open circuit. No output during this cycle



The AC Power Supply



Half Wave Rectifier

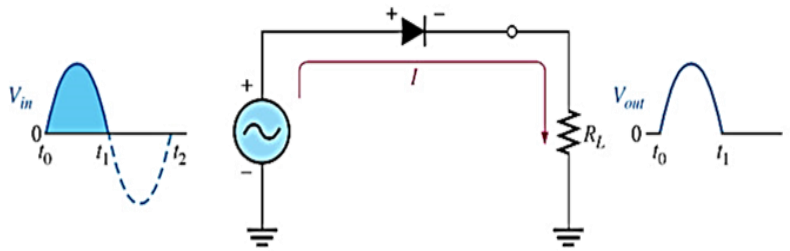


- A half wave rectifier(ideal) allows conduction for only 180° or half of a complete cycle.
- The output frequency is the same as the input.
- The average voltage V_{DC} or V_{AVG}

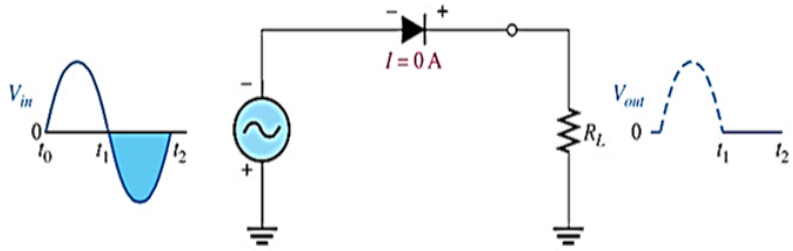
$$V_{AVG} = V_{d.c} = \frac{V_p}{\pi} = 31.8\% V_p$$

- The rms voltage

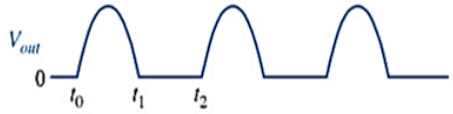
$$V_{rms} = \frac{V_p}{\sqrt{2}}$$



(a) During the positive alternation of the 60 Hz input voltage, the output voltage looks like the positive half of the input voltage. The current path is through ground back to the source.



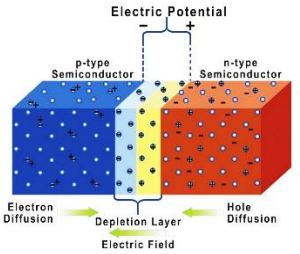
(b) During the negative alternation of the input voltage, the current is 0, so the output voltage is also 0.

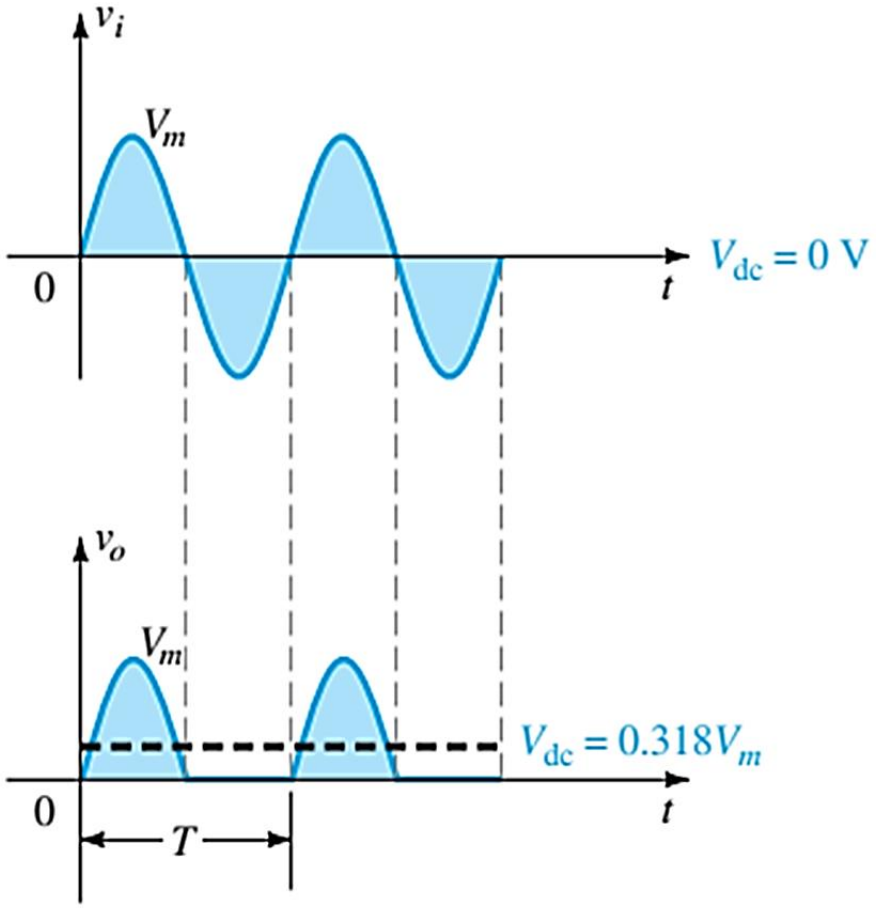


(c) 60 Hz half-wave output voltage for three input cycles

Half-wave rectifier operation. The diode is considered to be ideal.

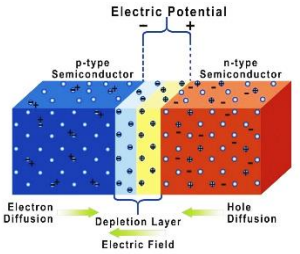
Half Wave Rectifier





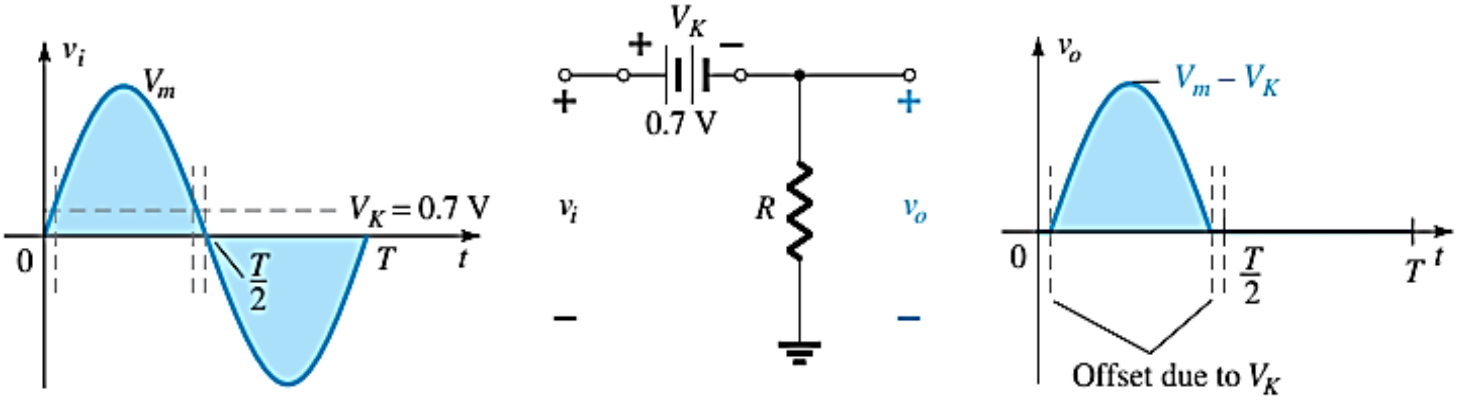
Half-wave rectified signal.

Potential Barrier V_K



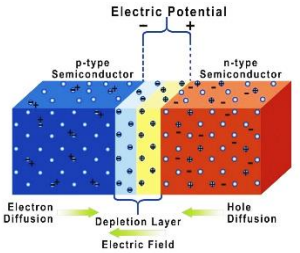
The effect of using a silicon diode with V_K 0.7 V for the forward-bias region.

- The applied signal must now be at least 0.7 V before the diode can turn "on."
- For levels of v_i less than 0.7 V, the diode is still in an open-circuit state and v_o = 0 V,
- When conducting, the difference between v_o and vi is a fixed



Effect of V_K on half-wave rectified signal.

Full Wave Rectifier



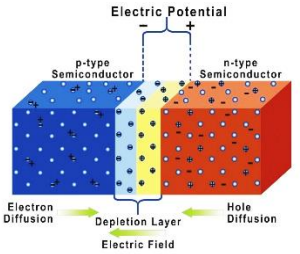
- A full-wave rectifier allows current to flow during both the positive and negative half cycles or the full 360º.
- Note that the output frequency is twice the input frequency
- The average voltage V_{DC} or V_{AVG}

$$V_{AVG} = V_{d.c} = \frac{2V_p}{\pi} = 63.7\%V_p$$

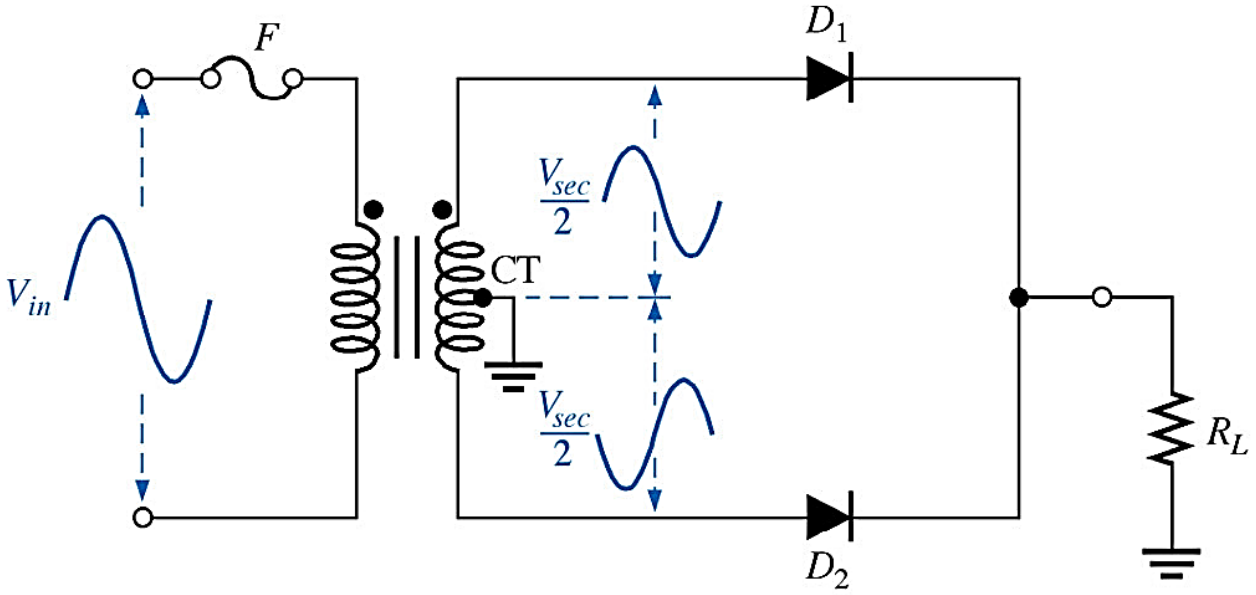
- The rms voltage

$$V_{rms} = \frac{V_p}{2\sqrt{2}}$$

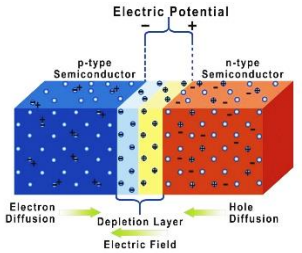
Full Wave Rectifier -Center Tap



- This method of rectification employs two diodes connected to a center-tapped transformer.
- The peak output is only half of the transformer's peak secondary voltage.



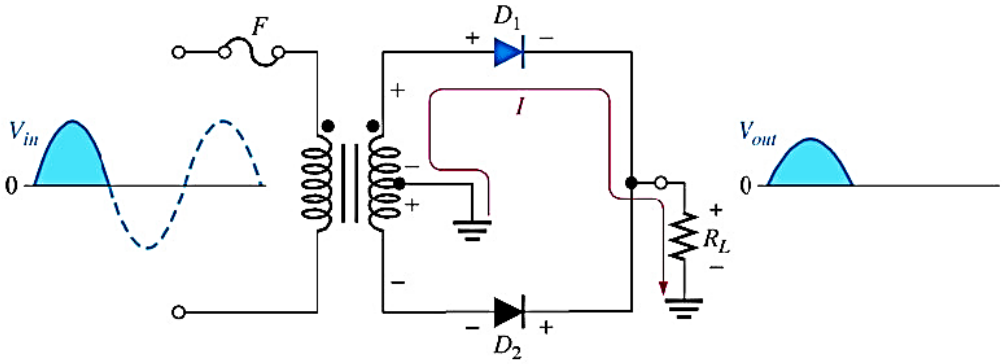
Full Wave Rectifier -Center Tap



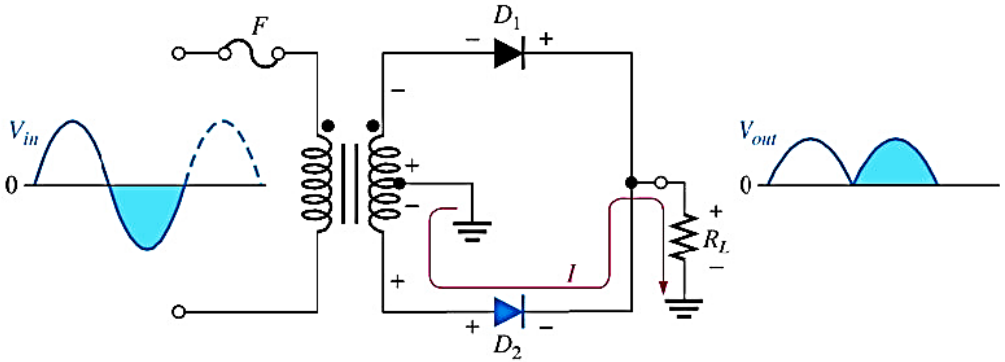
- Note the current flow direction during both alternations. Being that it is center tapped, the peak output is about half of the secondary winding's total voltage.
- Each diode is subjected to a PIV of the full secondary winding output minus one diode voltage drop.

$$PIV = V_{p(in)} - 0.7V$$

$$V_{p(out)} = \frac{V_{p(in)}}{2} - 0.7V$$

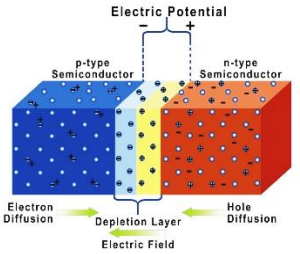


(a) During positive half-cycles, D_1 is forward-biased and D_2 is reverse-biased.



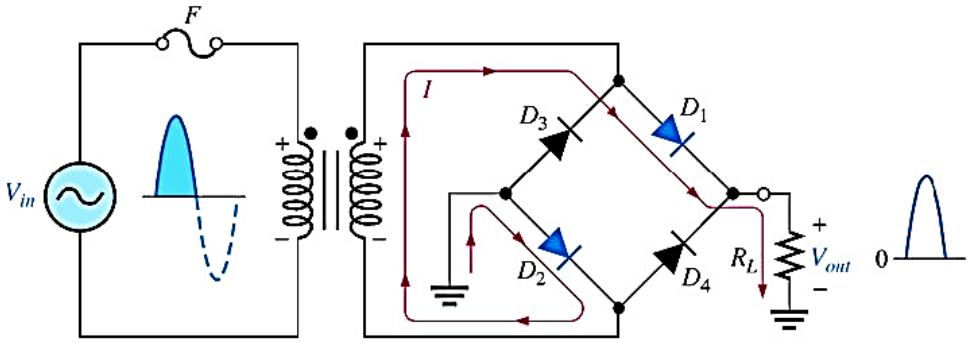
(b) During negative half-cycles, D_2 is forward-biased and D_1 is reverse-biased.

Full Wave Rectifier- Bridge

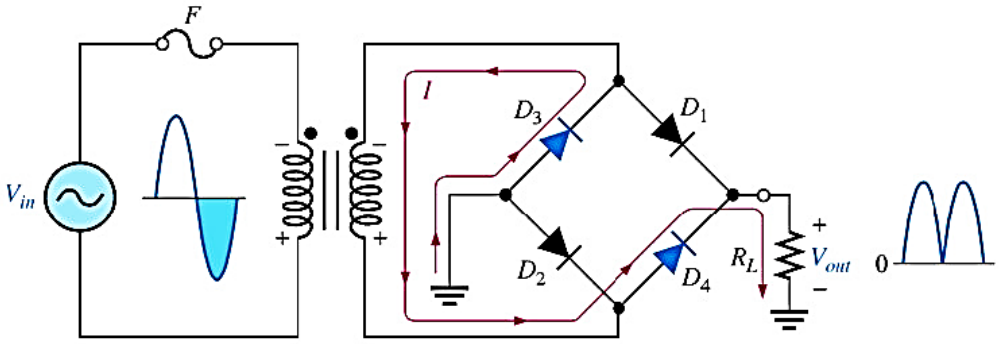


- The full-wave bridge rectifier takes advantage of the full output of the secondary winding.

- It employs four diodes arranged such that current flows in the same direction through the load during each half of the cycle.

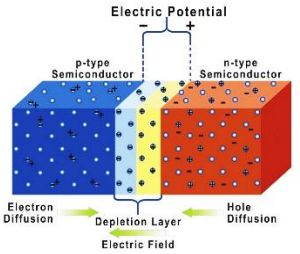


(a) During positive half-cycle of the input, D_1 and D_2 are forward-biased and conduct current. D_3 and D_4 are reverse-biased.



(b) During negative half-cycle of the input, D_3 and D_4 are forward-biased and conduct current. D_1 and D_2 are reverse-biased.

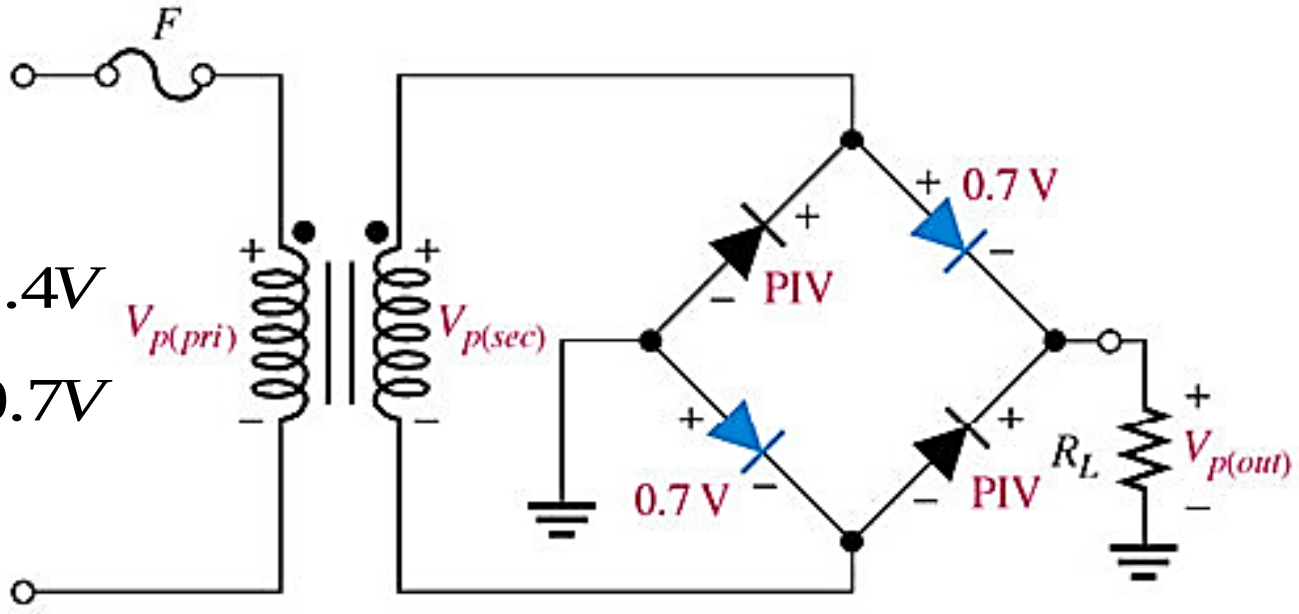
Full Wave Rectifier- Bridge



- The PIV for a bridge rectifier is approximately half the PIV for a center-tapped rectifier.
- Note that in most cases we take the diode drop into account.

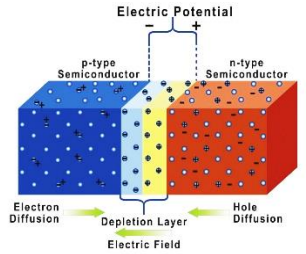
$$V_{p(out)} = V_{p(in)} - 1.4V$$

$$PIV = V_{p(out)} + 0.7V$$



(b) For the practical diode model (forward-biased diodes D_1 and D_2 are shown in blue). PIV = $V_{p(out)}$ + 0.7 V

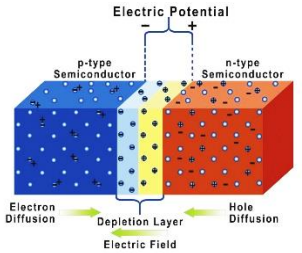
Summary of Rectifier Circuit



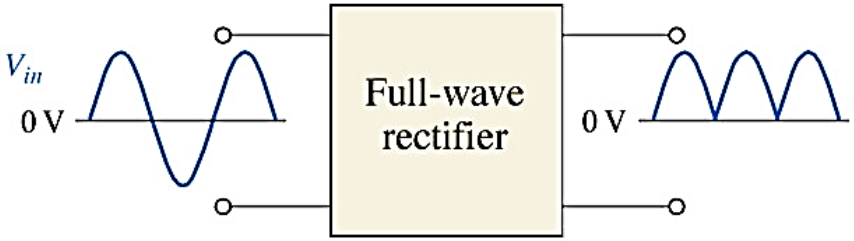
rectifier	Ideal(V_{DC})	Practical(V_{DC})
Half wave rectifier	$V_{DC}=0.318V_p$	$V_{DC}=0.318V_p - 0.7$
Full wave bridge rectifier	$V_{DC}=0.636V_p$	$V_{DC}=0.636V_p - 2(0.7)$
Full wave center tap rectifier	$V_{DC}=0.636V_p$	$V_{DC}=0.636V_p - 0.7$

V_p = peak of the AC voltage.

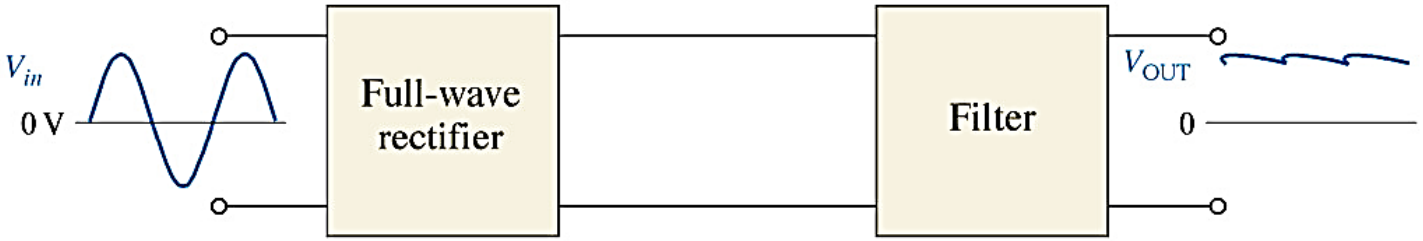
Power Supply Filter & Regulator



- The output of a rectifier is a pulsating DC. With filtration and regulation this pulsating voltage can be smoothed out and kept to a steady value.

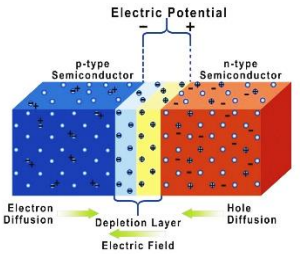


(a) Rectifier without a filter

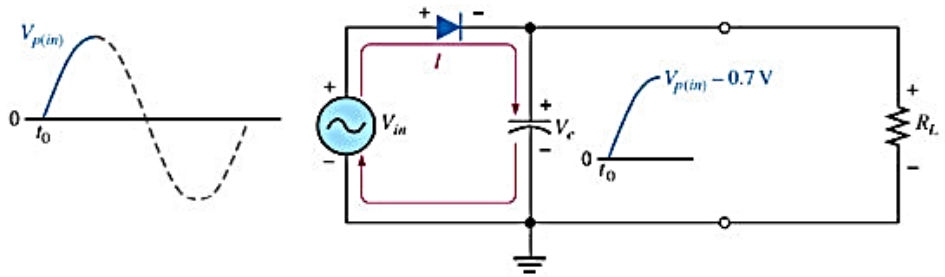


(b) Rectifier with a filter (output ripple is exaggerated)

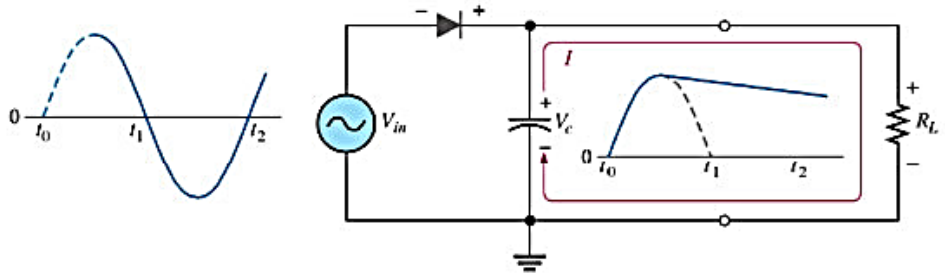
Power Supply Filter & Regulator



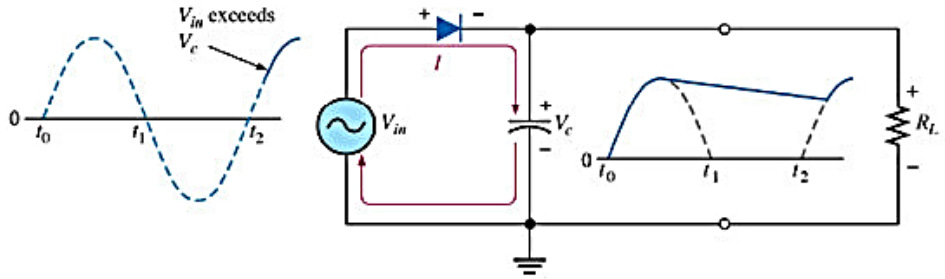
- A capacitor-input filter will charge and discharge such that it fills in the "gaps" between each peak.
- This reduces variations of voltage.
- The remaining voltage variation is called ripple voltage.



(a) Initial charging of capacitor (diode is forward-biased) happens only once when power is turned on.

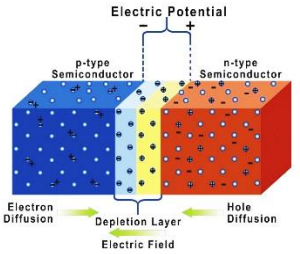


(b) The capacitor discharges through R_L after peak of positive alternation when the diode is reverse-biased. This discharging occurs during the portion of the input voltage indicated by the solid blue curve.

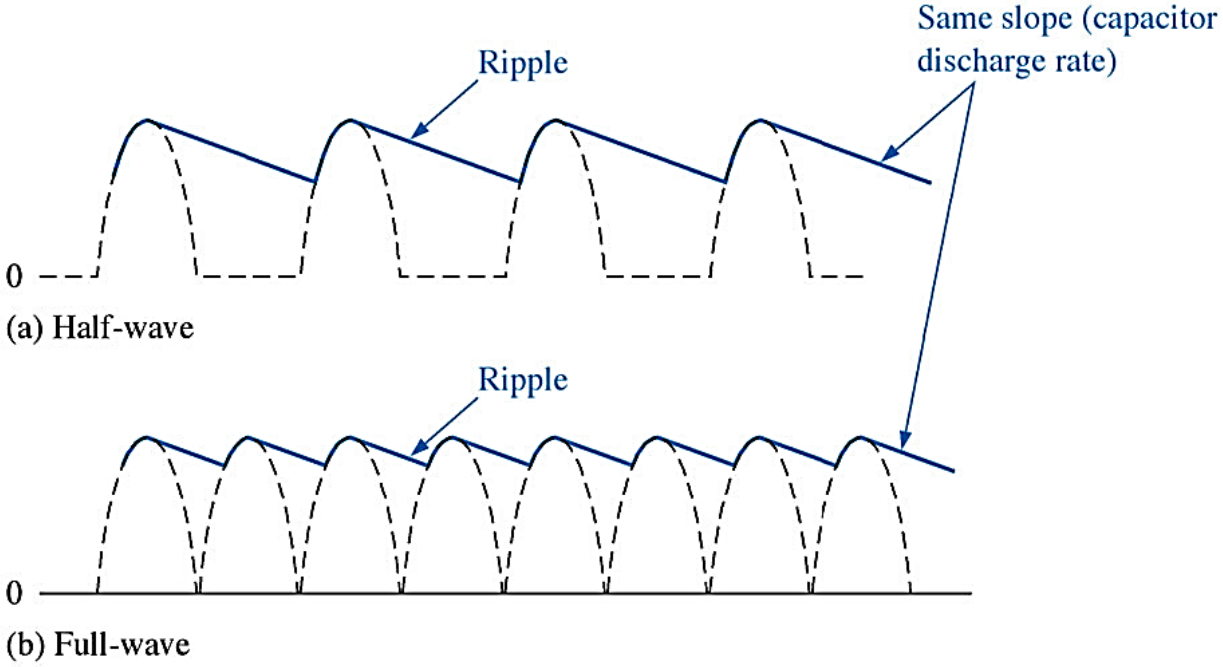


(c) The capacitor charges back to peak of input when the diode becomes forward-biased. This charging occurs during the portion of the input voltage indicated by the solid blue curve.

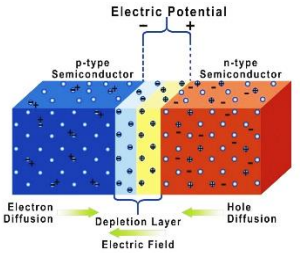
Power Supply Filter & Regulator



- The advantage of a full-wave rectifier over a half-wave is quite clear.
- The capacitor can more effectively reduce the ripple when the time between peaks is shorter.



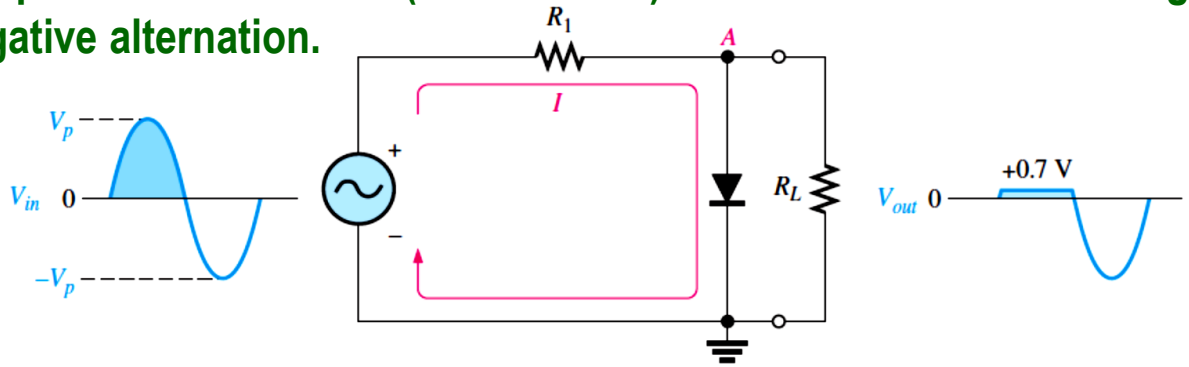
Diode limiter (Clippers)



- Diode circuits, called limiters or clippers, are sometimes used to clip off portions of signal voltages above or below certain levels.

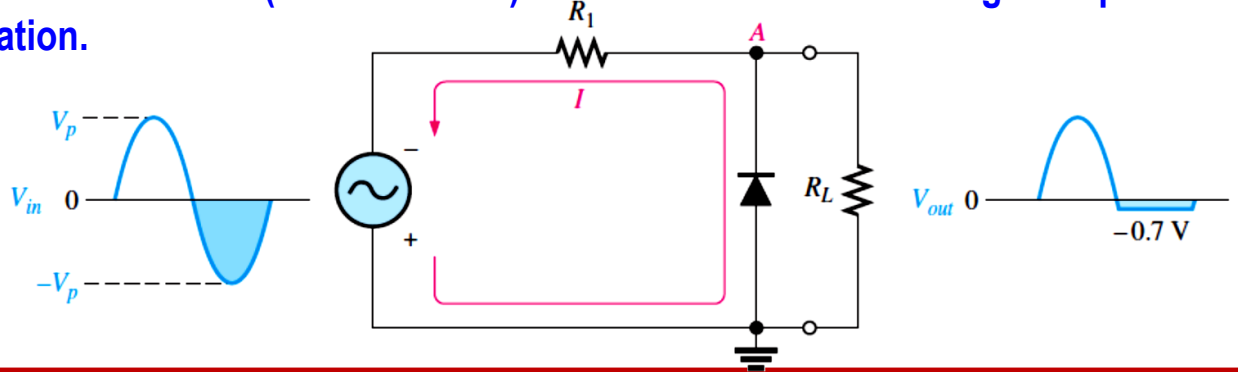
Barrier potential, for silicon is approximately 0.7 V.

- Limiting of the positive alternation. The diode is forward-biased during the positive alternation (above 0.7 V) and reverse-biased during the negative alternation.



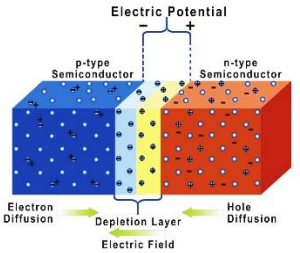
$$V_{out} = \left(\frac{R_L}{R_1 + R_L}\right) V_{in}$$

- Limiting of the negative alternation. The diode is forward-biased during the negative alternation (below– 0.7 V) and reverse-biased during the positive alternation.



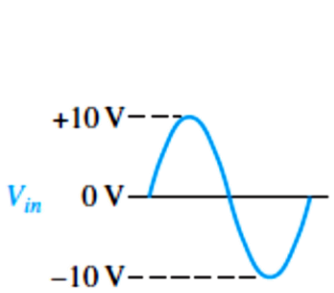
If R_1 is small compared to R_L, then $V_{out} \cong V_{in}$.

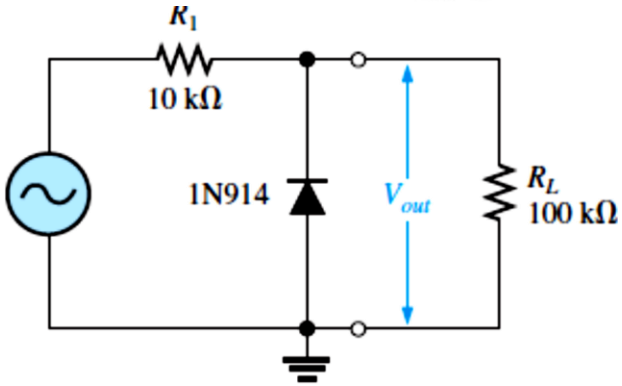
Example 1



- **Calculate V_{out}**

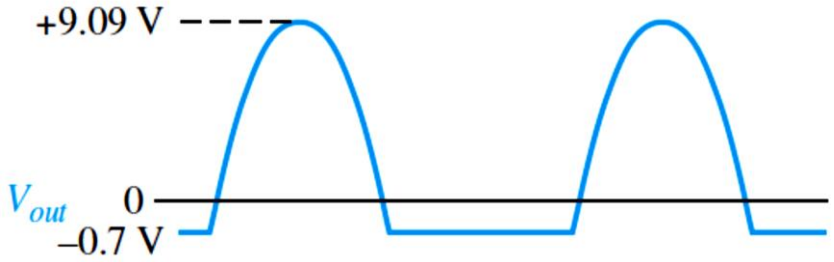
  Solution:



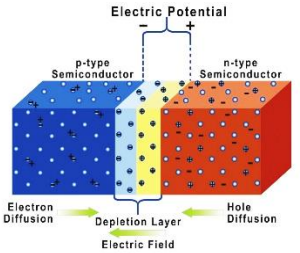


- The diode is forward-biased and conducts when the input voltage goes below -0.7 V. So, for the negative limiter, determine the peak output voltage across R_L by the following equation:

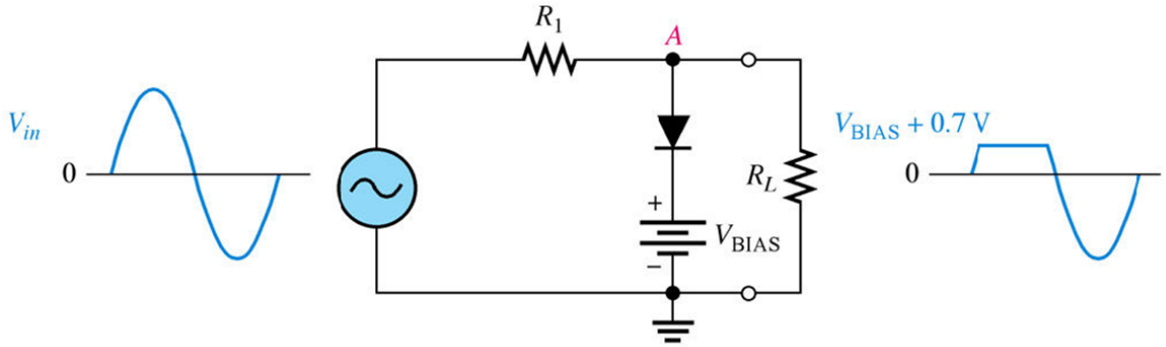
$$V_{p(out)} = \left(\frac{R_L}{R_1 + R_L}\right)V_{p(in)} = \left(\frac{100\ \text{k}\Omega}{110\ \text{k}\Omega}\right)10\ \text{V} = 9.09\ \text{V}$$



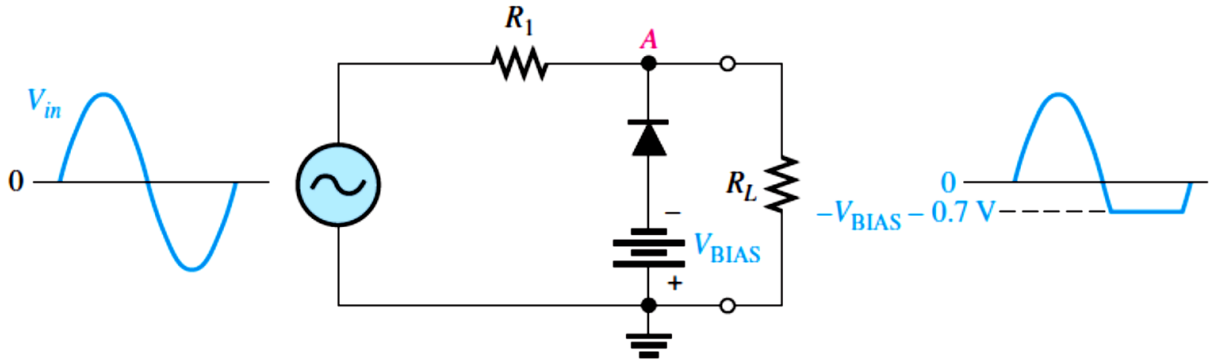
Biased Limiters



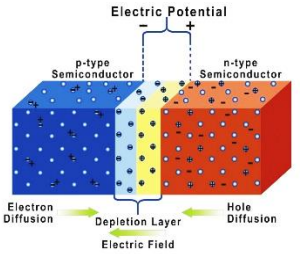
- The level to which an ac voltage is limited can be adjusted by adding a bias voltage, V_{BIAS} , in series with the diode
- This positive limiter will limit the output to V_{BIAS} + 0.7V



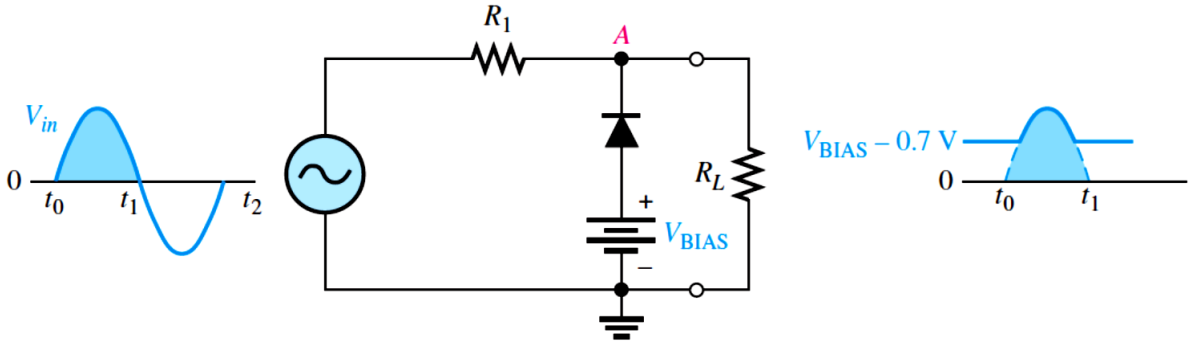
- This negative limiter will limit the output to -V_{BIAS} - 0.7V



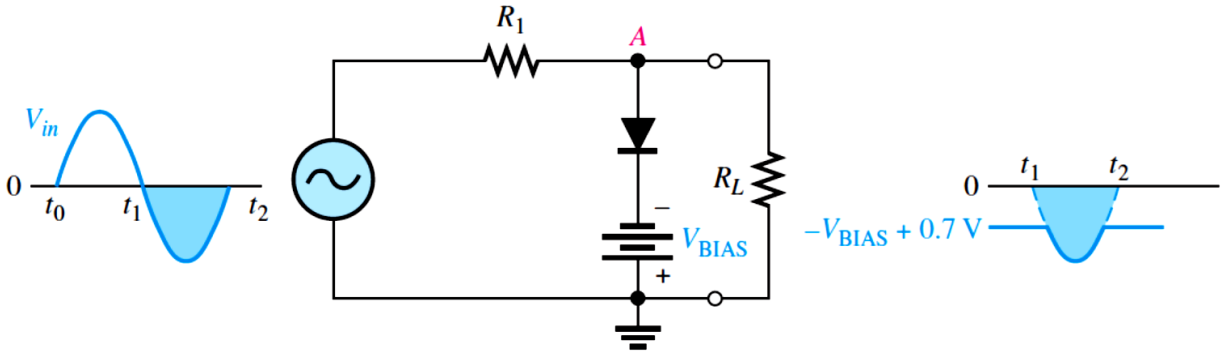
Biased Limiters



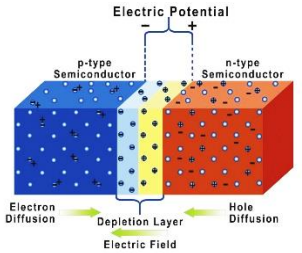
- By turning the diode around, the positive limiter can be modified to limit the output voltage to the portion of the input voltage waveform above V_{BIAS} - 0.7 V



- Negative limiter can be modified to limit the output voltage to the portion of the input voltage waveform below $-V_{BIAS}$ + 0.7 V



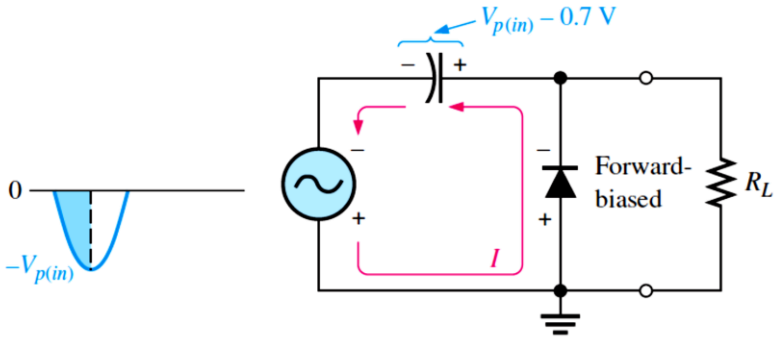
Diode Clampers



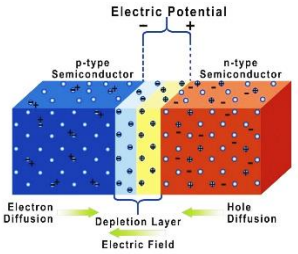
- A clamper is a network constructed of a diode, a resistor, and a capacitor that shifts a waveform to a different dc level without changing the shape of the applied signal.
- Clampers are sometimes known as dc restorers.
- The capacitor charges to the peak of the supply minus the diode drop $V_{p(in)}$ - 0.7 V.
- Once charged, the capacitor acts like a battery in series with the input voltage.
- The time constant of charge and discharge of the capacitor affect the output waveform.

$$\tau = RC$$

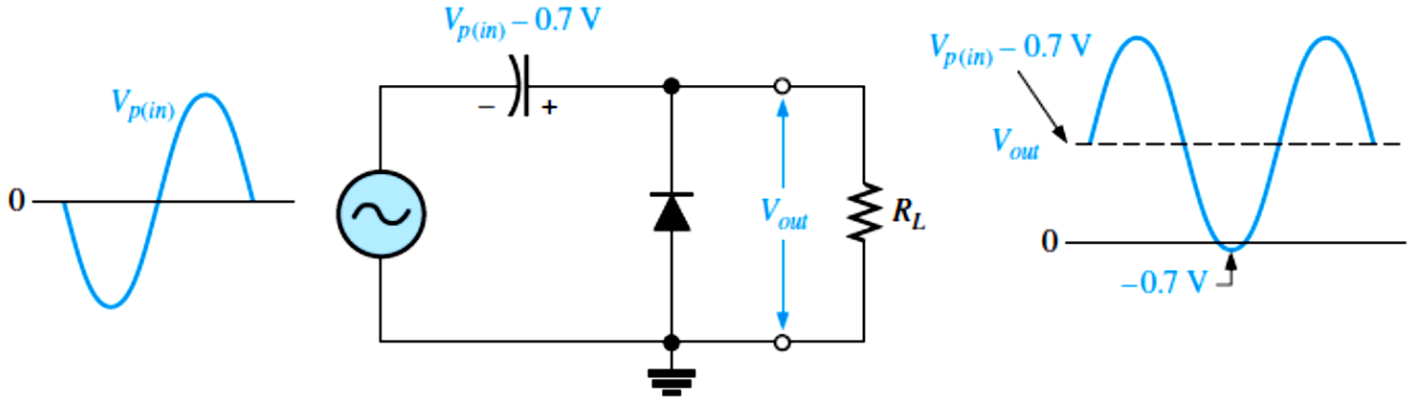
- An RC time constant of 10 times the input period will have a small amount of distortion at the ground level due to the charging current.



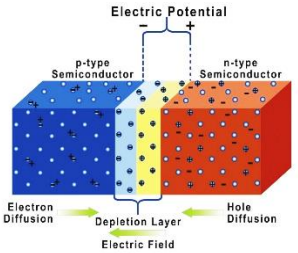
Positive and Negative Clamper



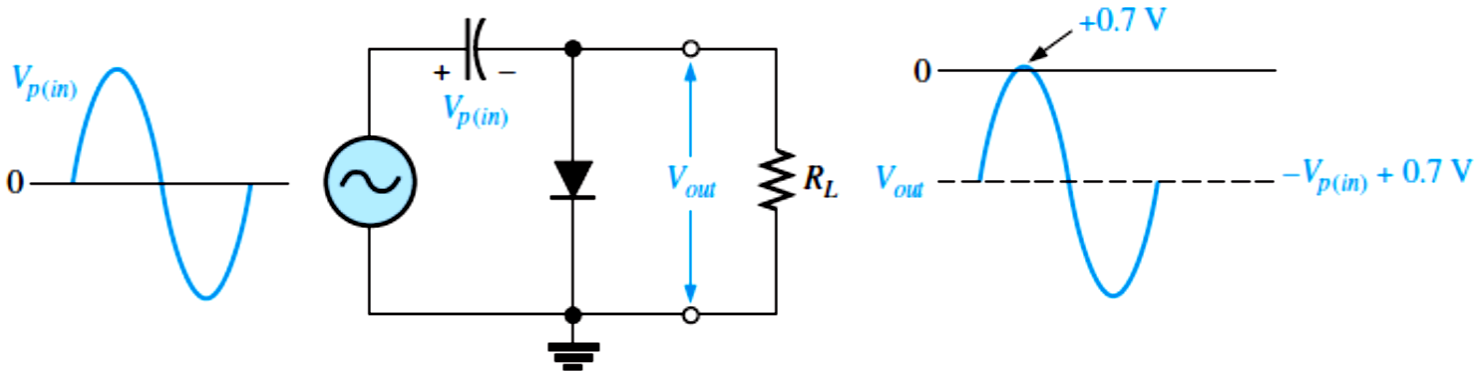
- **Positive Clamper**



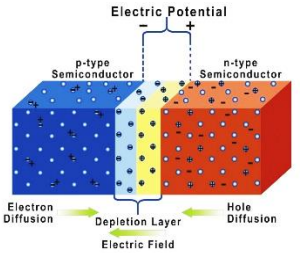
Positive and Negative Clamper

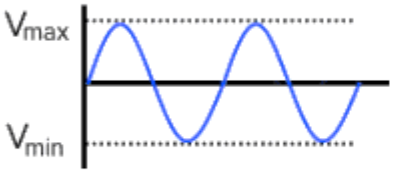


- **Negative Clamper**

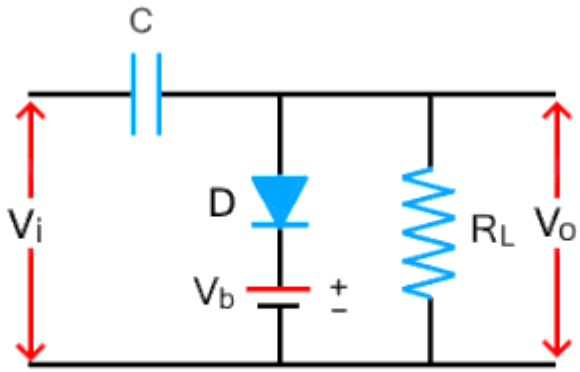


Biased Clampers

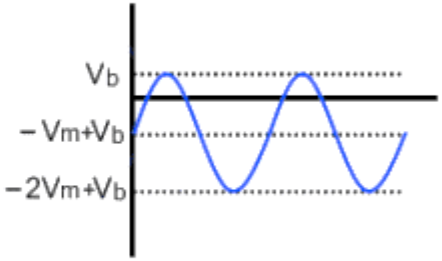




Input Signal

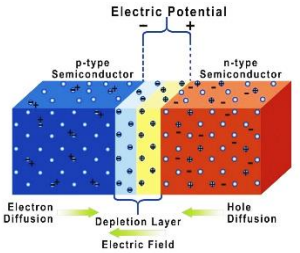


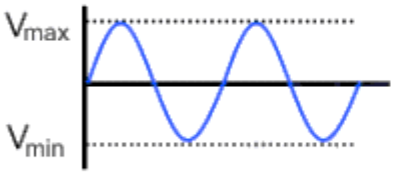
Negative Clamper with Positive Bias



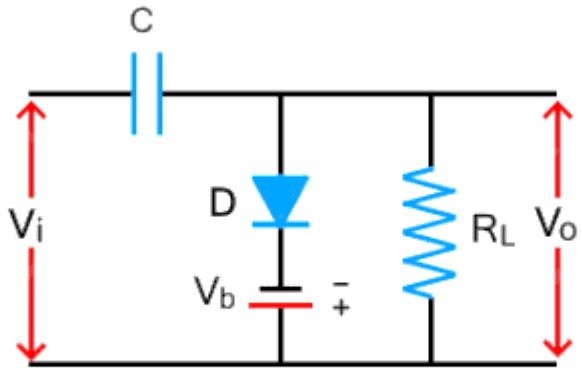
Output Signal

Biased Clampers

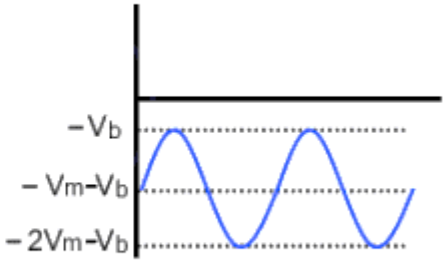




Input Signal

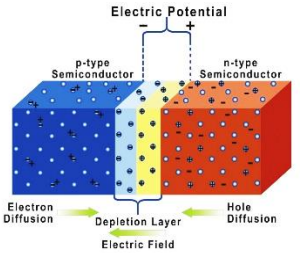


Negative Clamper with Negative Bias

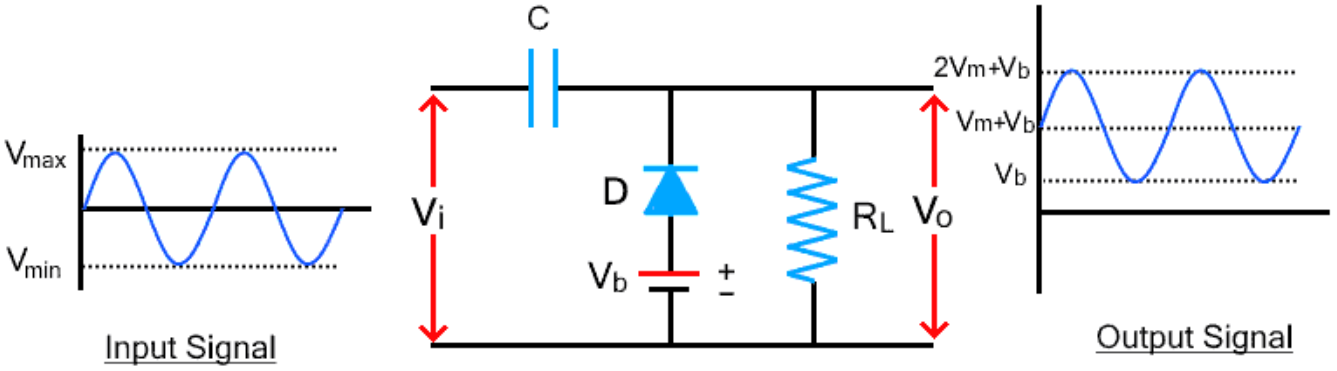


Output Signal

Biased Clampers

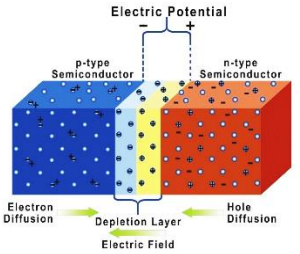


- The input signal can be any type of waveform such as sine, square, triangle.
- The DC source adjusts the DC clamping level

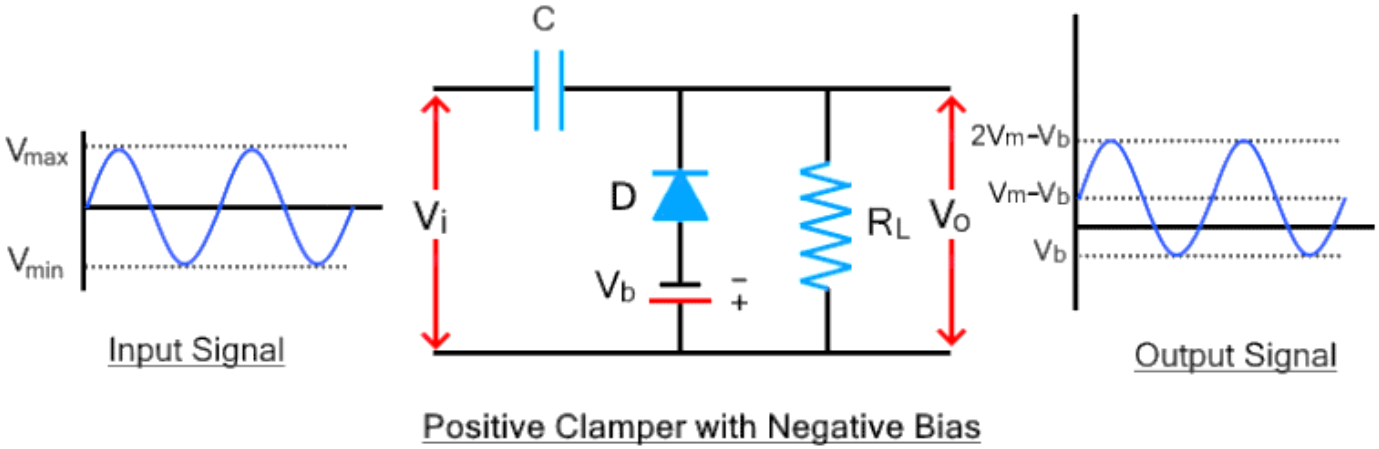


Positive Clamper with Positive Bias

Biased Clampers

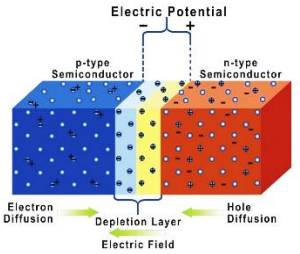


- The input signal can be any type of waveform such as sine, square, triangle.
- The DC source adjusts the DC clamping level

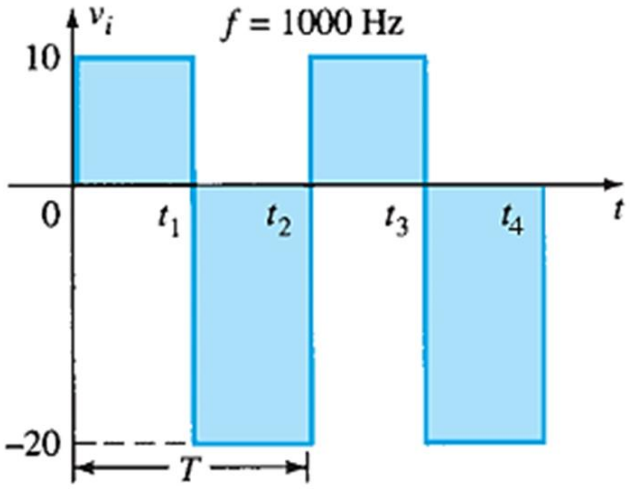


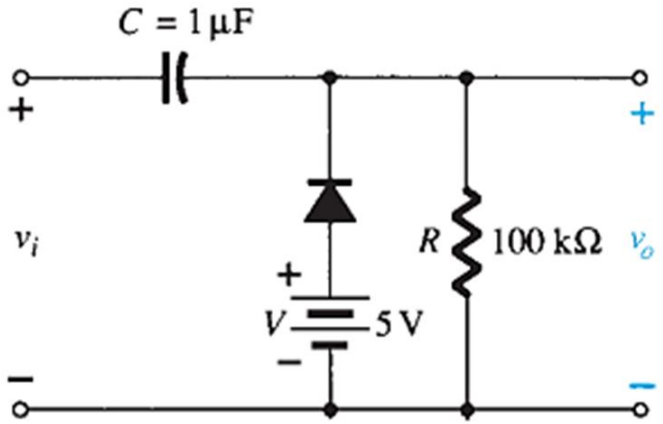
Positive Clamper with Negative Bias

Example 2

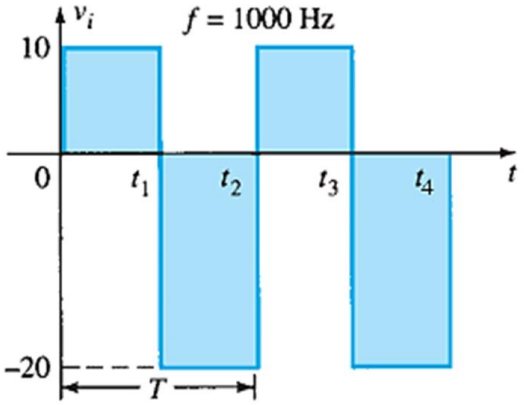


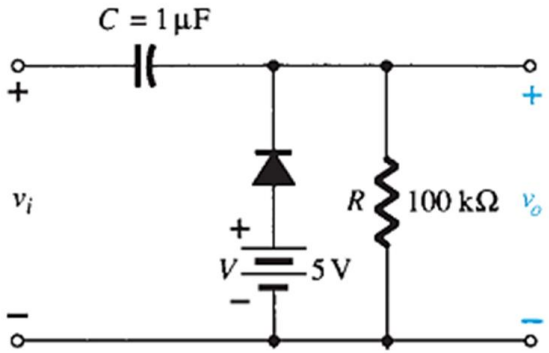
Determine v_o for the network of Figure below for the input indicated.

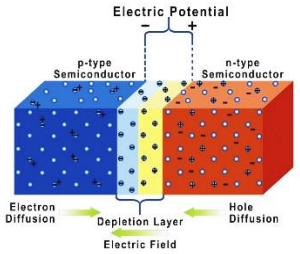




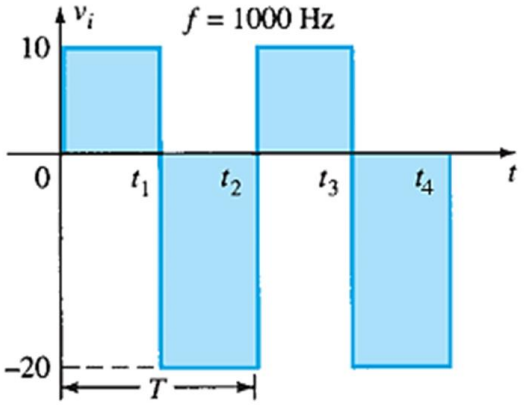
Example 2

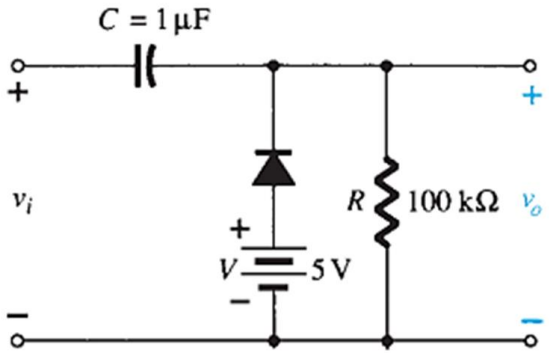

v_i
$f = 1000$ Hz
10
0
t_1
t_2
t_3
t_4
t
−20
T

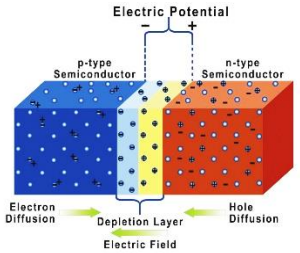

$C = 1\,\mu F$
+
v_i
−
R
100 kΩ
v_o
+
V
5 V
−


Electric Potential
p-type Semiconductor
n-type Semiconductor
Electron Diffusion
Depletion Layer
Hole Diffusion
Electric Field

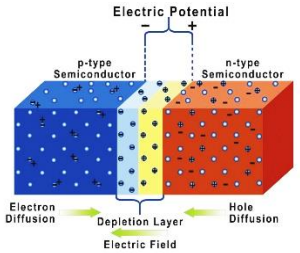
Example 2


v_i
$f = 1000$ Hz
10
0
-20
t_1
t_2
t_3
t_4
t
T


$C = 1\,\mu F$
+
v_i
−
R
100 kΩ
v_o
V
5 V

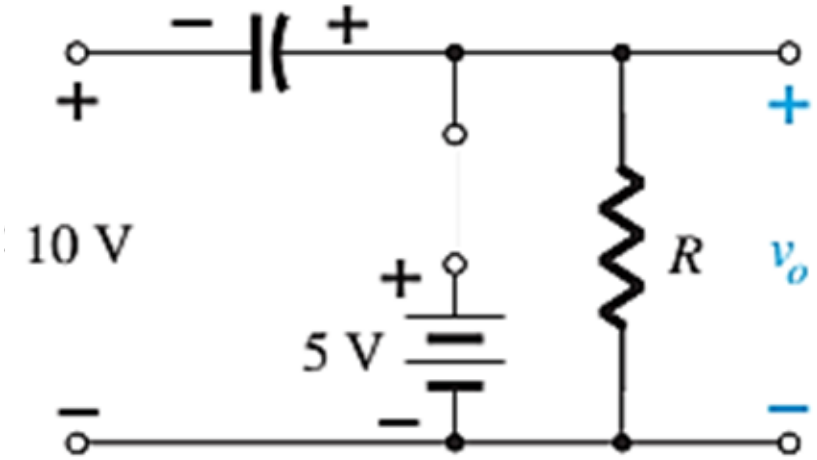

Electric Potential
p-type Semiconductor
n-type Semiconductor
Electron Diffusion
Depletion Layer
Hole Diffusion
Electric Field

Example 2



Solution: 1st half of the square wave

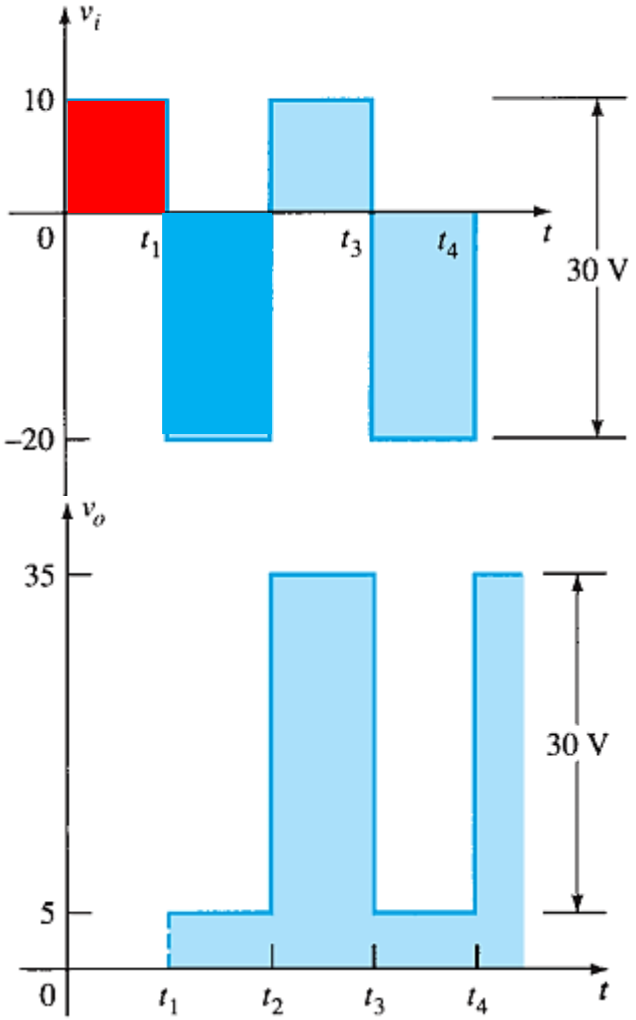
2nd half of the square wave



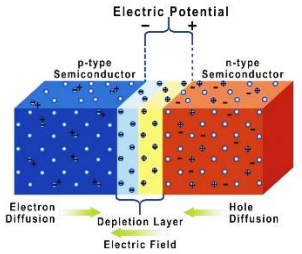
Determining v_o and V_C with the diode in the "on" state.

$$-20\text{ V} + V_C - 5\text{ V} = 0$$

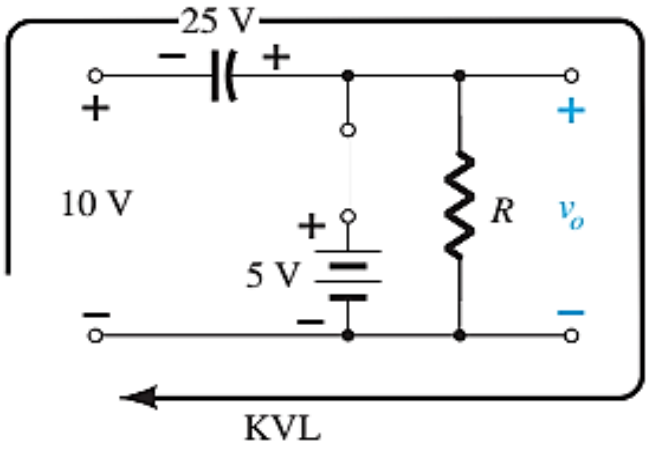
$$V_C = 25\text{ V}$$



Example 2



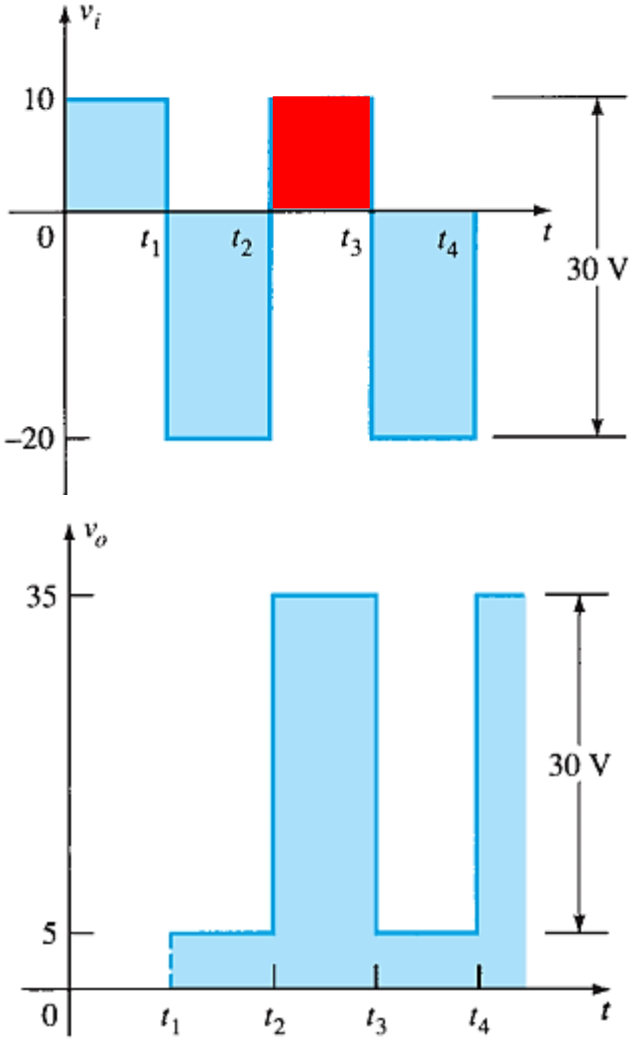
Solution:



Determining v_o with the diode in the "off" state.

$$+10\text{ V} + 25\text{ V} - v_o = 0$$

$$v_o = 35\text{ V}$$



Essay assignment

Voltage Multipliers

Zener Diode

Next lecture