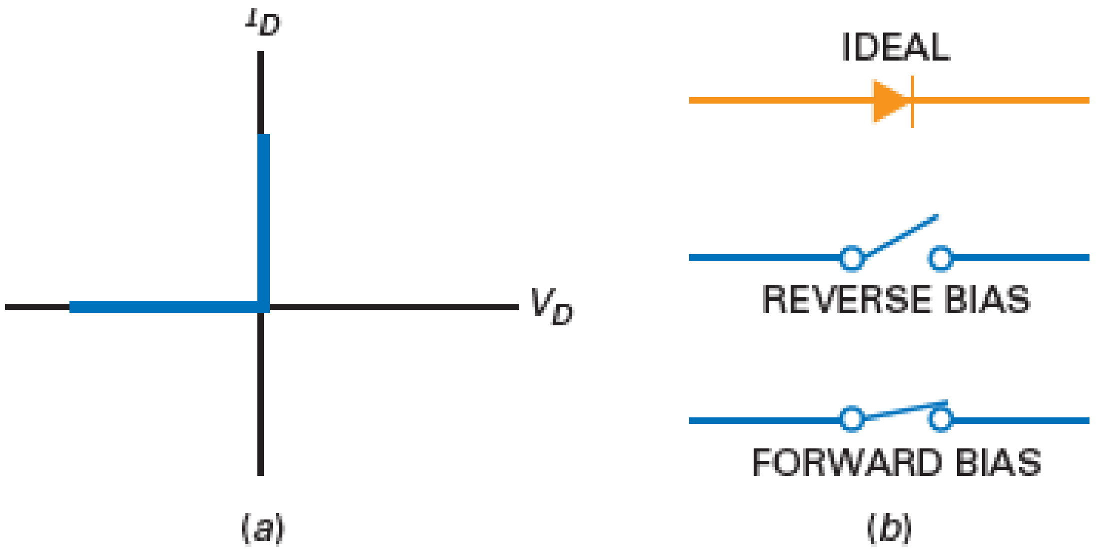
Diodes

Gunn Diode
LED
PIN Diode
Step Recovery Diode
Laser Diode
Photo Diode
Shockley Diode
Tunnel Diode
Varactor Diode
Schottky Diode
Zener Diode

Ideal diode

- The diode conducts well in the forward direction and poorly in the reverse direction. Ideally, a diode acts like a perfect conductor (zero resistance) when forward Biased and like a perfect insulator (infinite resistance) when reverse biased
- An ordinary switch has zero resistance when closed and infinite resistance when open. Therefore, an ideal diode acts like a switch that closes when forward biased and opens when reverse biased.
- The Ideal diode model treats a forward-biased diode like a closed switch with a voltage drop of zero volts



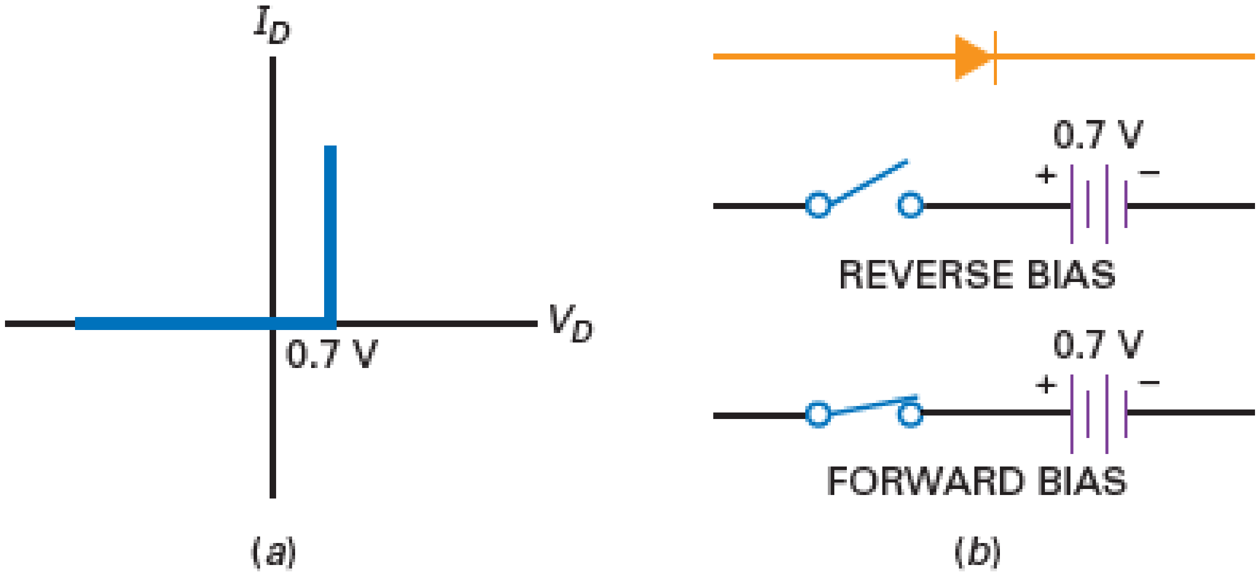
Constant voltage drop model

Figure *a* shows a current versus voltage for Constant voltage drop model.

No current - until 0.7 V appear across the diode. When the voltage reaches 0.7 v the diode turns on, 0.7 V can appear across the diode.

Figure *b* shows the equivalent circuit for the Constant voltage drop model a silicon diode. The diode act as a switch in series with a barrier potential of 0.7 V.

If the voltage across the diode is greater than 0.7 V, the switch will close. On the other hand, if the voltage is less than 0.7 V, the switch will open. In this case, there is no current through the diode.



Diode parameters

Maximum power rating

It is the maximum power that can be dissipated at the junction without damaging it.

Maximum forward current

It is the highest instantaneous forward current that a pn junction can conduct without damage to the junction.

Peak inverse voltage

It is the maximum reverse voltage that a diode can withstand without destroying the junction.

Knee Voltage

In the forward region, the voltage at which the current starts to increase rapidly is called the knee voltage or Cut in voltage of the diode. The knee voltage equals the barrier potential

$V_k = 0.7$ (Si), $V_k = 0.3$ (Ge)

Reverse current or leakage current

It is the current that flows through a reverse biased diode. This current is due to the minority carriers.

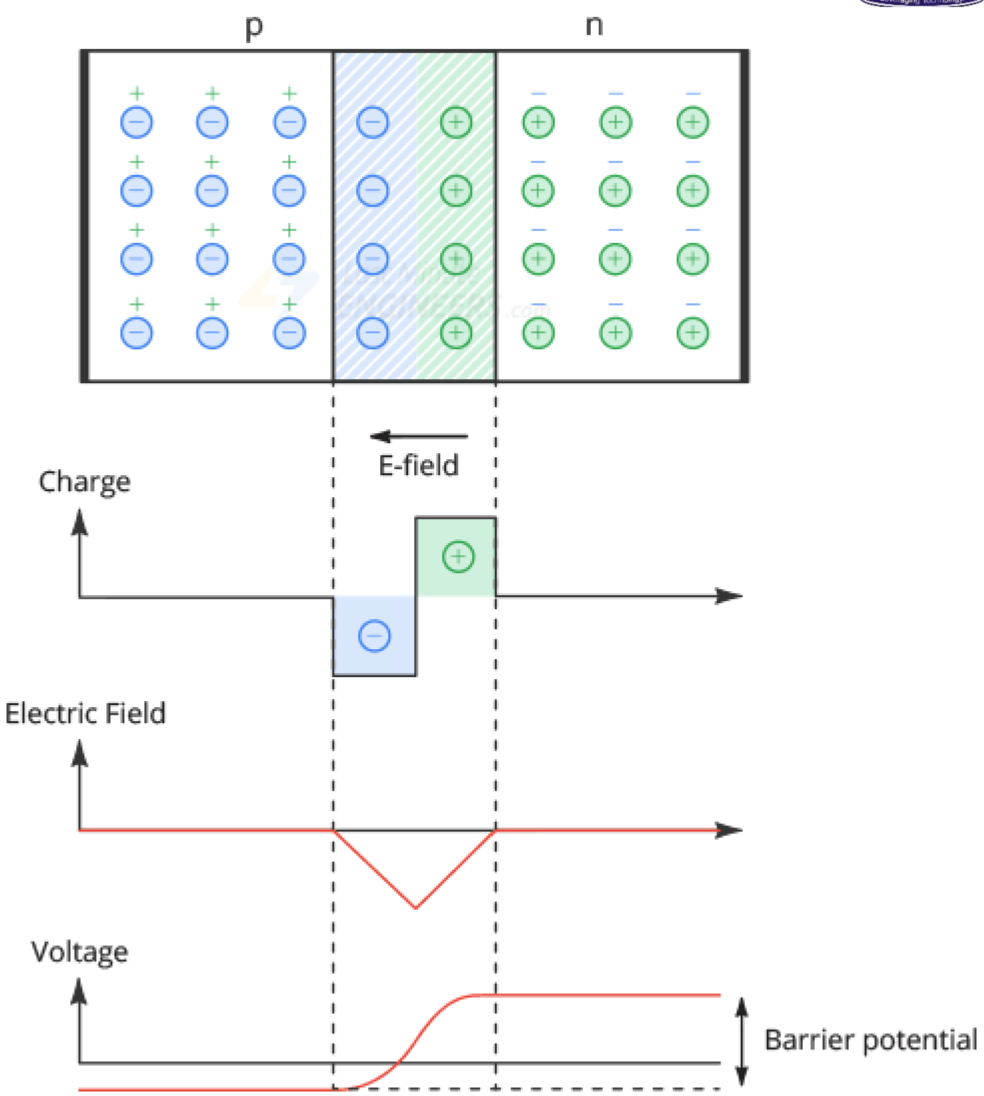
Depletion layer

The space charge region on either side of the junction, where an accumulation of immobile ions forms a layer near the junction, is called the depletion region.

Diffusion: It occurs for majority charge carriers due to concentration gradient. Holes diffuses from p-side to n-side while Electrons diffuses from n-side to p-side of the junction. This movement of charge carriers generates a diffusion current across the junction.

Drift current in a PN junction is caused by minority carriers moving under the electric field in the depletion region (electrons drift from p to n, holes from n to p). Its direction is opposite to diffusion current. Initially, diffusion dominates, but as the electric field builds up, drift increases until both balance. At this equilibrium, **no net current flows**.

$$W(mt) = \sqrt{\frac{2\varepsilon}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)V_o}$$



$\varepsilon = \varepsilon_o\, \varepsilon_{r,}$ $\varepsilon_o = absolute\ permmitivity\ of\ free\ space = 8.86 \times 10^{-12} F/m$

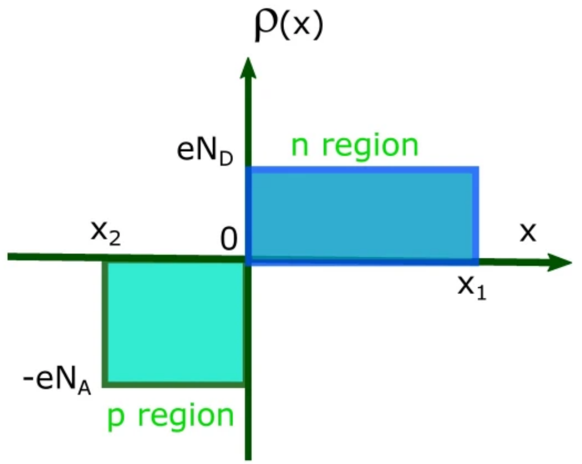
$\varepsilon_r =$ relative permittivity $\varepsilon_{r\,(Si)} =$,11.7 $\varepsilon_{r\,(Ge)} =$ 16

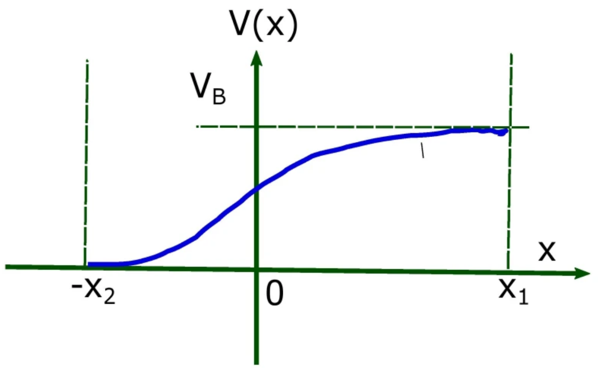
Depletion layer Cont.

Depletion layer consists of –ve ions (acceptor ions) on p-side and (+) ve ions (donor ions on N-side)
DL opposes majority carriers in crossing the junction, it helps the minority carriers in crossing the junction.
Width of Depletion layer $W = \frac{1}{\sqrt{doping}}$
If doing concentration of P and N regions are equal $(N_A = N_D)$ then $W_N = W_p = W/2$

Barrier Potential (Vo)

When a PN junction is formed:
•Electrons from the n-side diffuse into the p-side and recombine with holes.
•Holes from the p-side diffuse into the n-side and recombine with electrons.
•This leaves behind immobile charged ions → creating the depletion region.
•An electric field builds up across this region, which opposes further diffusion of majority carriers until an external forward bias reduces it.





•**Silicon (Si):** ~0.7 V
•**Germanium (Ge):** ~0.3 V

$$(V_o) = \frac{kT}{q} ln\left(\frac{N_A N_D}{n_i^2}\right)$$

Depends on:
•Semiconductor material (bandgap)
•Doping concentration

PN junction diode

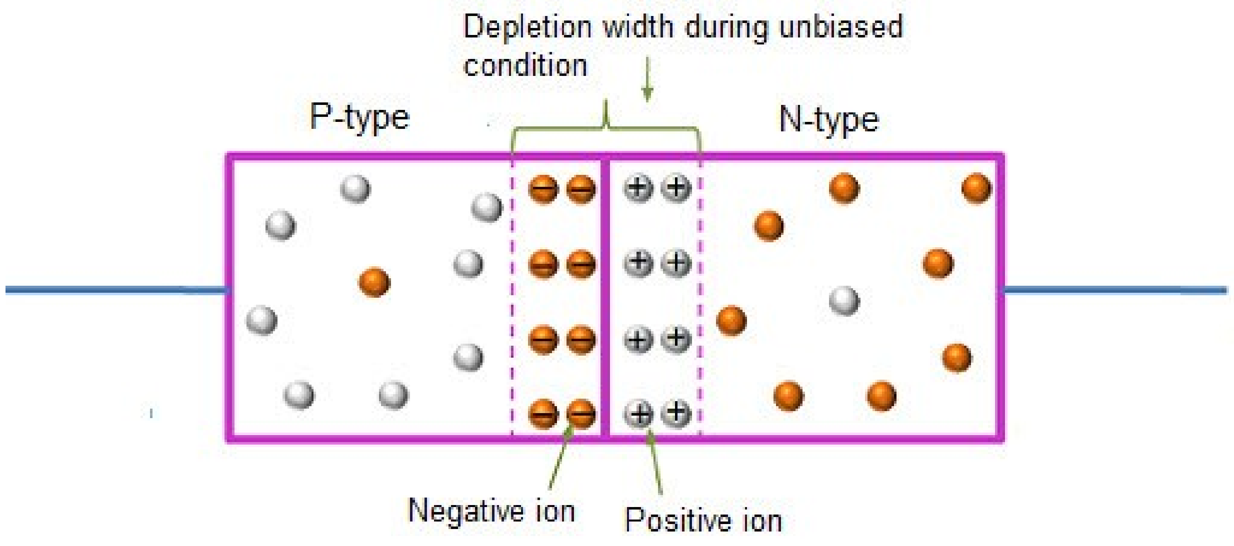
A PN junction diode is a semiconductor device formed by joining a p-type semiconductor with an n-type semiconductor The junction between the p and n regions creates special electrical properties. It allows current flow only in one direction (forward) and blocks it in the other (reverse).

Formation of PN Junction

- **P-type region**: Doped with *acceptor atoms* (e.g., Boron in Si), majority carriers = **holes**.
- **N-type region**: Doped with *donor atoms* (e.g., Phosphorus in Si), majority carriers = **electrons**.
- When they are joined **Electrons from n-side** diffuse into p-side and **recombine with holes while Holes from p-side** diffuse into n-side and recombine.
- This leaves behind **immobile ions** → forming a **depletion region** (no free carriers). An internal **electric field** is created → acts as a potential barrier (built-in potential).

Biasing:

- Unbiased
- Forward bias
- Reverse bias



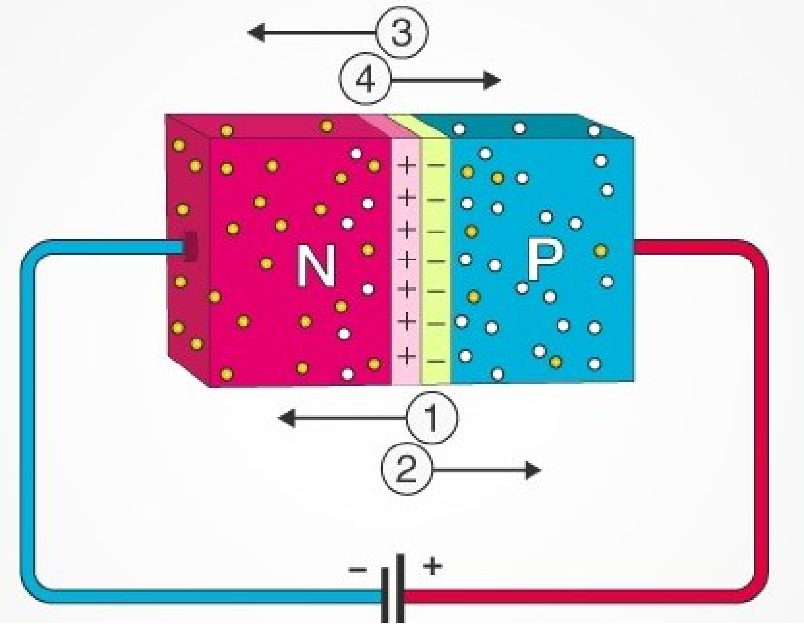
Forward bias

In **forward bias**, the battery's negative terminal is connected to the **N-type** and the positive terminal to the **P-type**. This reduces the depletion region. Electrons move from the N-side to the P-side toward the positive terminal, while holes move from the P-side to the N-side toward the negative terminal. The movement of these charge carriers allows **current to flow** through the diode.

- **Current flows exponentially** with applied voltage.
- Threshold voltage: ≈ **0.7 V (Si), 0.3 V (Ge)**.

$$\boxed{I_f = I_s(e^{V_d/\eta V_T} - 1)}$$

η = recombination factor
$\eta = 2$ for Si, $\eta = 1$ *for Ge*
$V_T = Thermal\ volatge = 25$ mV at room temperature



Forward voltage across the diode

$$\boxed{V_D = \eta\, V_T\, ln(\frac{I_f}{I_s})}$$

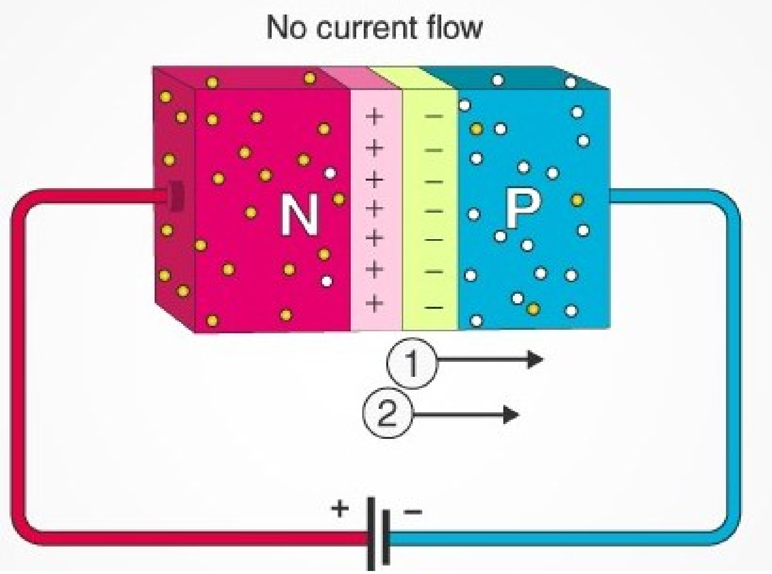
Forward voltage across diode decreases with temperature

For 1^oC V_D decreases by 2 mV

Reverse bias

When the p-type is connected to the battery's negative terminal and the n-type is connected to the positive side, the P-N junction is reverse biased. In this case, the built-in electric field and the applied electric field are in the same direction. When the two fields are added, the resultant electric field is in the same direction as the built-in electric field, creating a more resistive, thicker depletion region.

Junction voltage V_j = Sum of $V_{bi} + V_{RB}$
Width of depletion layer W $\propto \sqrt{V_{bi} + V_{RB}}$



When PN junction is reverse biased, the depletion layer increase
Barrier height $\uparrow$

- The current in reverse bias diode is only due to minority carriers.
- It is called reverse saturation current, leakage current, thermally generated current
- I_o is highly sensitive to temperature
- For increase of 1^oC I_o approximately increases by 7%.
- I_o double for every 10^oC

V-I Characteristics of P-N Junction Diode

In forward bias, p-type is connected to the +ve terminal and n-type to the -ve terminal, this reduces the potential barrier. For Si diodes, conduction starts at ~0.7 V; for Ge diodes, at ~0.3 V. Initially, current rises slowly, but once the barrier is overcome, current rises **exponentially**, giving a sharp upward curve.

In reverse bias:

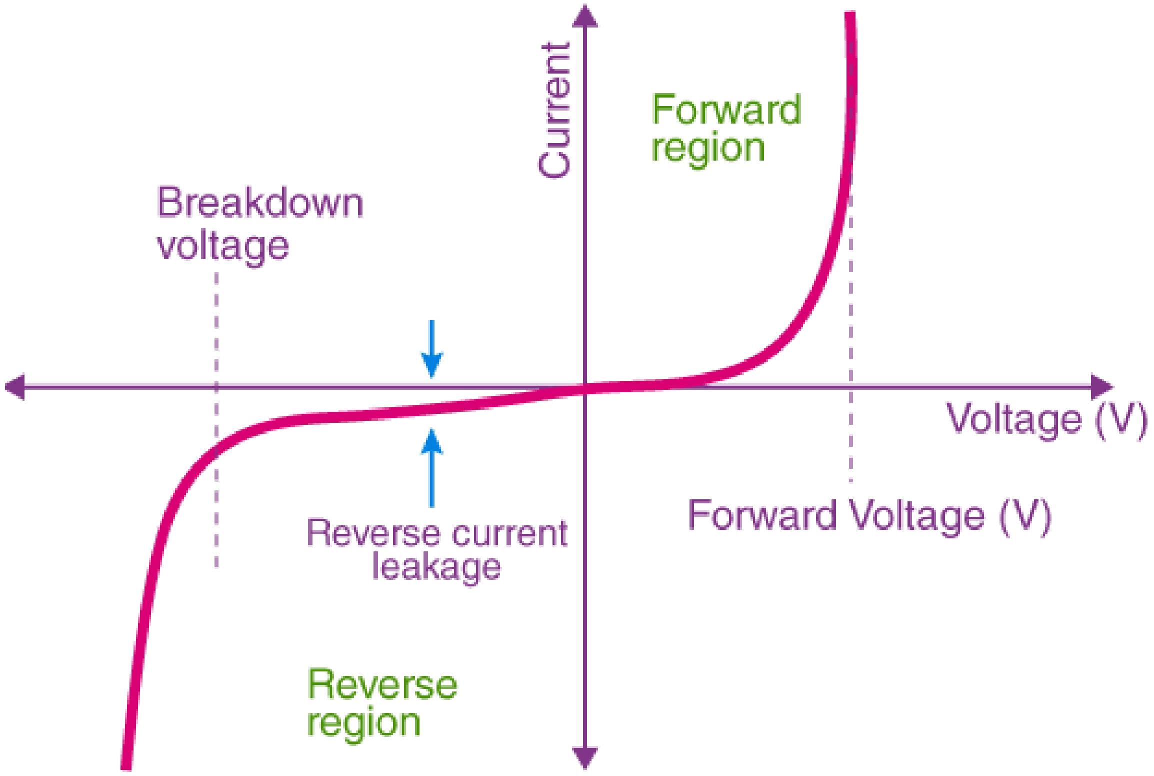
•At small reverse voltages, the current is almost **constant and very small** (few µA in Ge, nA in Si). This current is called **reverse saturation current** I_s

Breakdown Region:

•If the reverse voltage is increased beyond a certain value (called **breakdown voltage,**V_{BR}), the current suddenly increases sharply.

•Mechanisms:

- •**Zener breakdown** (low voltage, high doping) → quantum tunneling.
- •**Avalanche breakdown** (high voltage, low doping) → carrier multiplication.



Light-emitting diode (LED)

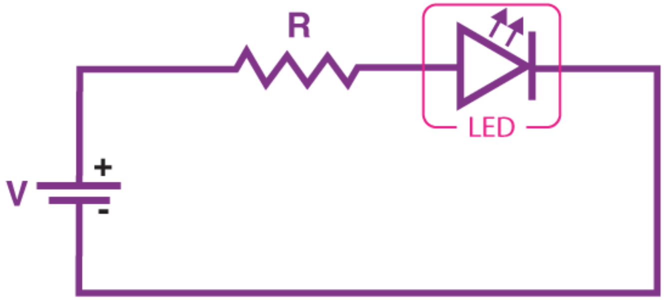
• LED is a **p-n junction diode** that emits light when forward biased.

When a voltage is applied in **forward bias**:

- **Electrons** from the n-region and **holes** from the p-region are injected across the junction.
- They recombine in the depletion region.
- During recombination, **electrons lose energy**.
- Instead of giving heat (as in ordinary diodes), in LEDs this energy is released as **photons (light)**.

This phenomenon is called **Electroluminescence**.

$$E_{photon} = hc/\lambda$$



LED Circuit

where E_g = bandgap of the semiconductor, determines the **color of LED light** (red, green, blue, etc.).

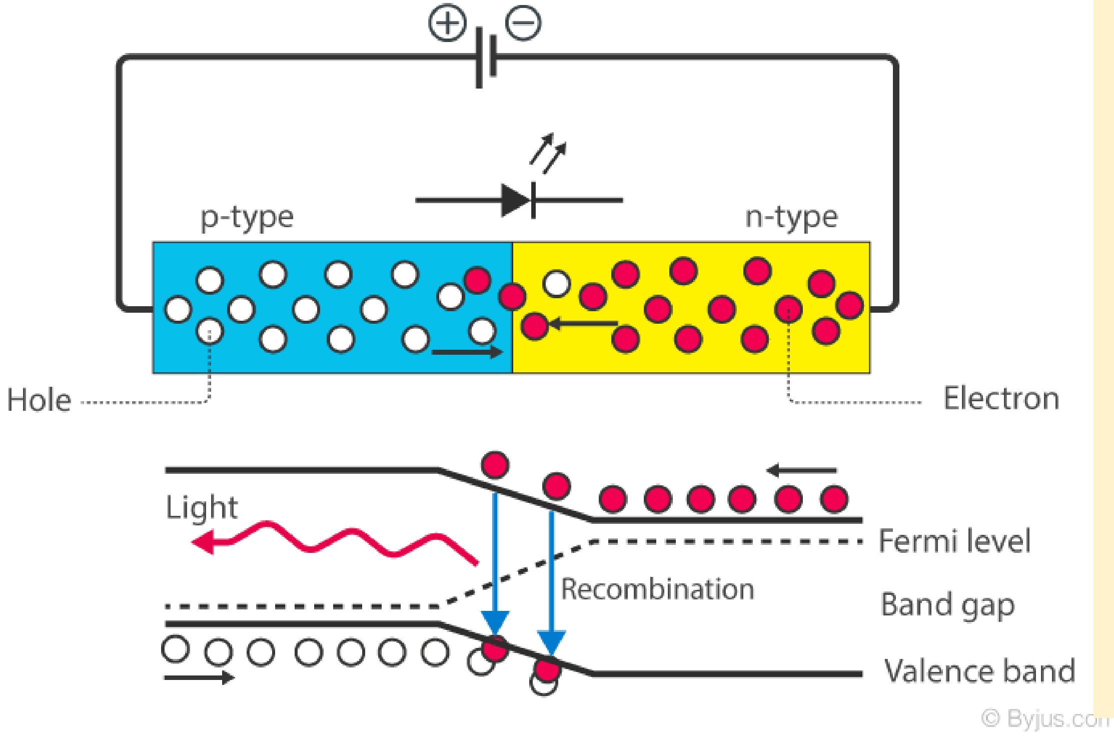
Applications:

- Used for TV back-lighting, Used in displays
- Used in Automotives
- LEDs used in the dimming of lights

Light-emitting diode (LED) Cont.

How does an LED work?

When the diode is forward biased, the minority electrons are sent from p → n while the minority holes are sent from n → p. At the junction boundary, the concentration of minority carriers increases. The excess minority carriers at the junction recombine with the majority charges carriers.



- ✓ The energy is released in the form of photons on recombination.
- ✓ In standard diodes, the energy is released in the form of heat. But in light-emitting diodes, the energy is released in the form of photons i.e. called electroluminescence.
- ✓ It is an optical phenomenon, and electrical phenomenon where a material emits light in response to an electric current passed through it. As the forward voltage increases, the intensity of the light increases and reaches a maximum.

$$\lambda = \frac{1.24}{E_g}\ \mu m$$

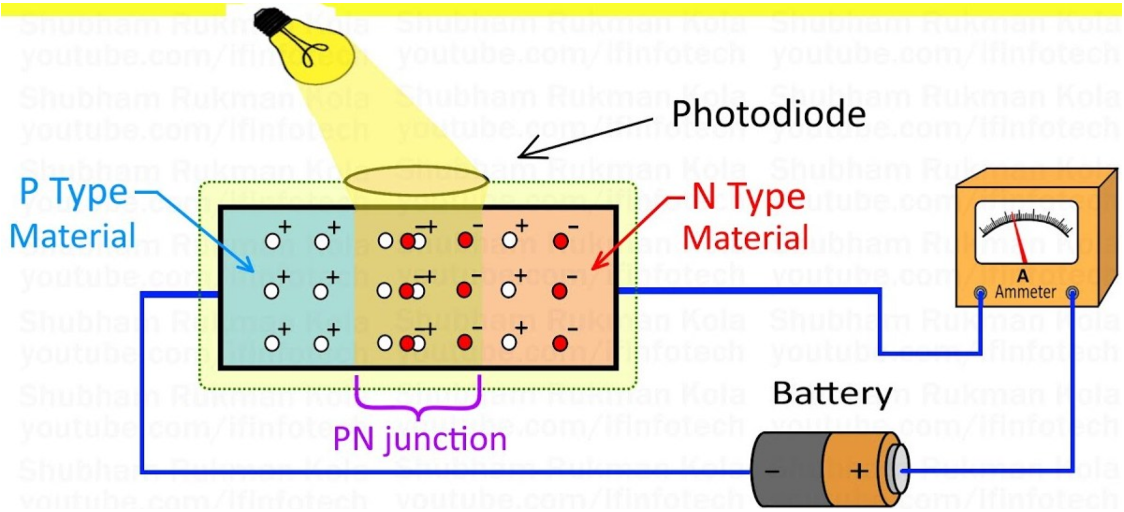
GaAs: Infrared light, GaP: Red and Green,
GaAsP: Yellow and Orange

Photo Diode

A **photodiode** is a semiconductor device that converts light energy into electrical current. It is usually operated in **reverse bias.** P-side → negative terminal and N-side → positive terminal. This biasing condition widens the depletion region. Typical photodiode materials are Si, Ge and InGaAs.

When light (photons) of sufficient energy ($h\nu \geq E_g$) falls on the diode, it strikes the depletion region. Photons **generate electron–hole pairs** in the depletion layer. The electric field in the depletion region **separates** the electron-hole pairs and electrons are pulled to the n-side, holes to the p-side.

- This movement of carriers produces a **photocurrent**, which is proportional to the **intensity of incident light**.
- Total diode current = **dark current (small reverse saturation current)** + **photocurrent**.

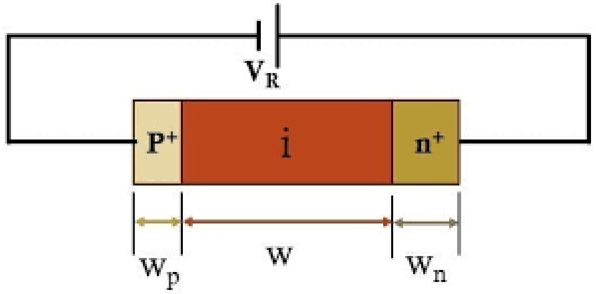


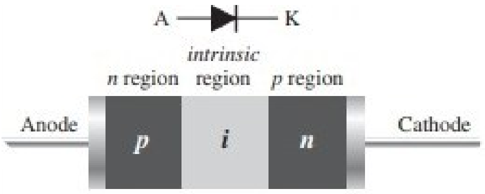
Applications of Photodiode

- solar cell panels.
- logic circuits.
- lighting regulation and
- optical communication

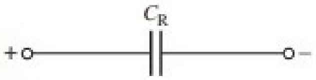
PIN Diode

PIN means Positive- Intrinsic-Negative. A diode with a wide and undoped intrinsic semiconductor region between a p-type and an n-type semiconductor region. The doping level of P and N layer is high and they are used for ohmic contacts while the thickness of the intrinsic layer is very narrow, which ranges from 10 – 200 microns.





Pin Diode Construction



Reverse-biased PIN Diode

Forward-biased PIN Diode

- In FB operation the depletion layer deceases, hence the potential barrier decreases with increase the flow of current. Hence it is called a **variable resistor.**
- In reverse bias region, with increase the reverse voltage, width of depletion region increases as far as whole mobile carriers swept away from the intrinsic region. It store the charges between two P and N plates, it behaves like a **parallel plate capacitor**.

Characteristics of Pin Diode

- ✓ The device works as a capacitor in reverse bias, where P and N serve as two parallel surfaces of capacitor plates
- ✓ PIN diode possesses very low reverse recovery time
- ✓ The intrinsic region of the PIN diode acts like an inferior rectifier which is used in various devices such as **attenuators**, **photodetectors**, **fast switches**, **high voltage power circuits**, etc.

Zener Diode

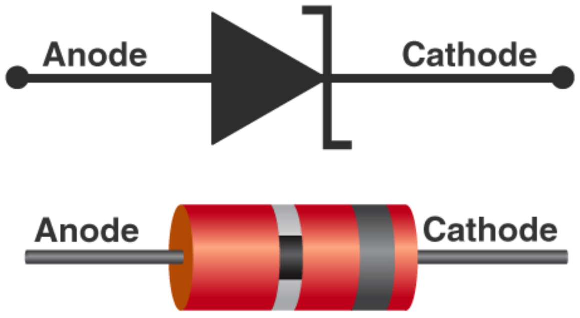
A Zener diode is a highly doped semiconductor device specifically designed to function in the reverse direction. It is engineered with a wide range of Zener voltages (V_Z), and certain types are even adjustable to achieve variable voltage regulation.

How does a Zener Diode work in reverse bias?

A Zener diode functions similarly to a regular diode when forward-biased. However, in reverse-biased mode, a small leakage current flows through the diode. As the reverse voltage increases and reaches the predetermined breakdown voltage (V_Z), current begins to flow through the diode. This current reaches a maximum level determined by the series resistor, after which it stabilizes and remains constant across a wide range of applied voltages.

There are two types of breakdowns in a Zener Diode: **Avalanche Breakdown** and **Zener Breakdown**.

Avalanche breakdown occurs in both normal and Zener diodes at high reverse voltage. Free electrons gain high energy, collide with atoms, and release more electrons → causing a chain reaction. This leads to a sudden large current through the diode.
In normal diodes, it may cause damage, but Zener diodes are designed to withstand it. Avalanche breakdown usually occurs in Zener diodes with Zener voltage > 6 V.



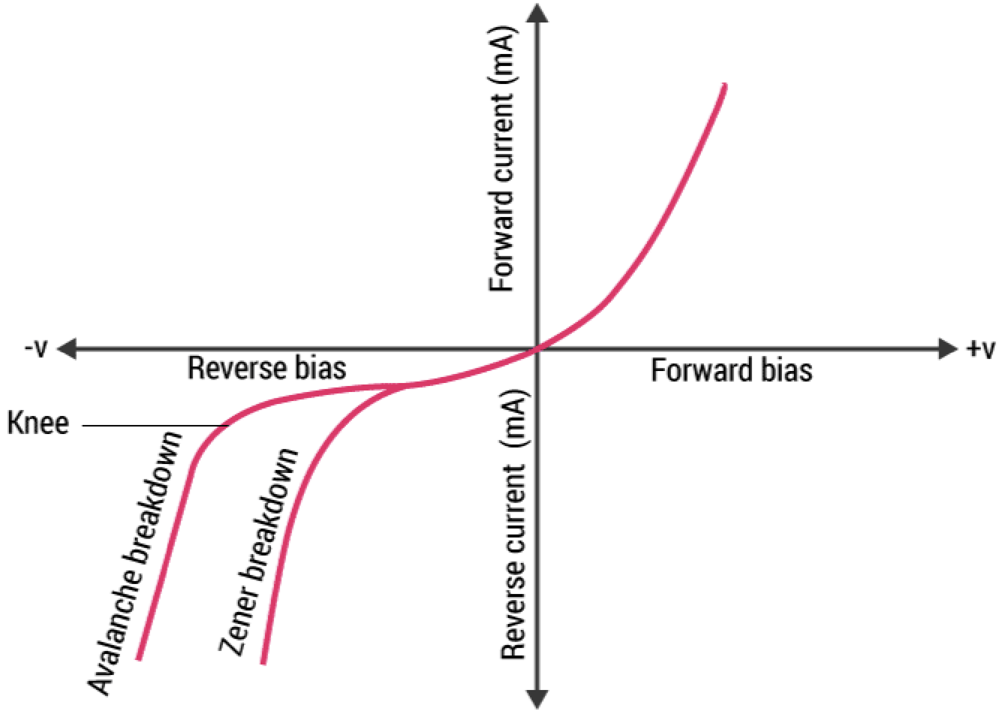
Zener Diode VI Characteristic

Zener breakdown

•When reverse voltage reaches the **Zener voltage**, the strong electric field in the depletion region pulls valence electrons from atoms.

•These electrons break free, causing a **sudden increase in current**.

•This process is called **Zener breakdown** and occurs in the breakdown region.



Forward Bias: it is almost identical to the forward characteristics of P-N junction diode.

•In reverse bias, a small saturation current I_o flows due to minority carriers.

•As reverse voltage increases and reaches a critical value, the current rises sharply.

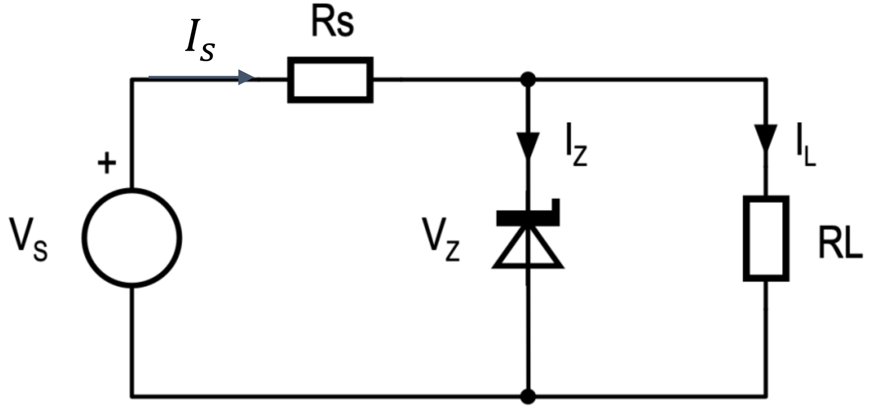
•This point is called the **breakdown voltage or Zener voltage (Vz)**.

Why Zener diode is highly doped: *"A heavily doped junction produces a sharper and well-defined breakdown voltage, which is essential for voltage regulation.*

•This makes the Zener diode hold voltage constant even when current changes."

Circuit Diagram

A resistor is used in series with the Zener diode and a load as a current limiting resistor to maintain the current.



$$I_{Z\,max} = \frac{V_S - V_Z}{Rs}$$

$$P_{Z\,max} = V_Z \frac{V_S - V_Z}{Rs}$$

$$R_{L\,min} = \frac{Rs\,Vz}{V_S - V_Z}$$

$$I_S = I_Z + I_L$$

$$I_L = \frac{V_Z}{R_L}$$

Specifications

Zener Voltage

The Zener voltage V_Z is the reverse breakdown voltage. It is the reference voltage that appears across the Zener diode in reverse biased. It can range from **2.4V** to **200V**.

Current

The rated Zener current is the maximum current the diode can allow at the rated Zener voltage. It can range from 200 uA to **200A**. The minimum current required for the breakdown that ranges between **5 mA to 10 mA**.

Power Rating

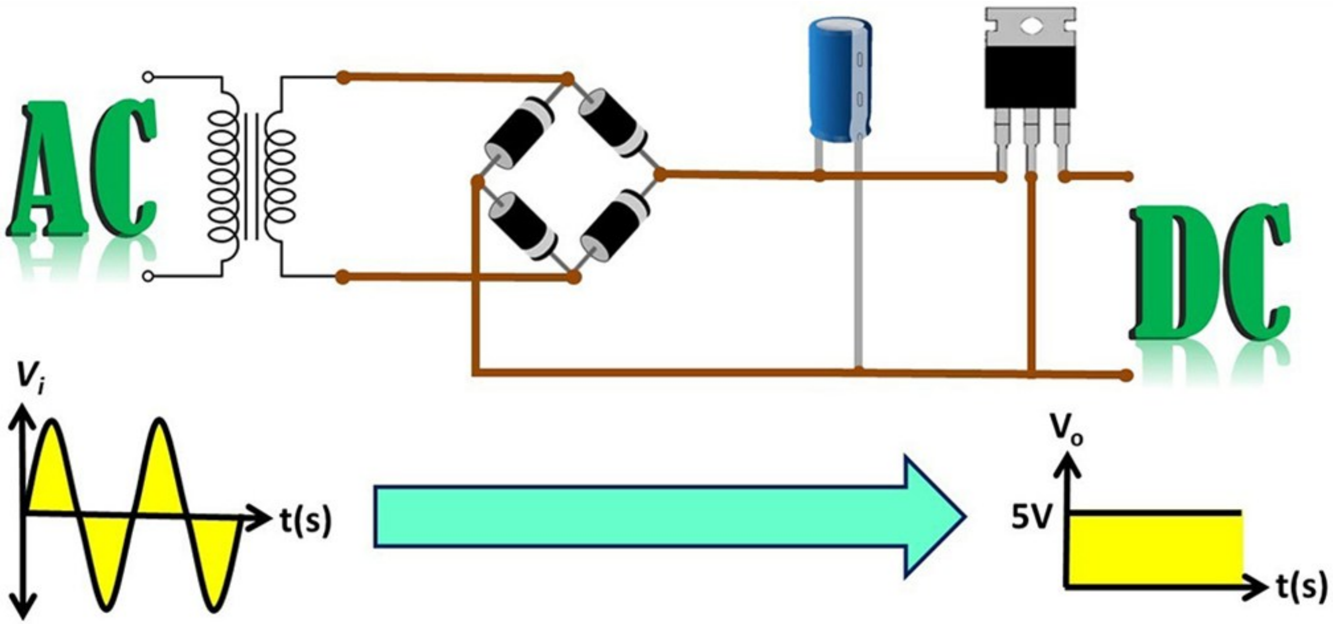
This is the maximum rated power the diode can tolerate. It is the product of Zener voltage and the current flowing through it. The power ratings of the Zener diode can range between **400 mW and 5 W**.

Zener Resistance

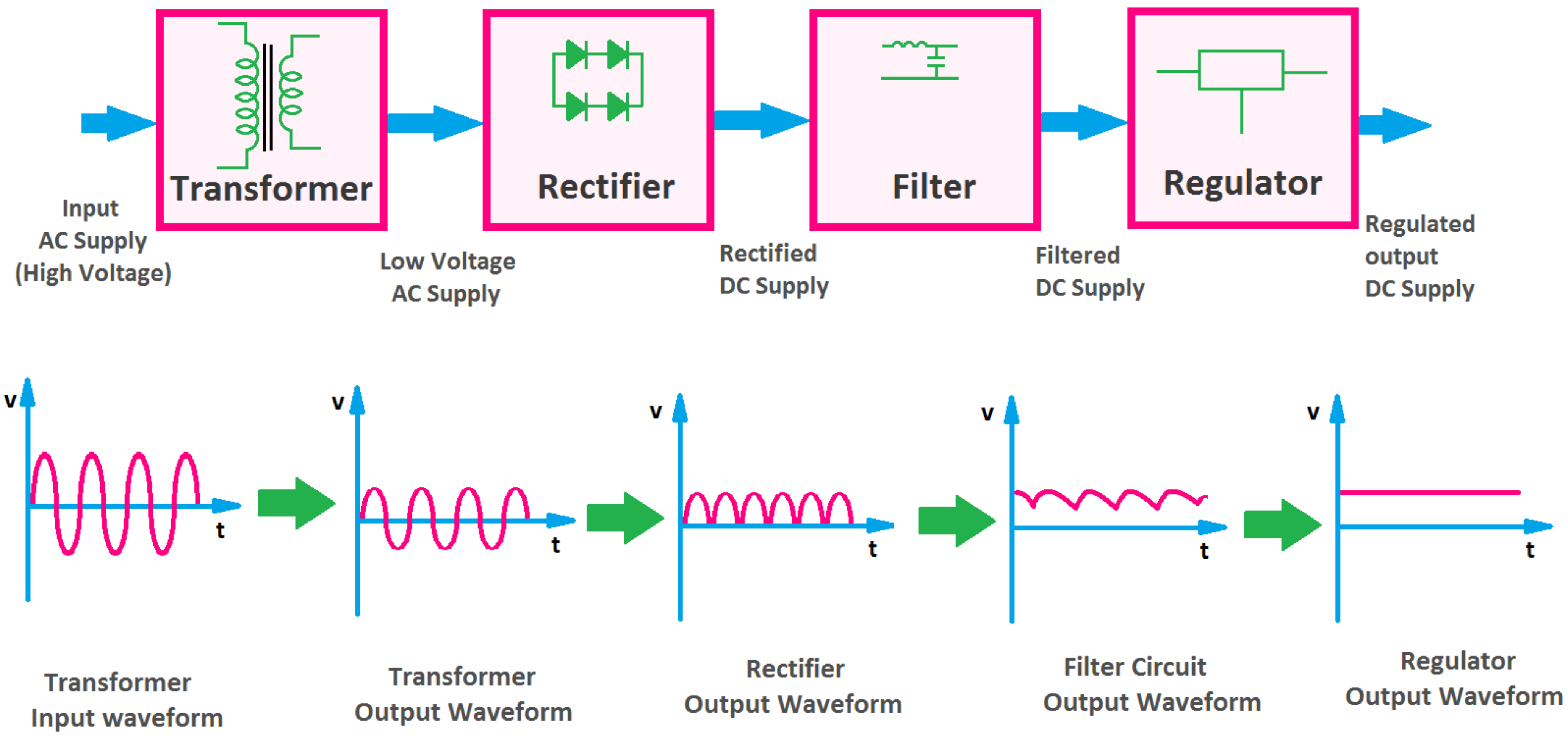
The Zener resistance is the resistance of the diode in the ON state (Zener breakdown region).

Rectifiers

- The application of rectifier circuits is in the conversion of AC to DC power. A circuit that accomplishes this conversion is usually called a DC power supply.
- Many familiar electrical and electronic appliances (e.g., radios, personal computers, TVs) require DC power to operate. For most applications, it is desirable that the DC supply to be as steady and ripple-free as possible.



Regulated Power supply diagram

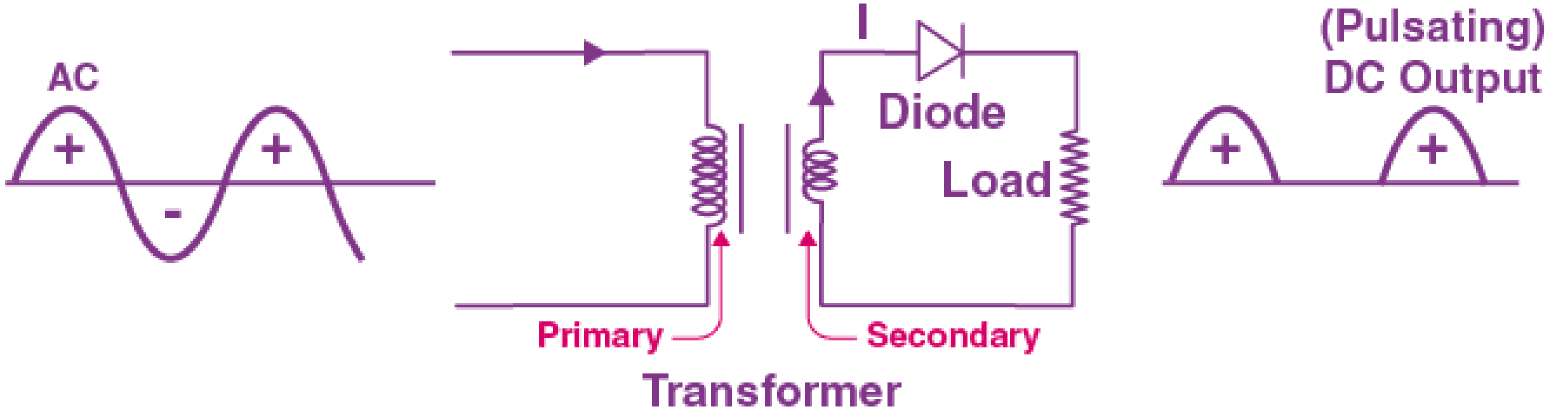


Classification of Rectifiers / Half-wave Rectifier

- Half – Wave Rectifier
- Full Wave Rectifier
  - Center-Tapped FWR
  - Bridge Rectifier

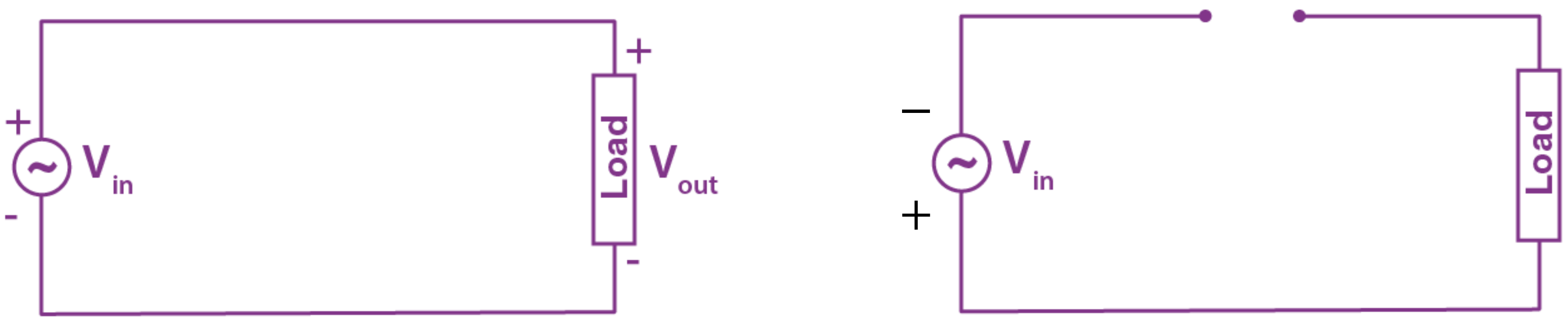
Half Wave Rectifier

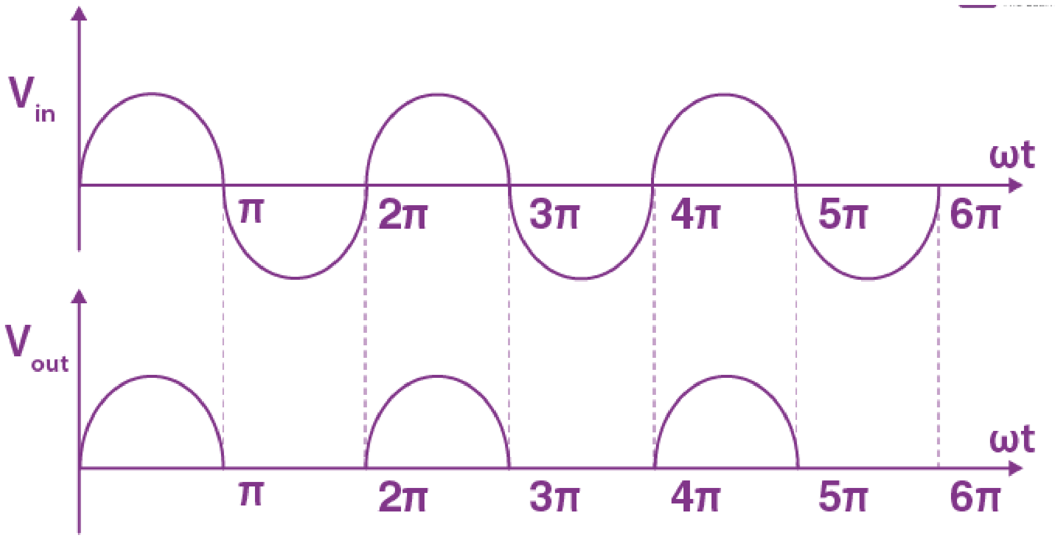
- A high AC voltage is applied to the primary side of the step-down transformer. The obtained secondary low voltage is applied to the diode.
- The diode is forward biased during the positive half cycle of the AC voltage and reverse biased during the negative half cycle.



Half-wave Rectifier working

When the diode is forward biased, it acts as a closed switch. But, during the negative half cycle of the AC source voltage, the equivalent circuit becomes an open switch





Half Wave Rectifier Formula

RMS Voltage (V_{rms}): To find out the RMS voltage of a half-wave rectifier, then

$$\boxed{V_{rms} = V_m/2}$$

Average DC Output Voltage (V_{dc}): The formula for the average DC output voltage (Vdc) of a half-wave rectifier is,

$$\boxed{V_{dc} = V_m/\pi}$$

Form Factor: It represent the ratio of rms voltage to the DC voltage

$$\boxed{\mathrm{FF} = \frac{V_{rms}}{V_{dc}}}$$

Form Factor is always ≥ 1 for square wave it is > 1

Ripple Factor :

Ripple factor determines how well a halfwave rectifier can convert AC voltage to DC voltage. It measures the percentage of ac component in the rectified output.

$$\boxed{\Upsilon = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}}$$

The ripple factor for HWR is **1.21**

Ideally Ripple factor value should be zero

Rectifier Efficiency (η): Rectifier efficiency (η) is the ratio of DC power output to AC power input. So, the formula for rectifier efficiency is: $\eta = (P_{dc}/P_{ac}) \times 100$

$$= (P_{load}/P_{in}) \times 100$$

$$= \left(I_{dc}{}^{2} * R / I_{rms}{}^{2} * R\right) \times 100$$

$$= 4 / \pi^{2} * 100$$

$$\eta \approx 40.6\%$$

Peak Inverse Voltage (PIV): It is a maximum reverse bias voltage that can eb applied across a diode before entering to breakdown region.

In a half-wave rectifier, the peak inverse voltage (PIV) is simply equal to the peak value of the AC input voltage.

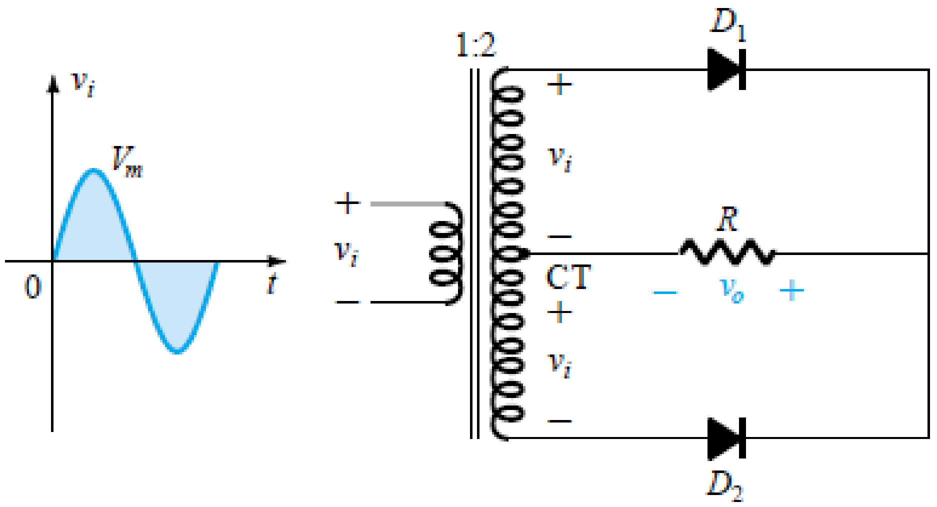
$$\text{PIV} = V_m$$

Center tapped Full Wave Rectifier

A full-wave rectifier converts an ac voltage into a pulsating dc voltage using both half cycles of the applied ac voltage.

This rectifier circuit designed with an AC source, two diodes, a load resistor & a center tapped transformer.

The two diodes are connected to the two ends of a center-tapped transformer.

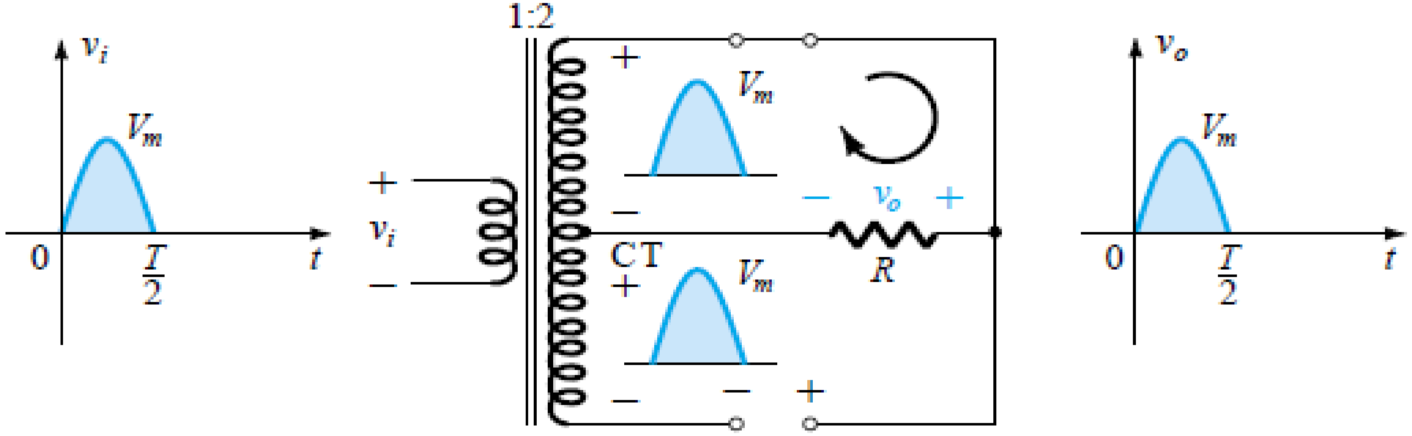


Center-tapped transformer full-wave rectifier

During the positive portion of Vi applied to the primary of the transformer, the network will appear as shown in Fig. 6

D1 - Forward biased- short-circuit

D2 – Reverse biased- open-circuit



Network conditions for the positive region of *vi*.

Center tapped Full Wave Rectifier

During the negative portion of the input the network appears as shown in Fig.7

D1 – Reverse biased- open-circuit

D2 - Forward biased- short-circuit

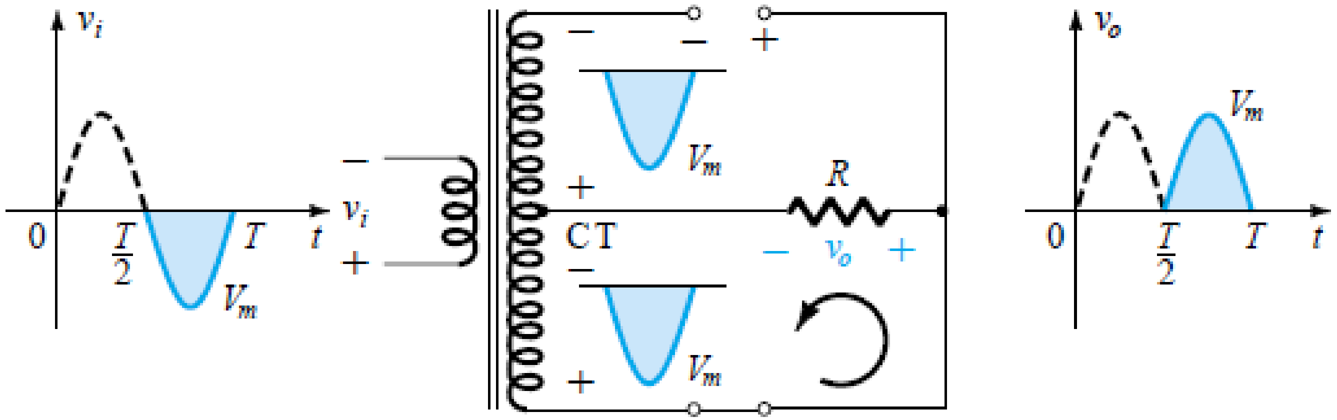
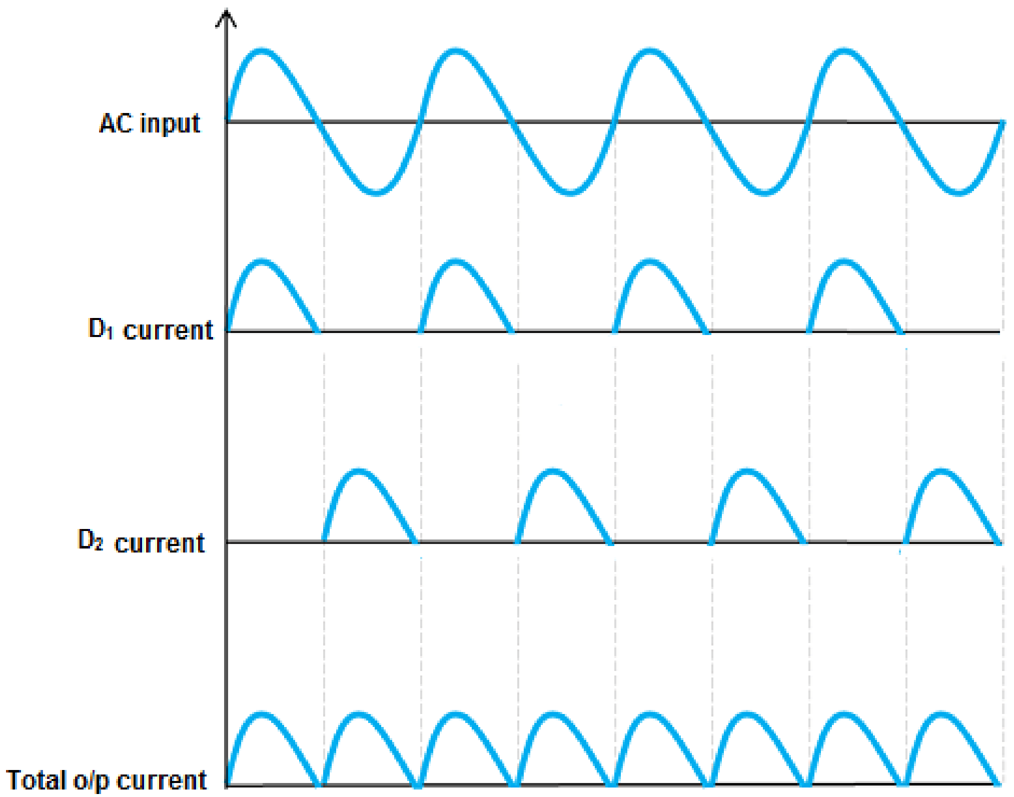


Fig 7 Network conditions for the negative region of vi.

Center tapped FWR Input and output wave forms



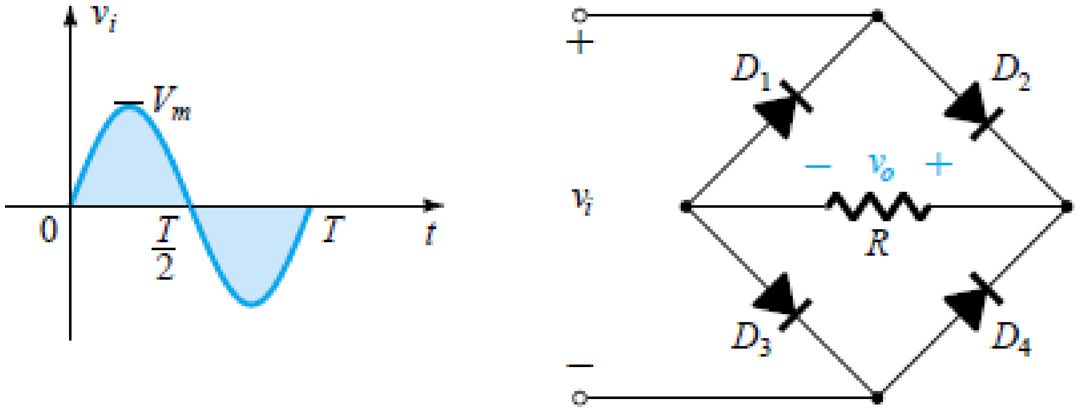
The main **advantage** is that the output and efficiency are high because an AC supply delivers power during both half cycles.

- The **Disadvantages** is Each diode utilizes only one-half of the voltage developed in the transformer secondary, and thus the DC output obtained is small.
- It is difficult to locate the center on the secondary for the tapping.
- The diode used must be capable of bearing high peak inverse voltage. The PIV is 2V.

Bridge Rectifier

This type of full wave rectifier uses **four diodes connected in a bridge configuration** to produce the desired output.

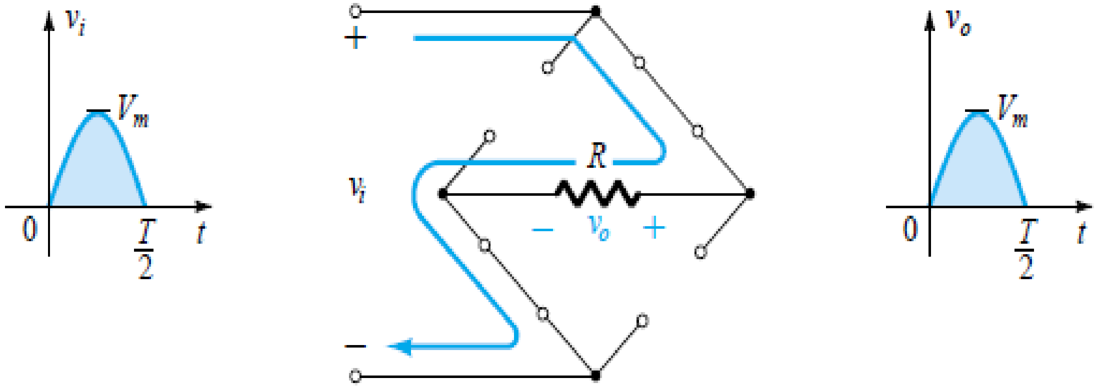
The main advantage of this bridge circuit is that it does not require a special centre tapped transformer, thereby reducing its size and cost. Four diodes labeled D_1 to D_4 are arranged with only two diodes conducting current during each half cycle



Full Wave Bridge Rectifier

During +ve half cycle:

Diodes D2 and D3 conduct in series while diodes D1 and D4 are reverse biased and the current flows through the load

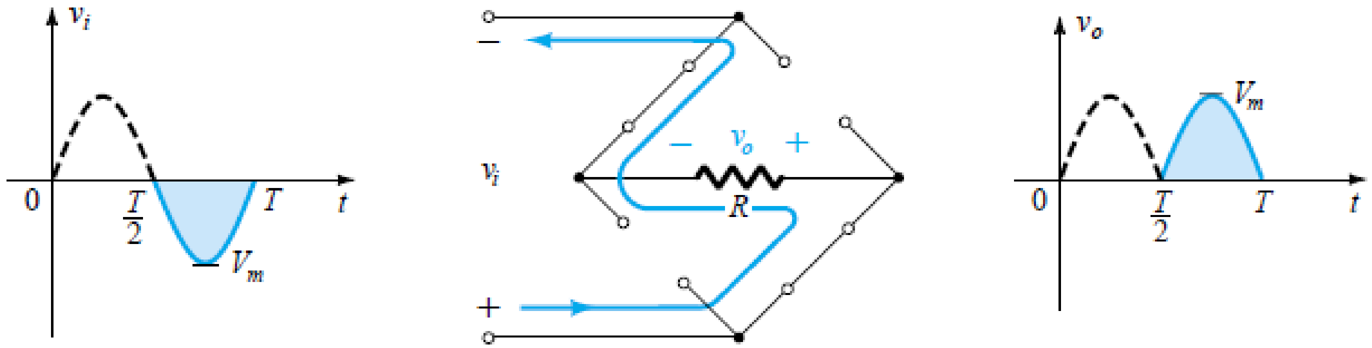


Bridge Rectifier Conti.

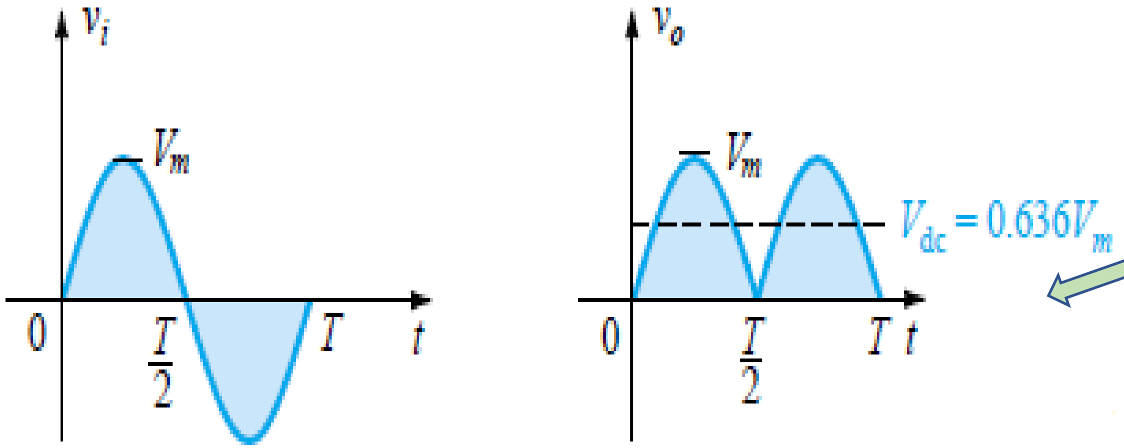
During -ve half cycle:

During the negative half cycle of the supply, diodes D1 and D4 conduct in series but diodes D2 and D 3 switch "OFF" as they are reverse biased.

The current flowing through the load is the same direction as before.



Conduction path for the negative region of V_i



Over one full cycle the input and output voltages will appear as shown

Input and output waveforms for a full-wave rectifier

Bridge Rectifier Conti.

The DC output it gives is not perfect from half/full wave rectifier — it still has some waves in it. That’s where filters come in.

Without Filter

When we use a full wave rectifier without a filter, the output is not pure DC. It still has a lot of ripples, or small up-and-down variations.

Problems:

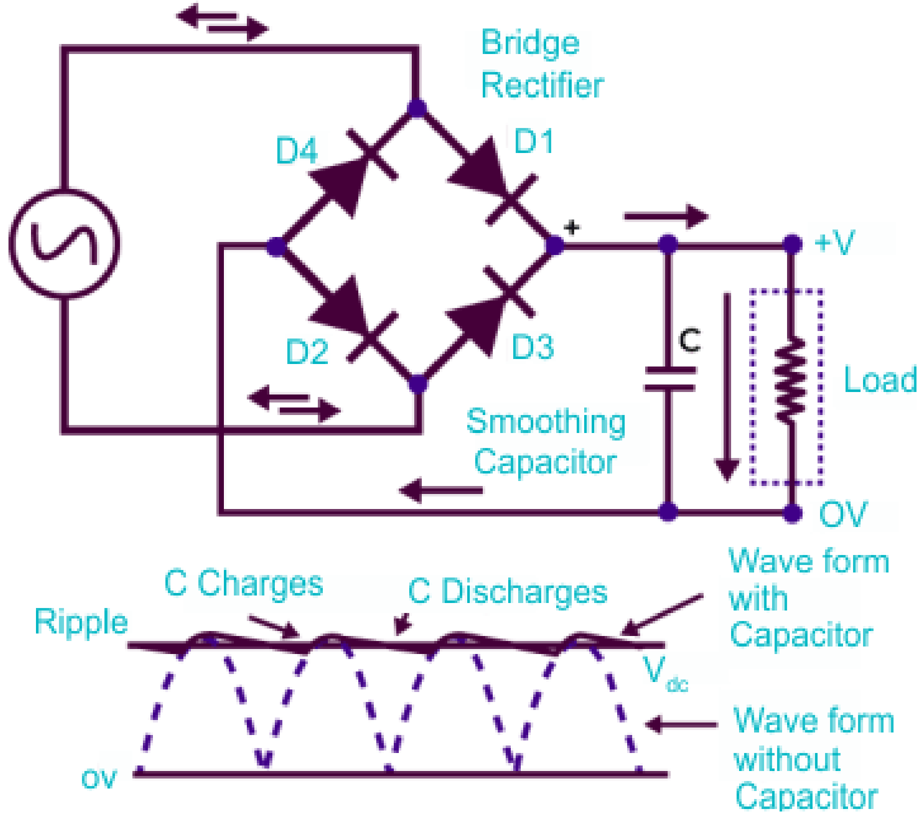
Such output can damage sensitive electronic devices.

With Filter

When we connect a **filter**, such as a capacitor, to the rectifier, the output becomes much smoother. The capacitor stores and releases energy to reduce the ripple. The output is almost a flat line — like pure DC. The voltage stays more steady.

How it works:

The filter charges when the voltage rises and It discharges slowly when the voltage falls. This helps keep the voltage from dropping too low between cycles.



$$V_{p-p} = \frac{V_m}{2fR_LC}$$

Analysis of Full-Wave Rectifier

Peak Current

The value of peak current (I_{max}) can be derived with the help of instantaneous value of applied voltage and the resistance of the diodes. The value of instantaneous voltage applied to the rectifier circuit can be given as:-

$$\boxed{V_s = V_{smax} sin\omega t}$$

Let's assume the forward resistance - R_f , load resistor R_L then the current flowing through the load resistor can be given as:-

$i_1 = I_{max} sin\omega t$ and $i_2 = 0$ for first half of AC cycle

and $i_1 = 0$ and $i_2 = I_{max} sin\omega t$ for second half of AC cycle

The total current i can be obtained by the sum of i_1 and i_2 for the whole cycle.

$$i = i_1 + i_2 = I_{max} sin\omega t$$

$$\boxed{I_{max} = \frac{V_{smax}}{R_f + R_L}}$$

Output Current

The current through the load is the same for both the cycles of the ac signal thus, the dc output current

$$I_{dc} = \frac{1}{\pi}\int_0^{\pi} i_1 \, d(\omega t)$$

$$I_{dc} = \frac{1}{\pi}\left[\int_0^{\pi} I_{max} \sin \omega t \; d(\omega t)\right]$$

$$I_{dc} = \frac{2I_{max}}{\pi}$$

Analysis of Full-Wave Rectifier Cont.

DC output voltage

The average dc voltage is given as $$V_{dc} = I_{dc}R_L = \frac{2I_{max}\,R_L}{\pi}$$

RMS Current

The rms current through the load R_L is given as

$$I_{rms}^2 = \frac{1}{\pi}\int_0^{\pi} i^2 \; d(\omega t)$$

$$I_{rms}^2 = \frac{1}{\pi}[\int_0^{\pi} I_{max}^2 \, sin^2\omega t \; d(\omega t)]$$

$$I_{rms}^2 = \frac{I_{max}^2}{2}$$

$$I_{rms} = \frac{I_{max}}{\sqrt{2}}$$

RMS Voltage: The rms value of a voltage across the load is given as

$$V_{L\,rms} = I_{rms}R_L = \frac{I_{max}\,R_L}{\sqrt{2}}$$

Form factor

The form factor is the ratio of rms value to the dc output value of current. It is given as

$$K_f = \frac{RMS\ value}{Average\ value} = \frac{I_{rms}}{I_{dc}}$$

$$K_f = \frac{I_{max}/\sqrt{2}}{2I_{max}/\pi} = \frac{\pi}{2\sqrt{2}} = 1.11$$

Peak factor

It is the ratio of the peak value of current to the rms value of current

$$K_p = \frac{Peak\ value}{RMS\ value} = \frac{I_{max}}{I_{max}\ /\ \sqrt{2}}$$

$$K_p = \sqrt{2}$$

Ripple factor

$$\Upsilon = \sqrt{K_f^2 - 1}$$

$$\Upsilon = \sqrt{(1.11)^2 - 1}$$

$$\Upsilon = 0.482$$

Analysis of Full-Wave Rectifier Cont.

The **peak inverse voltage (PIV)** of the diode is the peak value of the voltage that a diode can withstand when it is reversed biased .The peak inverse voltage of diode in center tapped full wave rectifier is 2 Vsmax and Bridge rectifier is Vsmax.

Rectification Efficiency: The rectification efficiency of full wave rectifier can be obtained by the ratio of dc power delivered to load and ac power present in the output $\boxed{\eta = \frac{P_{dc}}{P_{ac}}}$

For bridge rectifier, $\boxed{\eta = \frac{0.812}{1+\frac{R_F}{R_L}}}$

Advantages of Full Wave Rectifiers

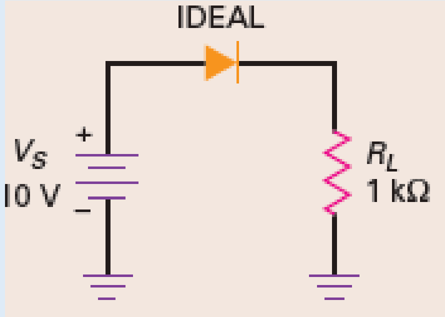
- The rectification efficiency of FWR is much higher than that of HWR. It is approximately double to that of HWR i.e. 81%.
- The filtering circuit required in FWR is simple because ripple factor is very low as compared to that of HWR . The value of ripple factor in FWR is 0.482 while in HWR it is about 1.21.
- The output voltage and output power obtained in full wave rectifiers are much more than that of half wave rectifiers.

Disadvantages of Full Wave Rectifiers

- The full wave rectifiers need more circuit elements than half wave rectifier which makes it costlier

Problem

Use the ideal diode model to calculate the load voltage and load current in the circuit.



Since the diode is forward biased, it is equivalent to a closed switch. :

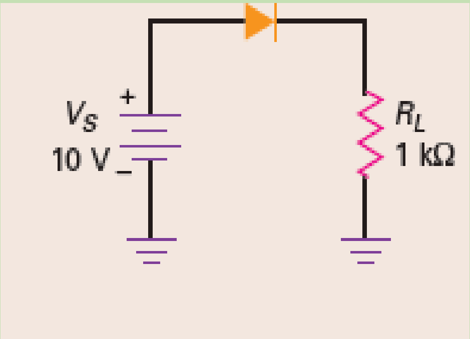
V_s= 10 V

With Ohm's law, the load current is:

$$I_L = \frac{10\text{ V}}{1\text{ k}\Omega} = 10\text{ mA}$$

Use Constant voltage drop model to calculate the load voltage and load current,

Solution



Since the diode is forward biased, it is equivalent to a battery of 0.7 V.

VL =10 V - 0.7 V =9.3 V

With Ohm's law, the load current is:

$$I_L = \frac{9.3\text{ V}}{1\text{ k}\Omega} = 9.3\text{ mA}$$

Problem

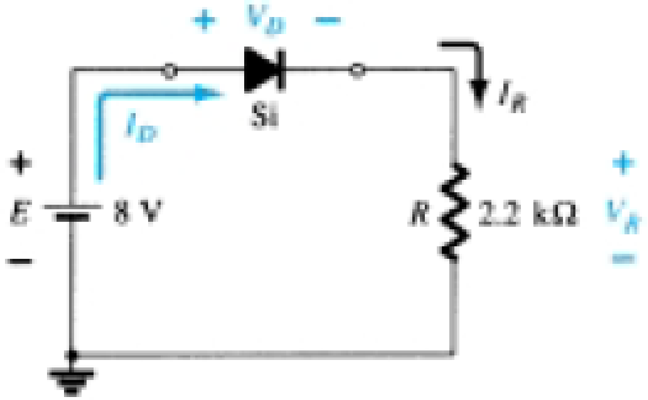
For the series diode configuration given in the Figure, determine V_D, V_R, and I_D.(Constant voltage drop model)

The diode is in the "on" state,

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

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

$$I_D = I_R = \frac{V_R}{R} = \frac{7.3\text{ V}}{2.2\text{ k}\Omega} \cong 3.32\text{ mA}$$



Q2. Calculate the thermal voltage when the temperature is 25°C.

a) 0V

b) 0V

c) 0.026V

d) 0.25V

Answer: b

Explanation: Thermal voltage V_T is given by k T/q

Where k is the boltzman constant and q is the charge of electron. This can be reduced to

$V_T = T_K/11600$

Therefore, V_T =

1. Calculate the forward bias current of a Si diode when forward bias voltage of 0.4V is applied, the reverse saturation current is 1.17×10^{-9}A and the thermal voltage is 25.2mV.

a) 9.156mA

b) 8.23mA

c) 1.256mA

d) 5.689mA

Answer: a

Explanation: Equation for diode current

$I=I_0\times(e^{(V/\eta V_T)}-1)$ where I_0 = reverse saturation current

η = ideality factor

V_T = thermal voltage

V = applied voltage

Since in this question ideality factor is not mentioned it can be taken as one.

$I_0 = 1.17 \times 10^{-9}$A, $V_T = 0.0252$V, $\eta = 1$, $V = 0.4$V

Therefore

Examples

3. Calculate the reverse saturation current of a diode if the current at 0.2V forward bias is 0.1mA at a temperature of 25°C and the ideality factor is 1.5.

a) 5.5×10^{-9} A

b) 5.5×10^{-8} A

c) 5.5×10^{-7} A

d) 5.6×10^{-10} A

Answer: c

Explanation: Equation for diode current

$I=I_0\times(e^{(V/\eta V_T)}-1)$ where I_0 = reverse saturation current

η = ideality factor

V_T = thermal voltage

V = applied voltage

Here, $I = 0.1mA$, $\eta = 1.5$, $V= 0.2V$, $V_T = T_K/11600$

Therefore, V_T at $T= 25+273=298$ is $298/11600 = 0.0256V$.

Therefore, reverse saturation current $I_0 = 0.1 \times \frac{10^{-3}}{e^{\frac{0.2}{1.5\times0.0256}}-1}$

$I_O=0.00055mA = 5.5\times10^{-7}A$.

Examples

4. Find the applied voltage on a forward biased diode if the current is 1mA and reverse saturation current is 10^{-10}. Temperature is 25°C and take ideality factor as 1.5.

a) 0.68V

b) 0726V

c) 0.526V

d) 0.618V

Answer: d

Explanation: Equation for diode current

$I=I_0\times(e^{(V/\eta V_T)}-1)$ where I_0 = reverse saturation current

η = ideality factor

V_T = thermal voltage

V = applied voltage

V_T at T= 25+273=298 is 298/11600 = 0.0256V, η = 1.5, I = 1mA, $I_0 = 10^{-10}$A

$$V = \eta V_T \ln\left(\left(\frac{I}{I_0}\right)+1\right) = 1.5\times 0.0256\times \ln\left(\frac{10^{-3}}{10^{-10}}+1\right) = 0.618V$$

Examples

5. Find the temperature at which a diode current is 2mA for a diode which has reverse sat on current of 10^{-9} A. The ideality factor is 1.4 and the applied voltage is 0.6V forward bias.

a) 69.65°C

b) 52.26°C

c) 25.23°C

d) 70.23°C

Answer: a

Explanation: Equation for diode current

$I=I_0\times(e^{(V/\eta V_T)}-1)$ where I_0 = reverse saturation current

η = ideality factor

V_T = thermal voltage

V = applied voltage

I_0 = 10-9A, η = 1.4, V =0.6V, I = 2mA

Thermal voltage

We know thermal voltage $V_T = T_K/11600$ .Therefore, $T_K = V_T x11600 = 0x11600 = 342.65K$ = 69.65°C.

Examples

Q3. A crystal diode having internal resistance rf = 20Ω is used for half-wave rectification. If the applied voltage v = 50 sin ω t and load resistance RL= 800 Ω, find :
(i) Im, Idc, Irms (ii) a.c. power input and d.c. power output (iii) d.c. output voltage (iv) efficiency of rectification.

Solution :

$$v = 50 \sin \omega t$$

$$\therefore \quad \text{Maximum voltage, } V_m = 50 \text{ V}$$

(i)

$$I_m = \frac{V_m}{r_f + R_L} = \frac{50}{20 + 800} = 0.061 \text{ A} = \mathbf{61 \text{ mA}}$$

$$I_{dc} = I_m/\pi = 61/\pi = \mathbf{19.4 \text{ mA}}$$

$$I_{rms} = I_m/2 = 61/2 = \mathbf{30.5 \text{ mA}}$$

(ii)

$$\text{a.c. power input} = (I_{rms})^2 \times (r_f + R_L) = \left(\frac{30.5}{1000}\right)^2 \times (20 + 800) = \mathbf{0.763 \text{ watt}}$$

$$\text{a.c. power input} = (I_{rms})^2 \times (r_f + R_L) = \left(\frac{30.5}{1000}\right)^2 \times (20 + 800) = \mathbf{0.763 \text{ watt}}$$

$$\text{d.c. power output} = I_{dc}^2 \times R_L = \left(\frac{19.4}{1000}\right)^2 \times 800 = \mathbf{0.301 \text{ watt}}$$

(iii)

$$\text{d.c. output voltage} = I_{dc} R_L = 19.4 \text{ mA} \times 800 \, \Omega = \mathbf{15.52 \text{ volts}}$$

(iv)

$$\text{Efficiency of rectification} = \frac{0.301}{0.763} \times 100 = \mathbf{39.5\%}$$

Examples

Q4. A half-wave rectifier is used to supply 50V d.c. to a resistive load of 800 Ω. The diode has a resistance of 25 Ω. Calculate a.c. voltage required.

Solution :

Solution :

Output d.c. voltage, $V_{dc} = 50\text{ V}$

Diode resistance, $r_f = 25\ \Omega$

Load resistance, $R_L = 800\ \Omega$

Let V_m be the maximum value of a.c. voltage required.

$$\therefore \quad V_{dc} = I_{dc} \times R_L$$

$$= \frac{I_m}{\pi} \times R_L = \frac{V_m}{\pi(r_f + R_L)} \times R_L \qquad \left[\because I_m = \frac{V_m}{r_f + R_L}\right]$$

or
$$50 = \frac{V_m}{\pi(25 + 800)} \times 800$$

$$\therefore \quad V_m = \frac{\pi \times 825 \times 50}{800} = \mathbf{162\ V}$$

Hence a.c. voltage of maximum value 162 V is required.

Q5. A full-wave rectifier uses two diodes, the internal resistance of each diode may be assumed constant at 20 Ω. The transformer r.m.s. secondary voltage from centre tap to each end of secondary is 50 V and load resistance is 980 Ω. Find : (i) the mean load current (ii) the r.m.s. value of load current.

Solution :

$$r_f = 20\ \Omega, \quad R_L = 980\ \Omega$$

$$\text{Max. a.c. voltage, } V_m = 50 \times \sqrt{2} = 70.7\ \text{V}$$

$$\text{Max. load current, } I_m = \frac{V_m}{r_f + R_L} = \frac{70.7\ \text{V}}{(20 + 980)\ \Omega} = 70.7\ \text{mA}$$

(i)

$$\text{Mean load current, } I_{dc} = \frac{2\,I_m}{\pi} = \frac{2 \times 70.7}{\pi} = \mathbf{45\ mA}$$

(ii)

R.M.S. value of load current is

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{70.7}{\sqrt{2}}\overline{AB} = \mathbf{50\ mA}$$

Q6. In the centre-tap circuit shown in Fig. 2, the diodes are assumed to be ideal i.e. having zero internal resistance. Find :(i) d.c. output voltage(ii) peak inverse voltage (iii) rectification efficiency.

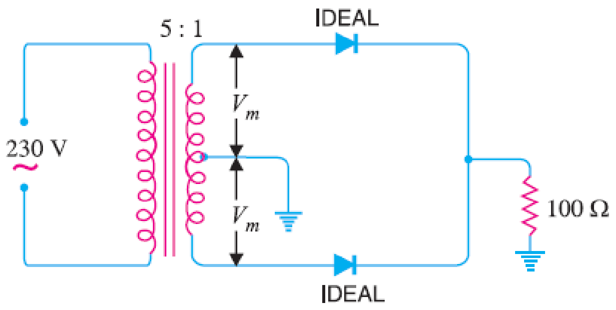


Fig. 2

Solution :

Primary to secondary turns, N1 / N2 = 5

R.M.S. primary voltage = 230 V

∴ R.M.S. secondary voltage

$= 230 \times (1/5) = 46$ V

Maximum voltage across secondary

$= 46 \times \sqrt{2} = 65$V

Maximum voltage across half secondary winding is

$V_m = 65/2 = 32.5$ V

(i) Average current, Idc =

$$\frac{2V_m}{\pi R_L} = \frac{2 \times 32.5}{\pi \times 100} = 0.207 \text{ A}$$

(ii) The peak inverse voltage is equal to the maximum secondary voltage, i.e

$$PIV = 65 \text{ V}$$

(iii)

$$\text{Rectification efficiency} = \frac{0.812}{1 + \frac{r_f}{R_L}}$$

Since $r_f = 0$

Rectification efficiency = **81.2 %**