GRADE XII
Physics
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CHAPTER 22: SEMICONDUCTOR DEVICES

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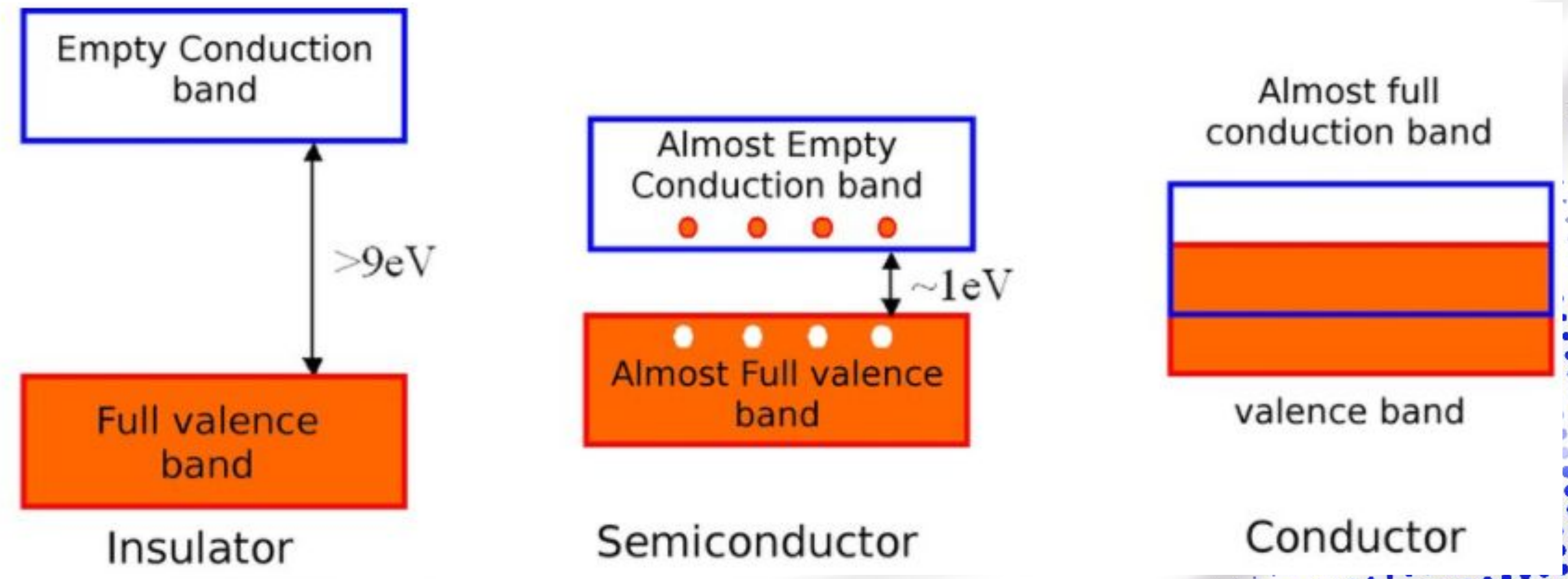
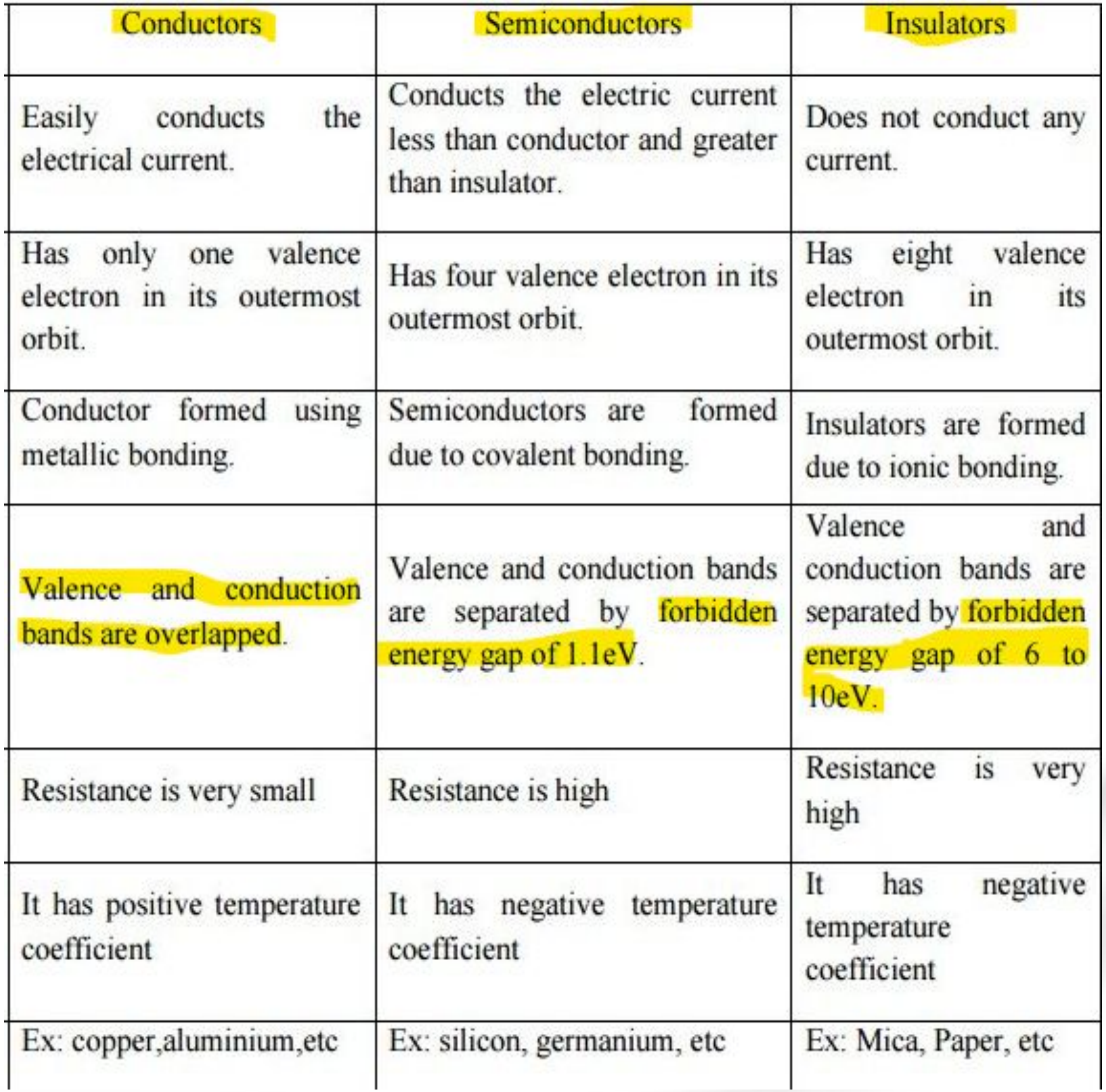
Revision

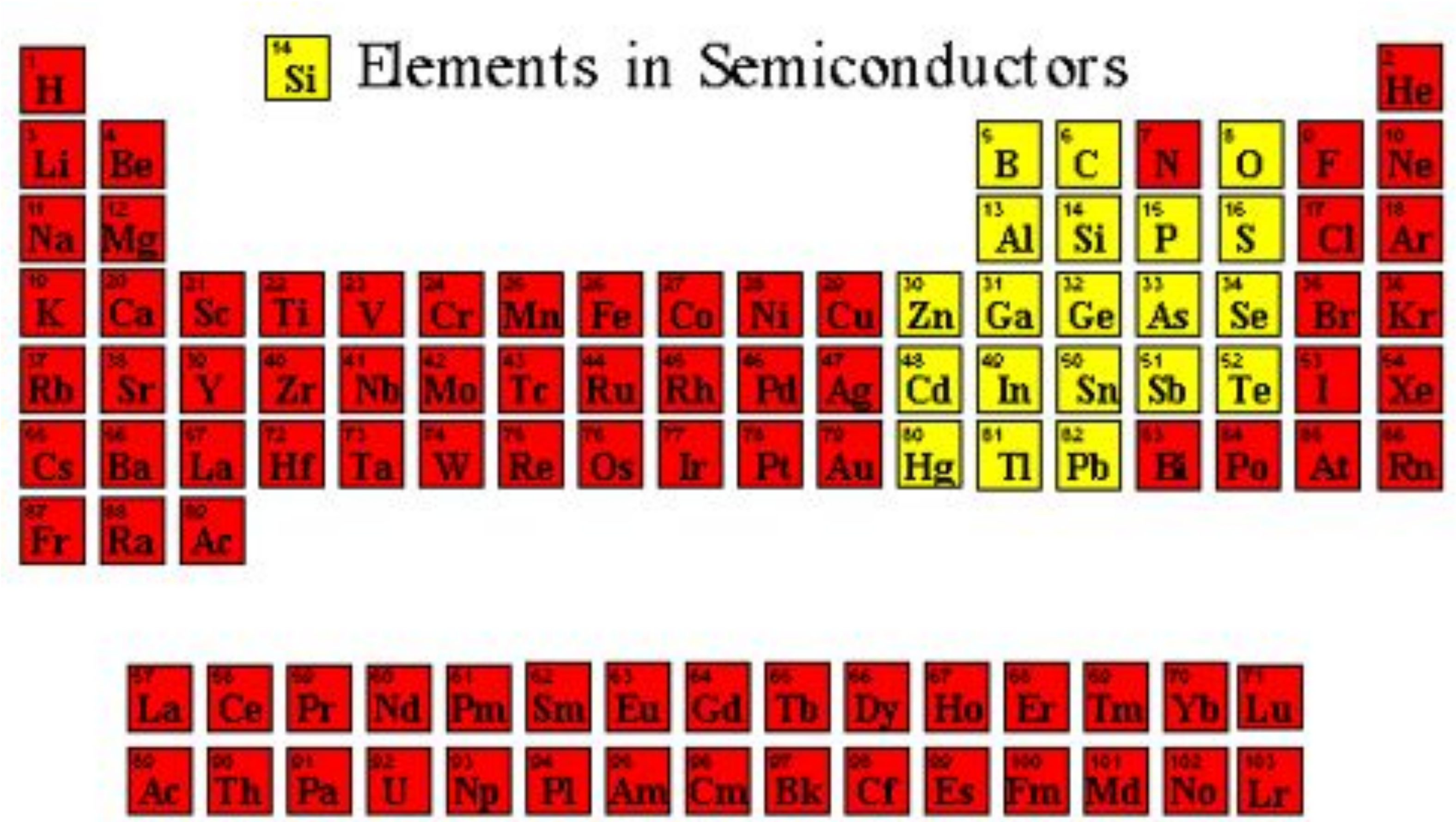
Differences between Metal, Insulator and Semiconductors on the basis of band theory





Conductors	Semiconductors	Insulators
Easily conducts the electrical current.	Conducts the electric current less than conductor and greater than insulator.	Does not conduct any current.
Has only one valence electron in its outermost orbit.	Has four valence electron in its outermost orbit.	Has eight valence electron in its outermost orbit.
Conductor formed using metallic bonding.	Semiconductors are formed due to covalent bonding.	Insulators are formed due to ionic bonding.
Valence and conduction bands are overlapped.	Valence and conduction bands are separated by forbidden energy gap of 1.1eV.	Valence and conduction bands are separated by forbidden energy gap of 6 to 10eV.
Resistance is very small	Resistance is high	Resistance is very high
It has positive temperature coefficient	It has negative temperature coefficient	It has negative temperature coefficient
Ex: copper,aluminium,etc	Ex: silicon, germanium, etc	Ex: Mica, Paper, etc

SEMICONDUCTORS



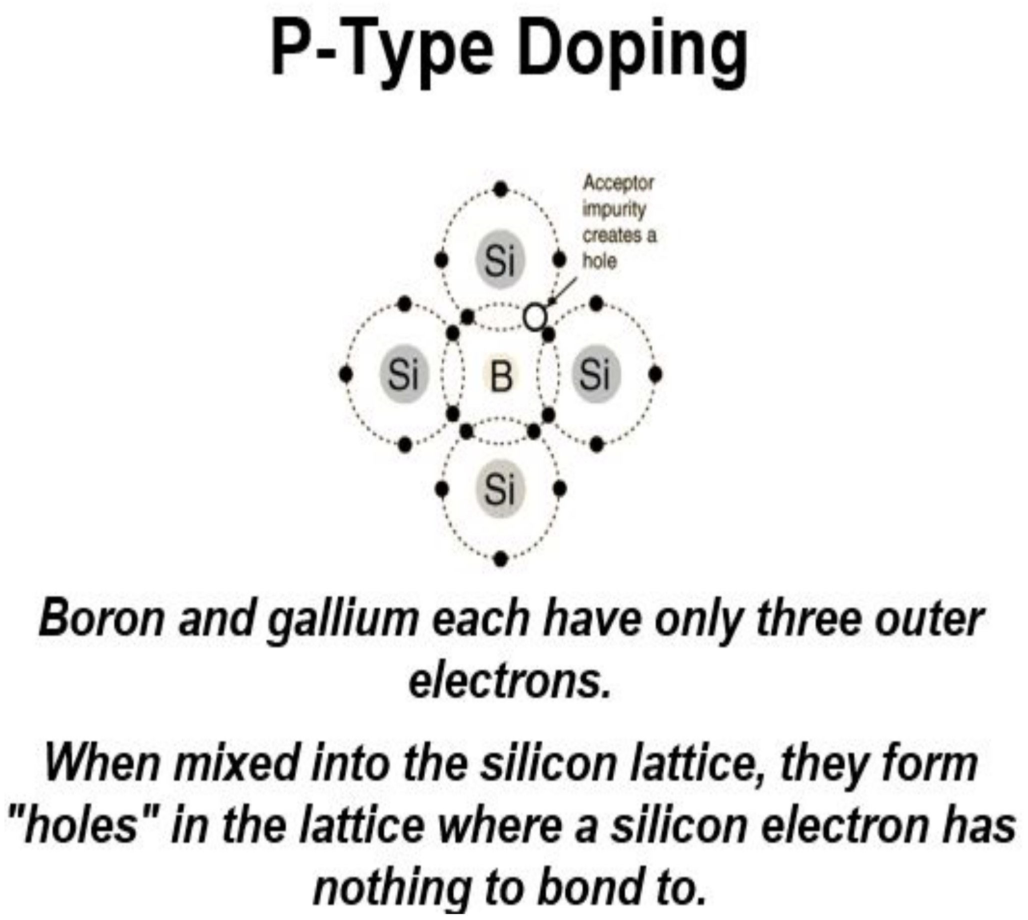
14 Si Elements in Semiconductors

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Ac	Th	Pa	U	Np	Pl	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

Doping

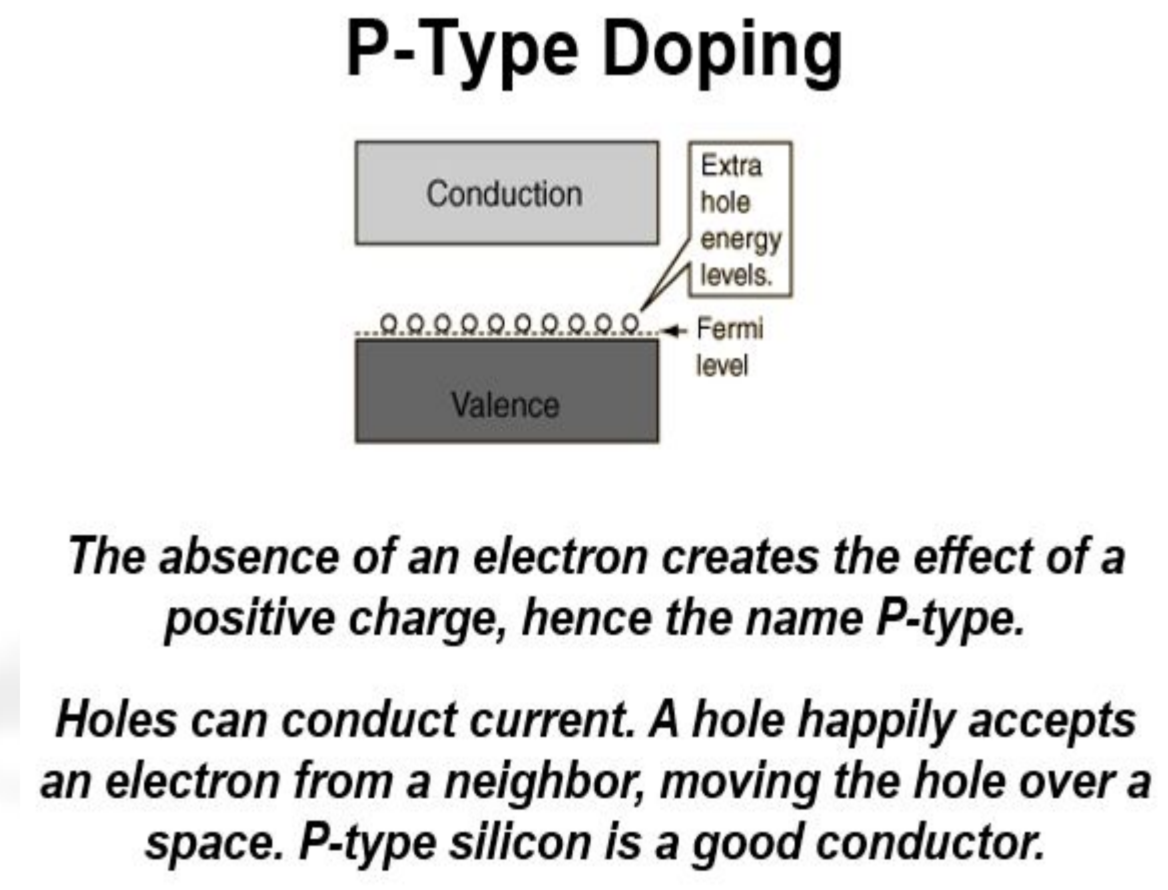
- Doping means adding impurities to pure semiconductor.



P-Type Doping

Boron and gallium each have only three outer electrons.

When mixed into the silicon lattice, they form "holes" in the lattice where a silicon electron has nothing to bond to.

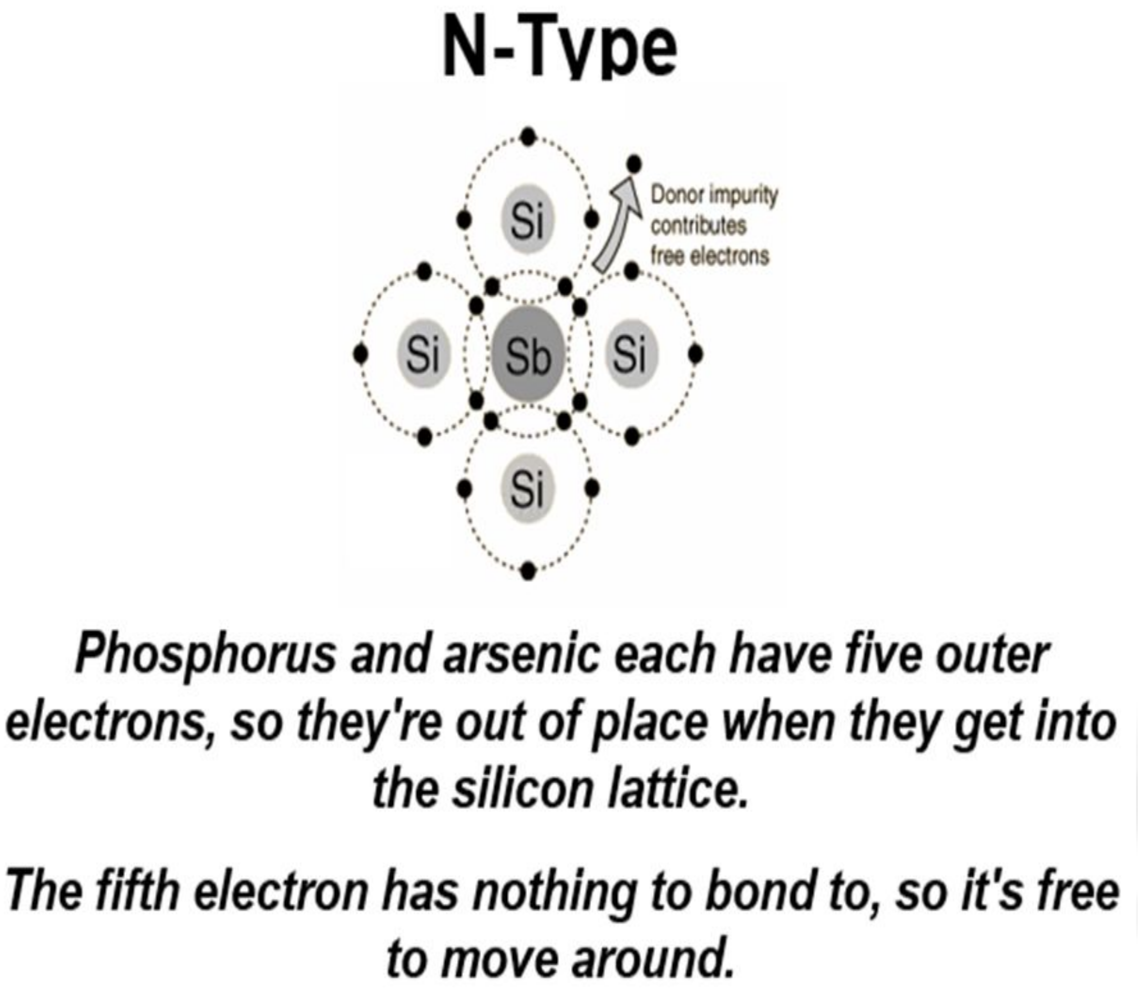


P-Type Doping

The absence of an electron creates the effect of a positive charge, hence the name P-type.

Holes can conduct current. A hole happily accepts an electron from a neighbor, moving the hole over a space. P-type silicon is a good conductor.

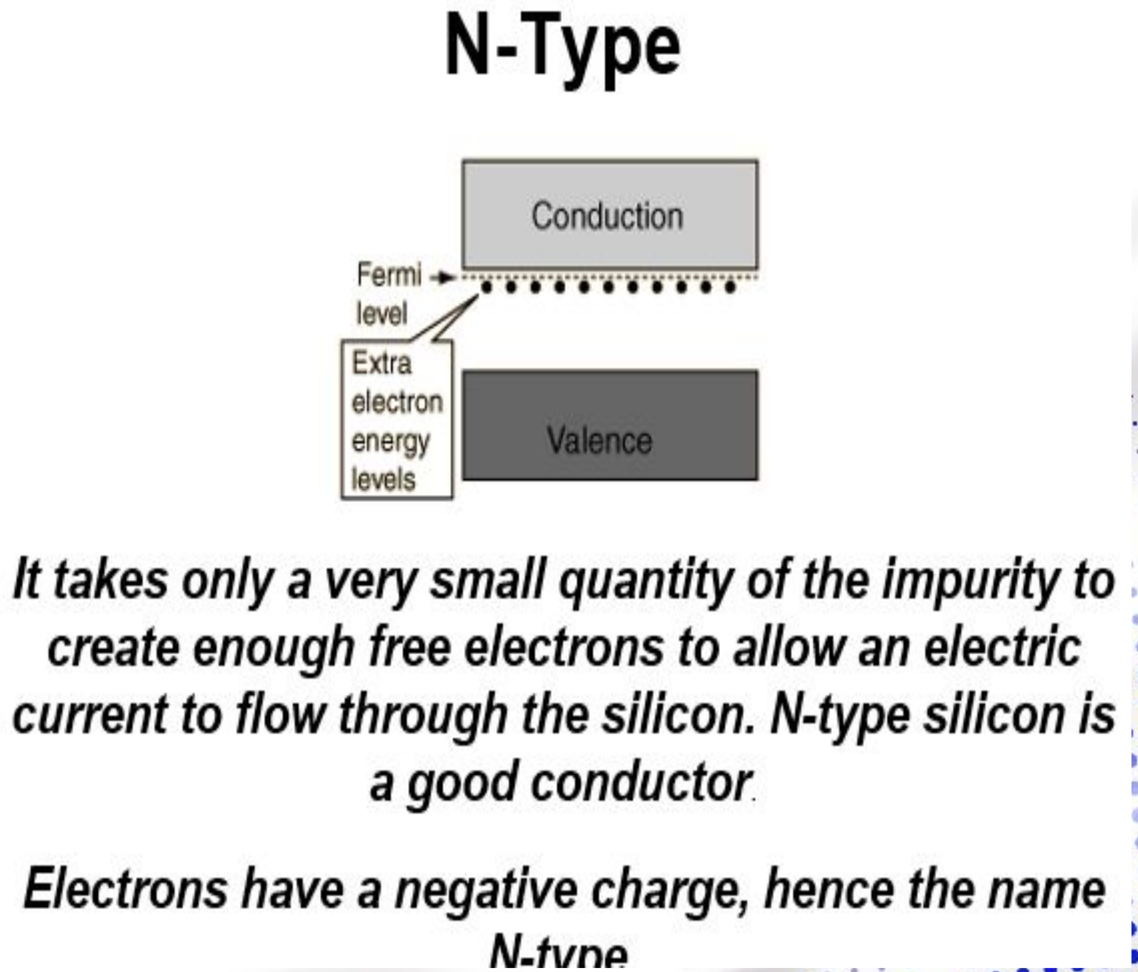
Doping



N-Type

Phosphorus and arsenic each have five outer electrons, so they're out of place when they get into the silicon lattice.

The fifth electron has nothing to bond to, so it's free to move around.



N-Type

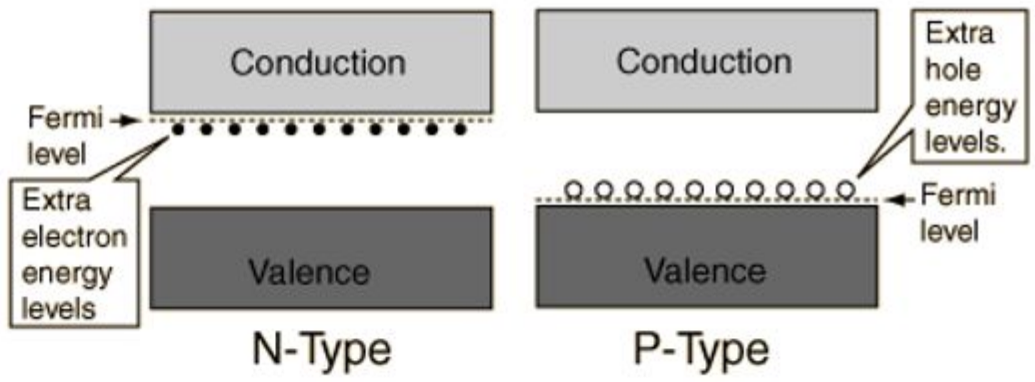
It takes only a very small quantity of the impurity to create enough free electrons to allow an electric current to flow through the silicon. N-type silicon is a good conductor.

Electrons have a negative charge, hence the name N-type

PN Junction

- An arrangement consisting a p -type semiconductor brought into a close contact with n-type semiconductor, is called a p -n junction.

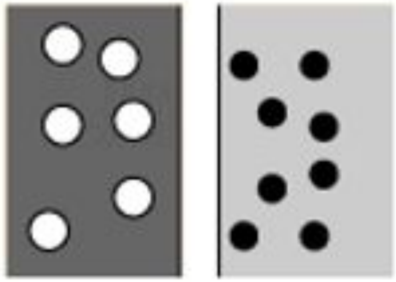
P-N Junction



In the n-type region there are extra electrons and in the p-type region, there are holes from the acceptor impurities .

P-N Junction

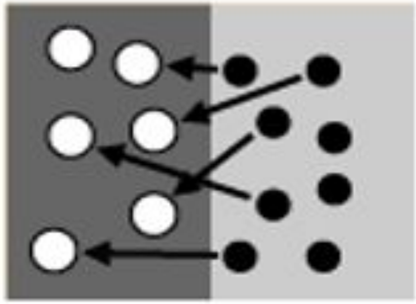
In the p-type region there are holes from the acceptor impurities and in the n-type region there are extra electrons.



● Electron ○ Hole ⊖ Negative ion from filling of p-type vacancy. ⊕ Positive ion from removal of electron from n-type impurity.

P-N Junction

When a p-n junction is formed, some of the electrons from the n-region which have reached the conduction band are free to diffuse across the junction and combine with holes.



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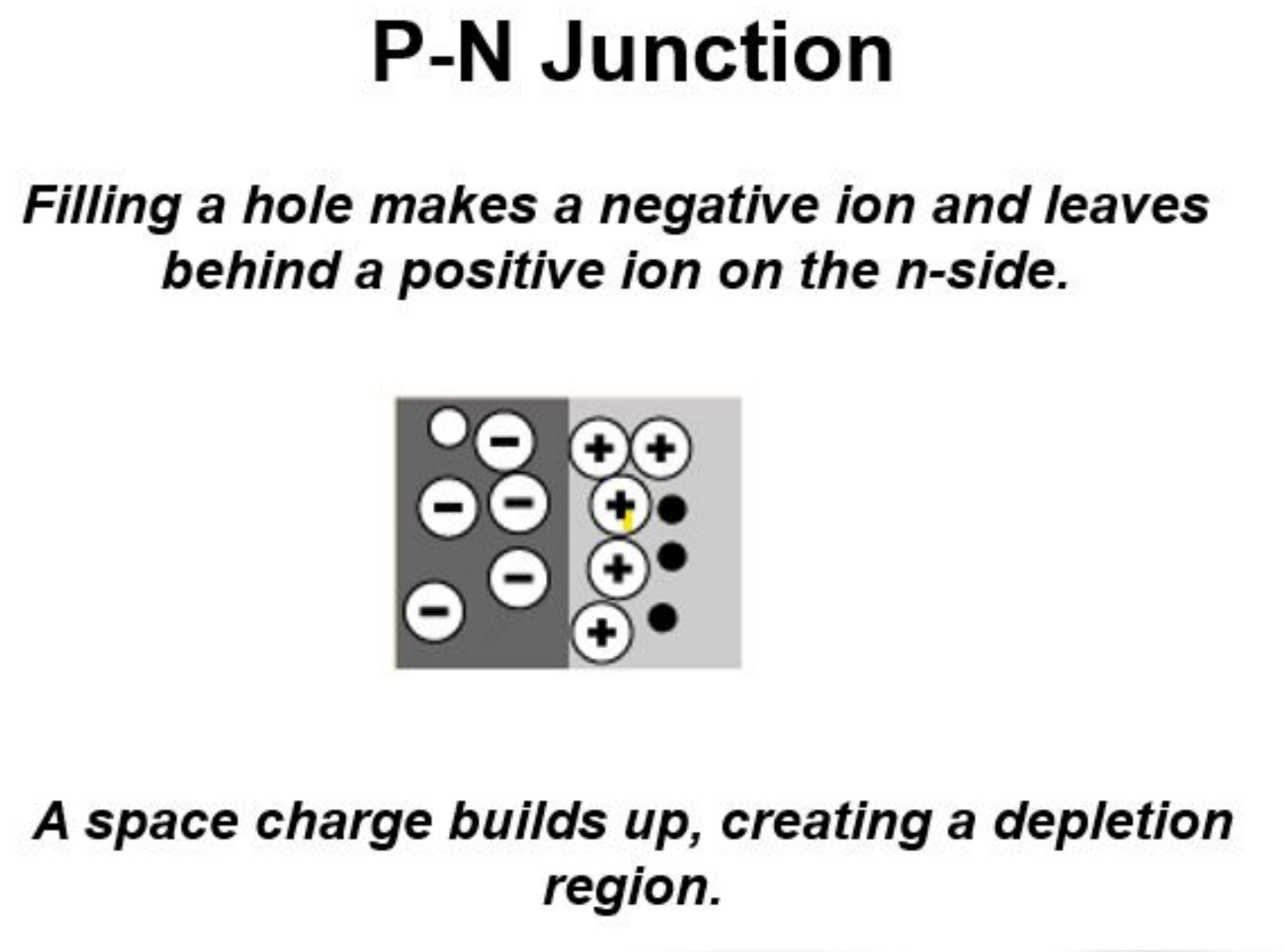


P-N Junction

Filling a hole makes a negative ion and leaves behind a positive ion on the n-side.

A space charge builds up, creating a depletion region.

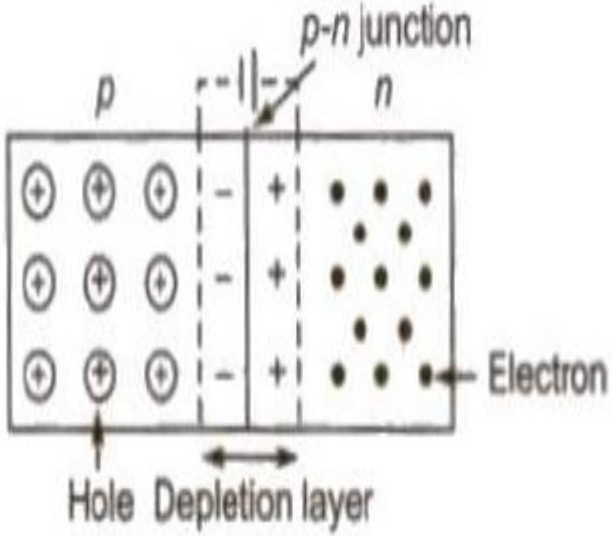
Contd....

- The concentration of holes is higher in P-region than N-region and concentration electrons is higher in N-region than in P-region.
- Due to these differences in concentrations of electrons and holes, charge gradients(change in concentration of charge per unit distance) are created.
- The charge gradient causes charge to diffuse. (holes diffuse from P to N-region and electrons diffuse from N to P-region)
- When electron from N-region diffuse into hole, it leaves behind a positive ion having lost one electron.
- Similarly, When hole from P-region diffuse into electron, it leaves behind a negative ion having gain one electron.
- In this way large number of electron-hole pairs diffuse across the junction, a number of immobile positive ion are created in the N-region and same number of negative immobile ions are created across P-region.

PN Junction

Depletion Layer and Barrier Potential

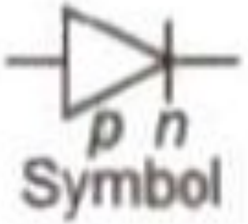
- The region at the junction in which the positive and negative ions gather separately and it is free from free mobile charge carriers is called depletion layer.
- When a depletion layer is formed at PN junction a number of positive charge stakes at one side and a number of negative ions stakes at other sides of junction.
- Since two stakes of positive and negative ions are separated by a small distance, electric field is set up in the depletion layer called barrier field.
- The barrier field then set up a potential difference across the depletion layer called barrier potential.
- This zone controls the behavior of diode.



Junction Diode

- It is the device in which P-type semiconductor and N-type semiconductor is placed in contact forming a junction between them.

  It is the simplest form of diode.



Biasing a diode

- When PN diode is connected to external source,

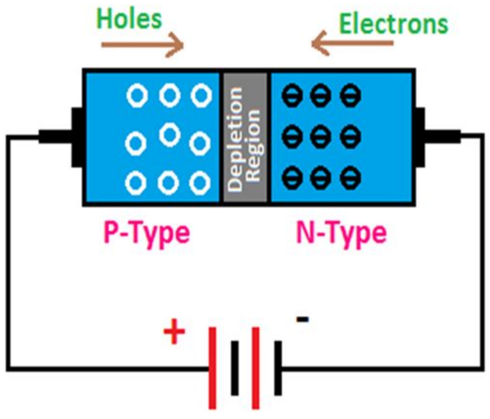
  it is ready for operation called biasing of diode.

Forward Biasing:

- In this biasing, the p -side is connected to

  positive terminal and n-side to negative terminal of a battery

Contd…



PN Junction Diode Forward Biasing

- The p-type region is connected to the positive terminal of the battery, the holes in the p-type region repel and move towards the junction.
- On the other hand, the n-type region is connected to the negative terminal of the battery, so electrons in the n-type region also repel and move towards the junction.
- As a result, the width of the depletion decreases and the potential barrier is broken down, so currents start flowing through the diode.
- The PN Junction diode act as a conductor and the flow of current depends upon the applied forward voltage.
- The diode offers very low resistance called forward resistance.
- Diode works as an close circuit.

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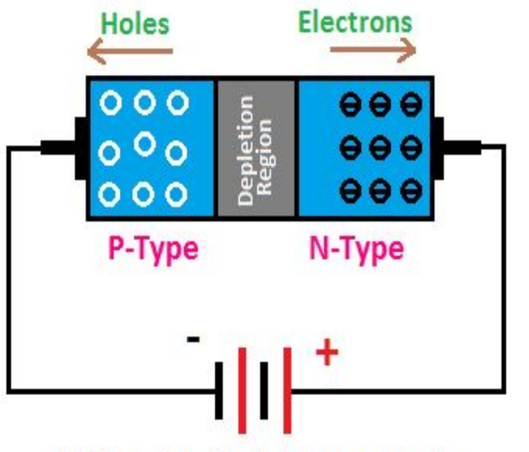
Reverse Biasing



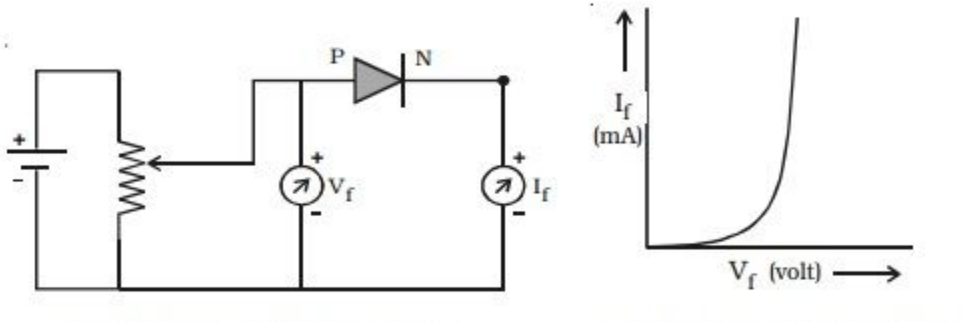
PN Junction Diode Reverse Biasing

- In this biasing, the p -side is connected to positive terminal and n-side to negative terminal of a battery.
- The p-type region is connected to the negative terminal of the battery, the holes in the p-type region attract and move away from the junction.
- On the other hand, the n-type region is connected to the positive terminal of the battery, so electrons in the n-type region also attract and move away from the junction.
- As a result, the width of the depletion increases and the potential barrier goes increasing, so currents cannot flow through the diode.
- The PN Junction diode act as a insulator .
- The diode offers very high resistance called reverse resistance.
- Diode works as an open circuit.

Semiconductor Diode Characteristics

- Graphical representation between voltage (V) and current (I) in a semiconductor diode called diode characteristics.

Forward Characteristics:



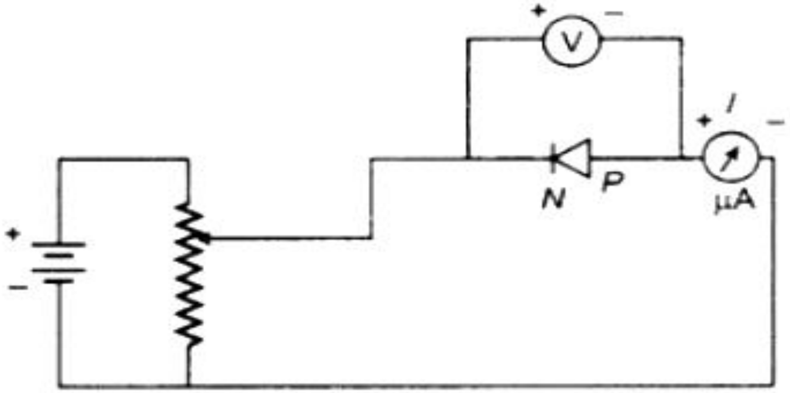
(a) Diode circuit–Forward bias *(b) Forward characteristics*

Fig Forward bias characteristics of a diode

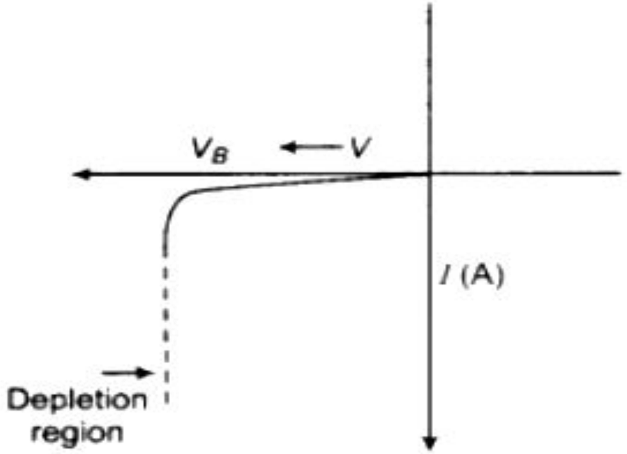
- The forward voltage is gradually increased and corresponding milliammeter is noted
- A graph is plotted between the set of voltages and current thus obtained.
- At first no current flows through the circuit. Once the external voltage exceeds the barrier potential, current increases rapidly.
- The forward voltage at which the diode current increases rapidly is called knee voltage (V_k).

Contd...

- Reverse Characteristics:
- The reverse voltage is gradually increased and corresponding milliammeter is noted.
- A graph is plotted between the set of voltages and current thus obtained.
- At first reverse current rises very slowly and becomes very small over long range, of reverse voltage.
- This reverse current is due to minority charge carriers in the diode known as reverse saturation current.
- The reverse voltage at which the reverse current starts rising sharply is called breakdown voltage (V_B).



Experimental arrangement for P-N junction reverse bias characteristic



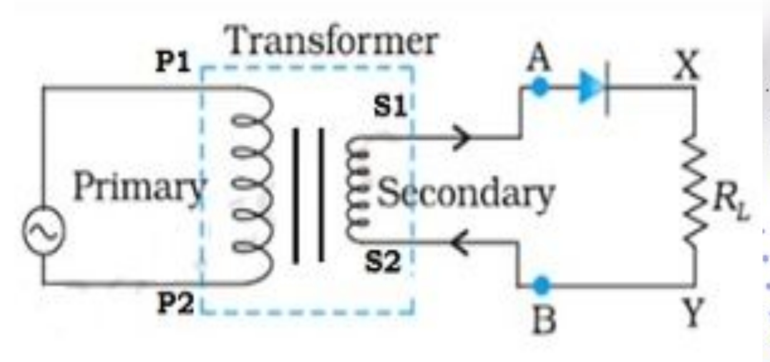
P-N junction reverse bias characteristic curve

Rectification

- It is the process in which AC is converted into DC. And the devices used for rectification is called rectifier.

1. Half Wave Rectifier:

Circuit Diagram:



❑ Only half cycle of AC is converted into Dc.

 The AC voltage to be rectified is connected between the primary of the transformer

 To one coil of the secondary , the p junction of the diode is connected

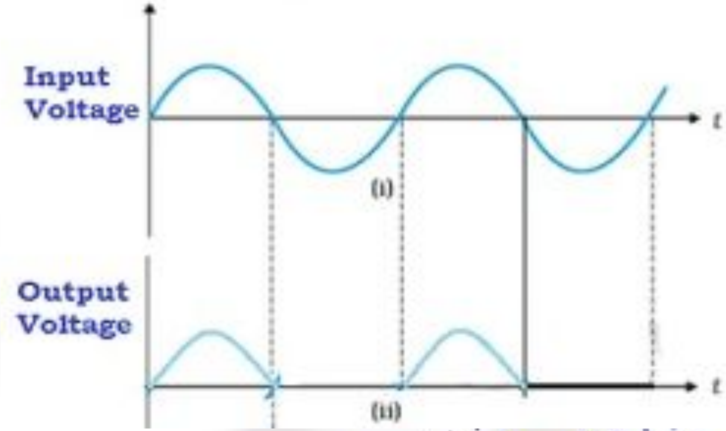
 The output is measured across the load resistance R_L

Working:

Contd…

Case 1

- During the positive half cycle of the input AC voltage, say S_1 becomes positive and S_2 becomes negative
- The p-n junction is forward biased and hence the resistance of the p-n junction diode becomes low
- Hence, current flows in the circuit and we get output across the load resistance R_L



Case 2

- During the negative half cycle of the input AC voltage, S_1 becomes negative and S_2 becomes positive
- The p-n junction is reverse biased and hence the resistance of the p-n junction diode becomes high
- Hence, no current flows in the circuit and we do not get any output across the load resistance R_L.
- When the diode is forward biased, the AC cycle pass through it and when it is reverse biased, it blocks the ac cycle.
- Hence only positive half of the AC appears across the load R_L

-

2. Full Wave Rectifier

➢ It converts full cycle of AC into DC.

Working

➢ During the positive half of the input cycle of AC voltage,

the junction diode D_1 is forward biased.

▪ The diode D_2 is reverse biased and hence no current due to D_2

We get output when the same is measured across the

load resistance R_L due to the diode D_1 alone

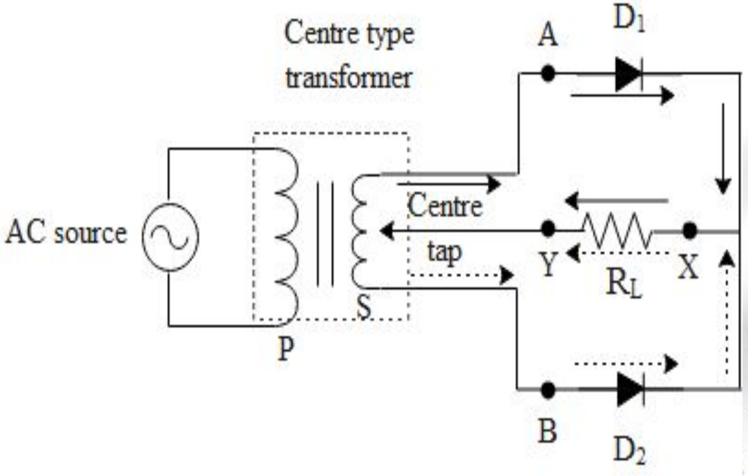
➢ During the negative half of the input cycle of AC voltage,

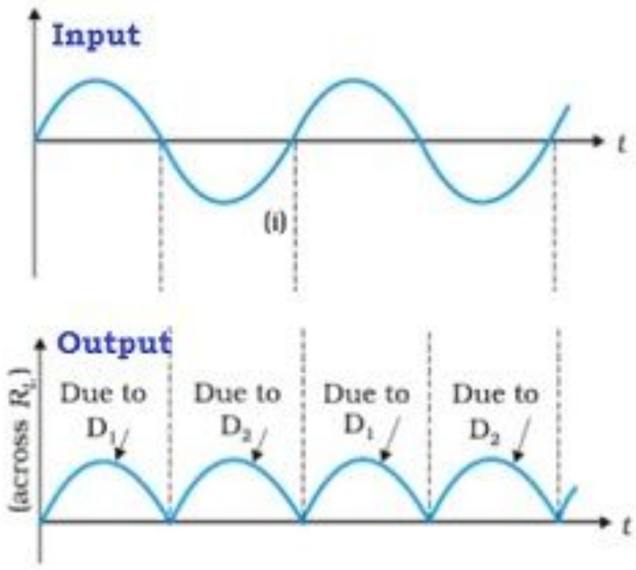
the junction diode D_2 is forward biased.

- The diode D_1 is reverse biased and hence no current due to D1
- We get output when the same is measured across

the load resistance R_L due to the diode D_2 alone

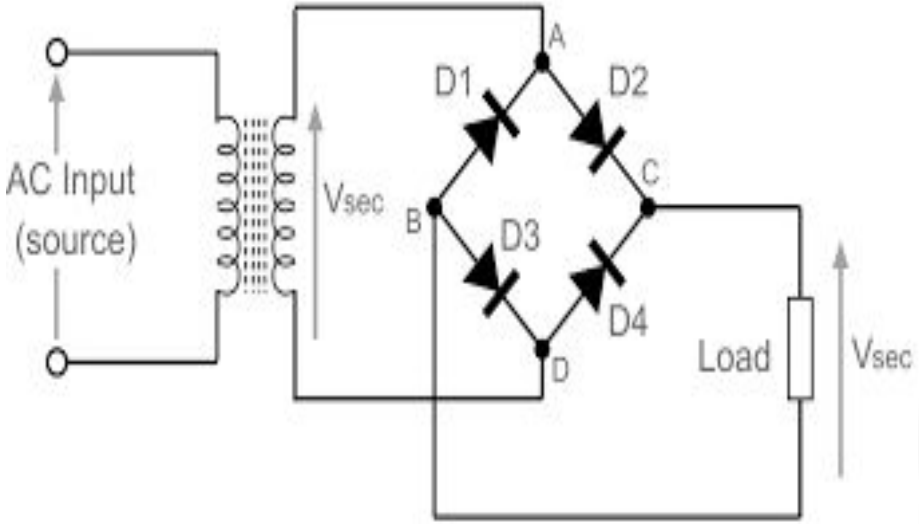
➢ Hence both cycles of the AC appears across the load R_L along the same

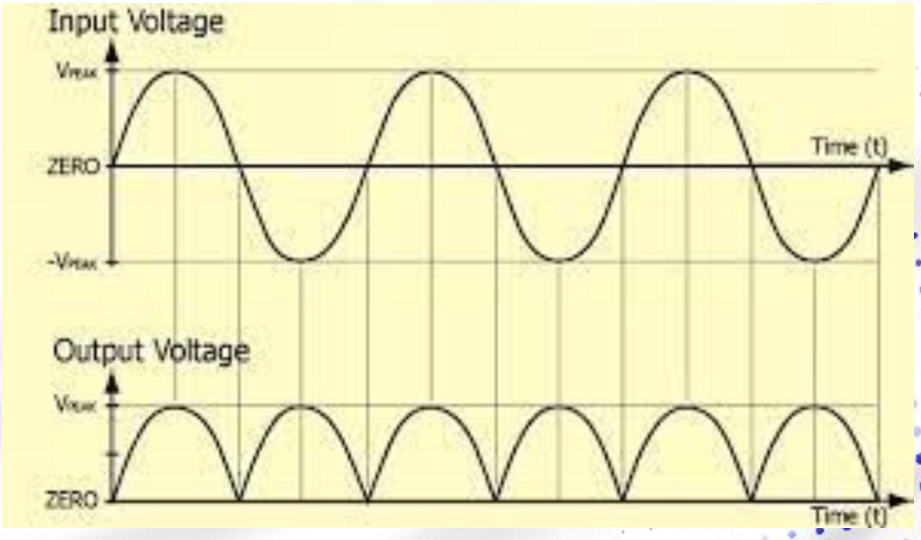




3. **Bridge Rectifier**

- It converts full cycle of AC into DC.
- It consist of four diode arranged in the form of Wheatstone bridge.
- The AC signal is applied at the input terminals, and the output is observed across the load resistor.





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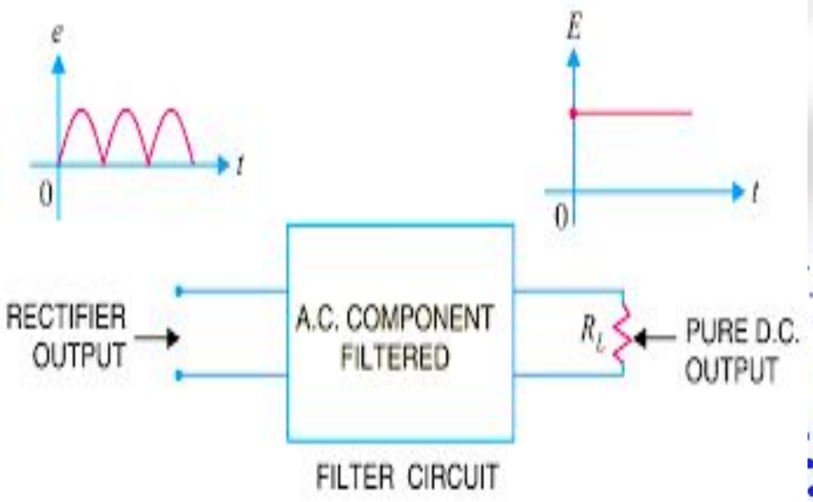
- In the first positive half cycle of the AC signal, the diodes $D_2$and D_3 become forward biased and start conducting. At the same time, the diodes D_1 and D_4 will be reverse biased and will not conduct. The current will flow through the load resistor via the two forward-biased diodes..
- Now, during the negative half cycle of the AC signal, the diodes D_1 and D_4 will be forward biased and diodes D_2 and D_3 will become reverse biased. It is worth noting at this point that the current that will be flowing through the load resistor will have the same direction as it has with the positive half cycle. Therefore, no matter the polarity of the input signal, the output polarity will always be the same.

Filter Circuit

- The output of a rectifier is a pulsating DC (i.e. not a pure DC)
- The circuit which is connected between a rectifier and load to convert pulsating DC into steady DC is called Filter.
- It contains the passive elements like inductor, capacitor or their combinations.



➢ We know that inductive reactance of inductor

$$X_L = 2\pi f L$$

- For DC, f = 0, so $X_L = 0$, so inductor offers zero or low resistance for DC and allows DC to pass through it but blocks the AC.

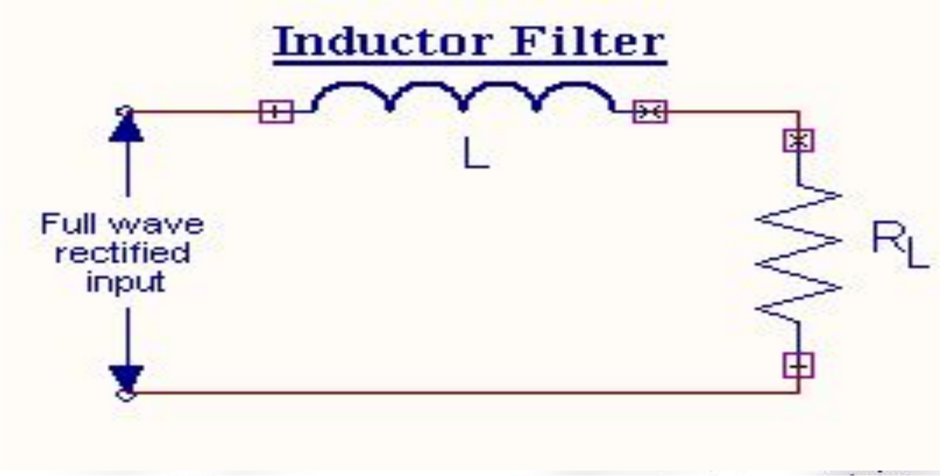
➢ We know that Capacitive reactance of capacitor

$$X_C = \frac{1}{2\pi f C}$$

- For DC, f = 0, so $X_C = \infty$, so capacitor offers infinite or high resistance for DC and blocks DC to pass through it but allows the AC.

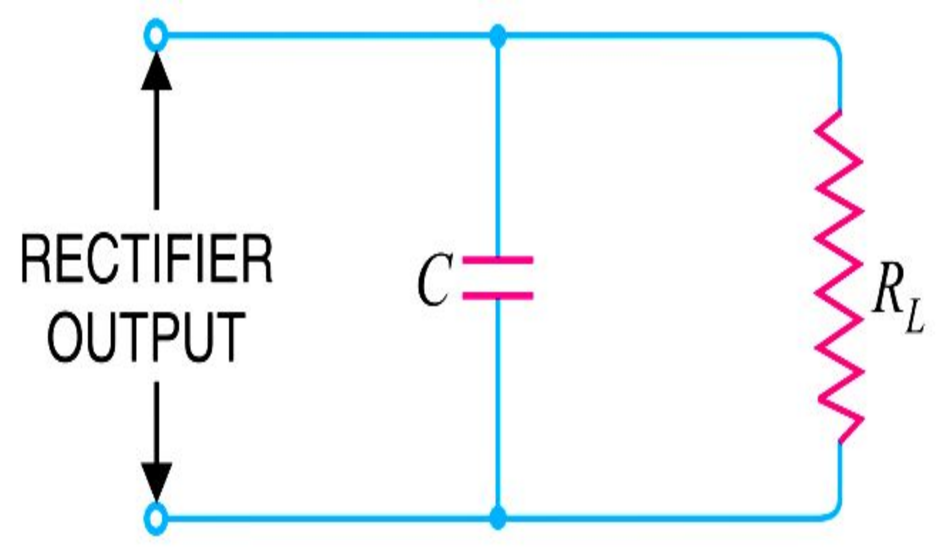
Inductor Filter

- In this filter an inductor is connected in series with load resistance.
- As inductor offers high resistance for AC and zero or low resistance for DC, it blocks AC to pass through it but allows the DC. This action reduces AC component across the load considerably.



Capacitor Filter

- In this filter a capacitor is connected across load resistance.
- As capacitor offers infinite or high resistance for DC and low resistance for AC, it blocks DC to pass through it but allows the AC. This action reduces AC component across the load considerably.



LC Filter

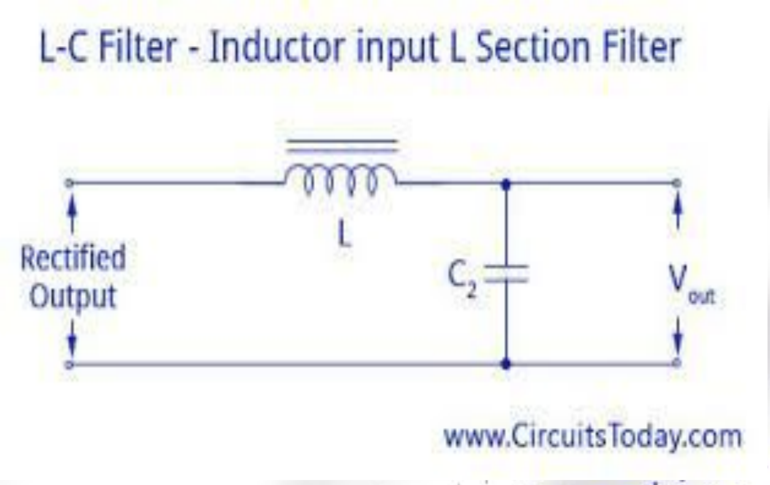
- In this filter an inductor is connected in series with load resistance and capacitor is connected across the load.
- As inductor offers high resistance for AC and low resistance for DC, it blocks AC to pass through it but allows the DC.
- The remaining AC component which is not block by inductor bypass through capacitor as it allows AC to pass through it. And the filtered DC appear across load.

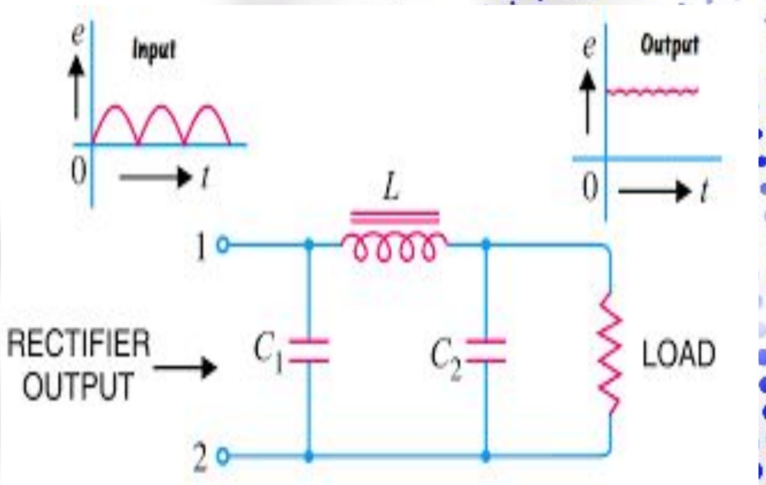
π Filter

- It consists of two capacitor and inductor connected in the form of Greek letter π.

Working:

- first of all, capacitor C_1 offer low resistance to AC component so that it bypass appreciable amount of ac to ground
- Inductor offering high resistance to ac so pass appreciable amount of dc component to circuit and block ac as well.
- Capacitor C_2 act as C_1 and ground remaining ac component.
- In this way only DC component is available at output.





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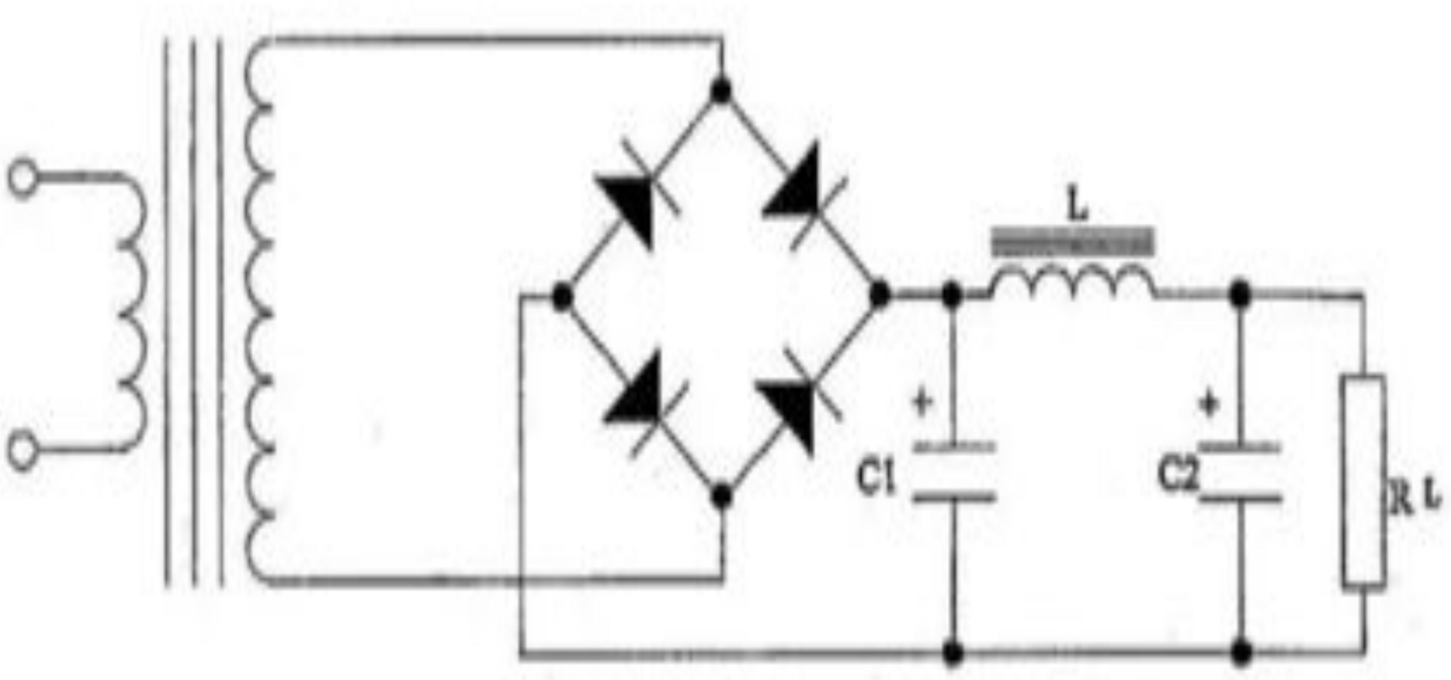
- Bridge rectifier with π Filter



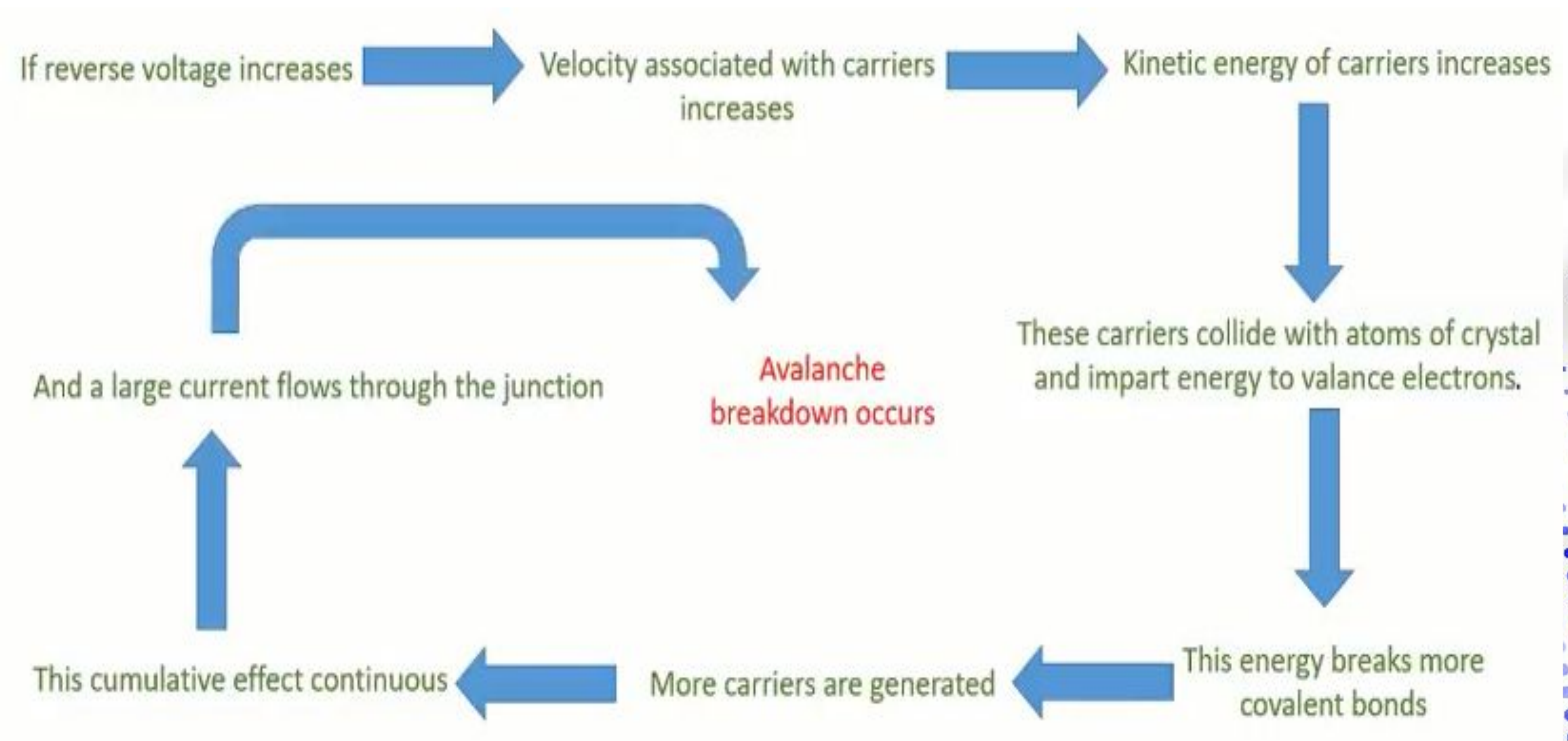
Reverse Breakdown

- When a PN junction is reversed biased it allows very small current to flow through it known as reverse saturation current. This current is due to the movement of minority charge carriers and it is almost independent of the voltage applied.
- If reverse bias is made too high, the current through PN junction increases abruptly and the voltage at which this phenomenon occurs is called ***breakdown voltage*** .
- At this breakdown voltage , the crystal structure breaks down.
- This crystal structure returns to the normal state when excess reverse bias is removed , provided that overheating has not permanently damaged the crystal.
- There are two processes which causes junction breakdown. One is ***Zener breakdown*** and another one is ***Avalanche breakdown*** .

- Q. Write down the difference between avalanche and Zener breakdown?

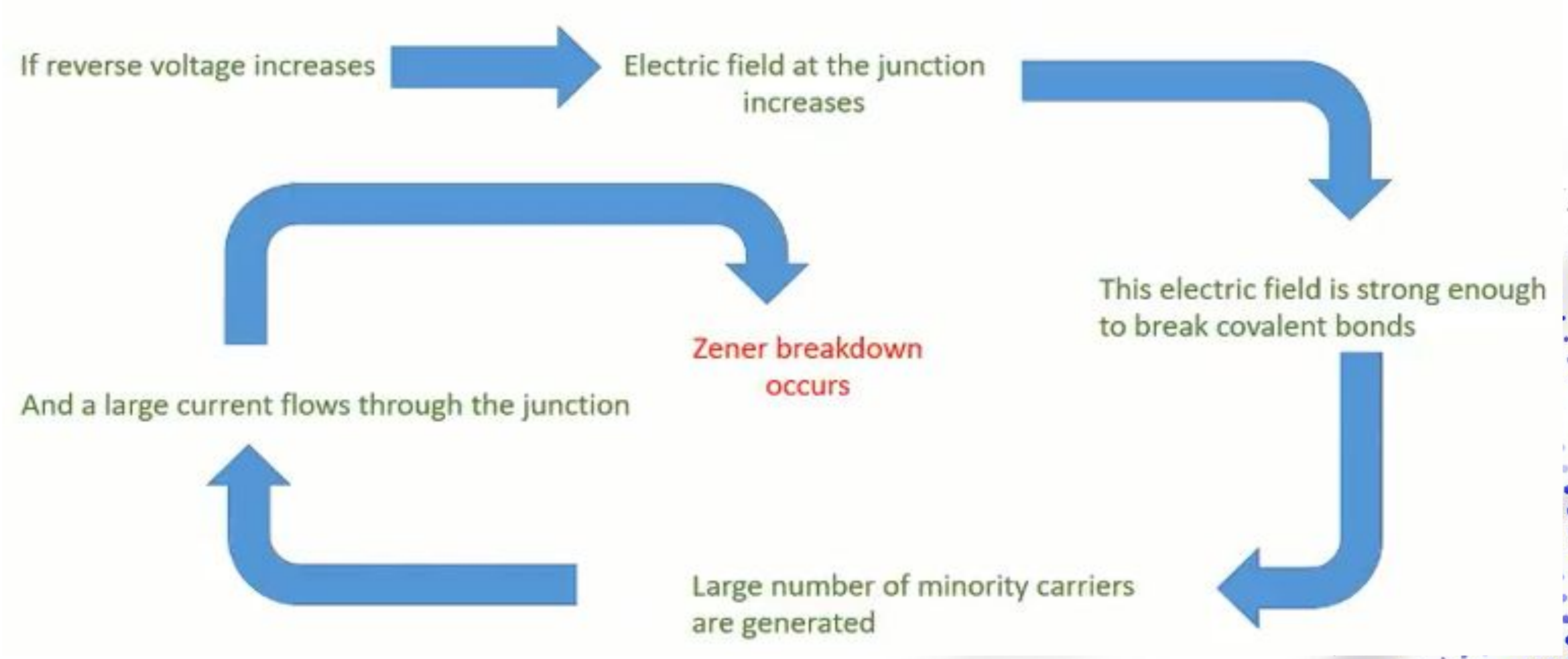
• *Avalanche breakdown:*

- This breakdown occurs in lightly doped PN junctions with wider depletion layer and lower concentration of impurity atoms.
- This breakdown occurs in a diodes above 6V.



Zener breakdown

- This breakdown occurs in heavily doped PN junctions with narrower depletion layer and higher concentration of impurity atoms.
- This breakdown occurs in a diodes below 4V.



If reverse voltage increases

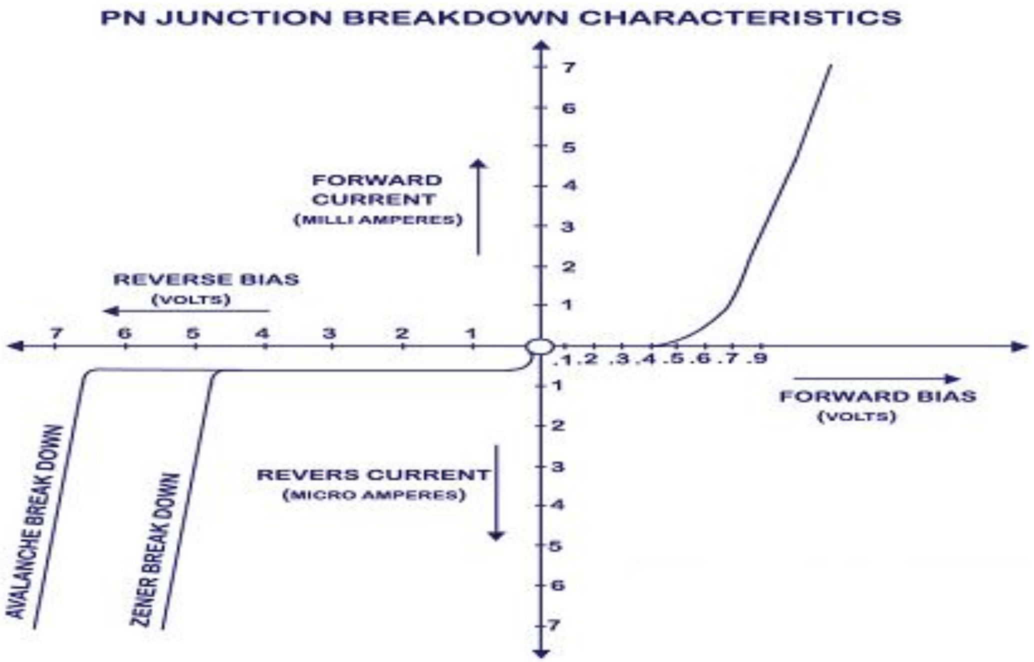
Electric field at the junction increases

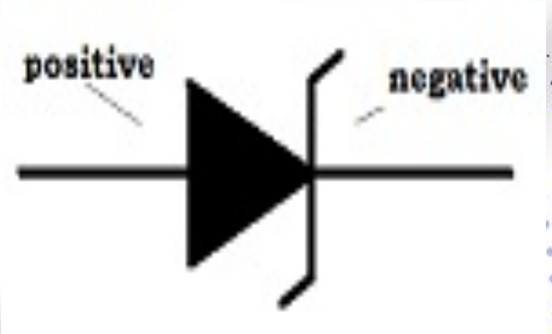
This electric field is strong enough to break covalent bonds

Large number of minority carriers are generated

And a large current flows through the junction

Zener breakdown occurs

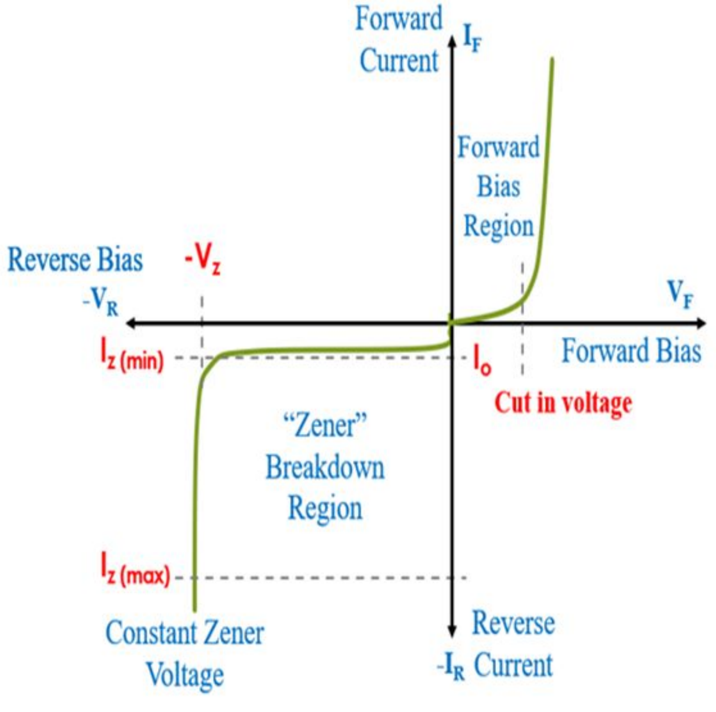




Zener Diode

- It is a special purpose diode, named after the inventor C. Zener
- It is designed to operate under reverse bias in the breakdown region
- It has heavily doped p- side and n-side. Due to this, the depletion region formed is very thin. Hence, the field at the junction is extremely high about for a small reverse bias voltage.
- The high electric field strength is high enough to pull the valence electrons from the host atoms on the p-side which is accelerated to the n-side. This is known as ionization.

- Characteristics – The Current – Voltage characteristics of Zener diode is shown alongside.
- As seen from the graph, when the applied reverse bias voltage in Zener diode reaches the breakdown voltage Vz of the Zener diode, there is a large change in current
- The Zener voltage remains constant even though the current through the diode varies over wide range. This property of Zener diode is used for regulating the supply voltages so that they are constant for Zener.

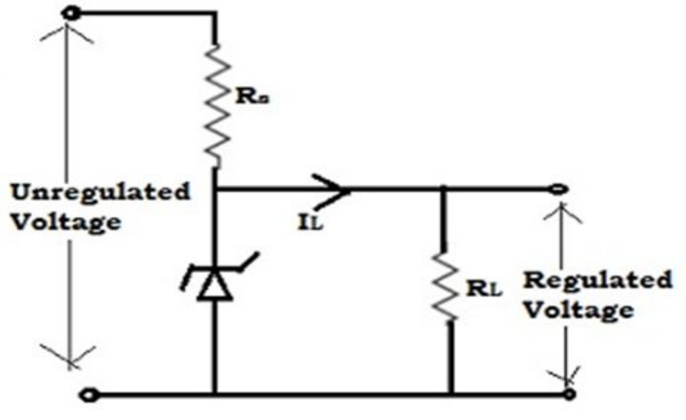


Zener Diode as Voltage Regulator

- The unregulated DC voltage from the output of the rectifier is connected to the Zener diode through a series resistance R_s such that the Zener diode is reverse biased.
- The output is measured across the load resistance R_L.

Zener Diode as Voltage Regulator

Working:



Regulation with varying input voltage:

- When the input voltage increases, the current through Rs and

  Zener diode increases
- This increases the voltage drop across Rs without any change in
- voltage across the Zener diode
- This is because in the breakdown region, the Zener voltage remains constant even though the current in the Zener diode changes
- Similarly, when the input voltage decreases, the current through Rs and hence Zener diode decreases
- The voltage drop across Rs decreases without any change in the voltage across the Zener diode
- Thus, the increase or decrease in the input voltage results in increase or decrease of voltage drop across Rs without any change in voltage across the Zener diode

This way, Zener diode behaves as a voltage regulator

- **Regulation with varying load resistance:**
- When the load resistance R_L decreases, the load current I_L increases. this causes Zener current to decrease. As a result of this the input current and the voltage drop across the series resistance remains constant. Thus the load voltage V_L is also constant.
- When the load resistance R_L increases, the load current I_L decreases. This causes Zener current to increase. This again keeps the value of input current and the voltage drop across the series resistance remains same. Thus the load voltage V_L is also constant.
- In this way Zener diode acts as a voltage regulator.

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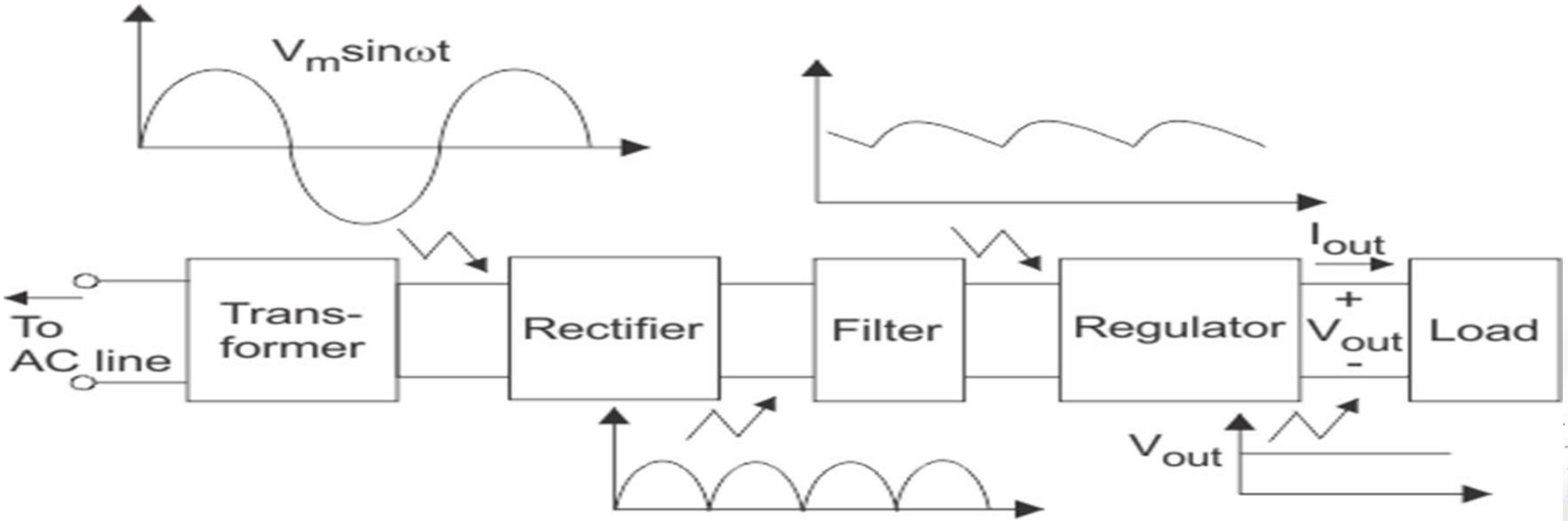


Components of typical linear power supply

Transistor

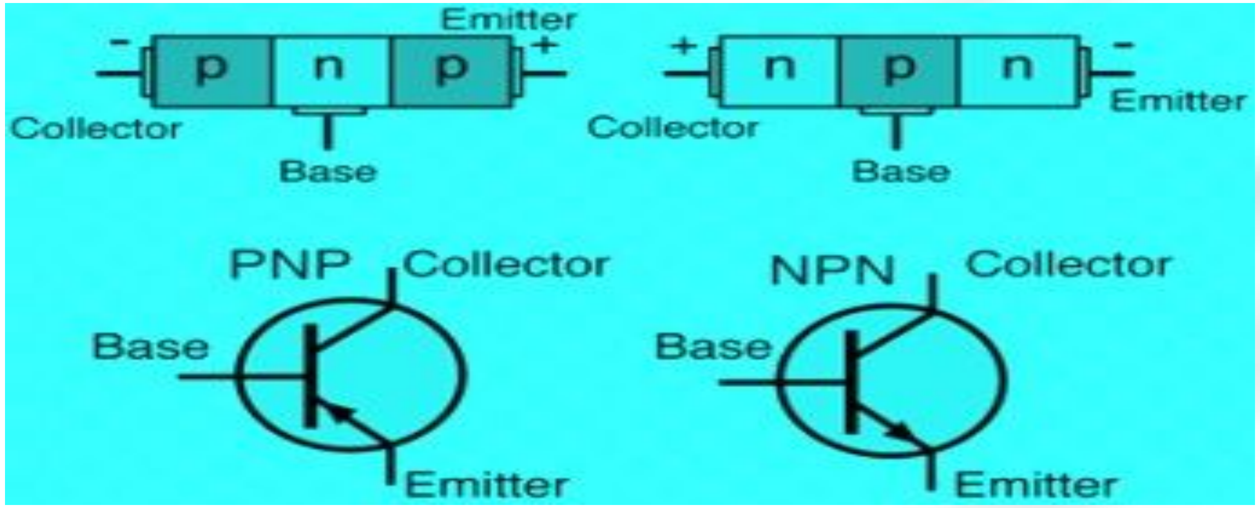
The transistor is three terminal electronic device formed by the combination of two PN junction.

- Basically transistor is the crystal with three doped region. (emitter, base and collector)

Emitter: It is supplier of the transistor. It is heavily doped region and thicker than base
Collector: It is thickest region. Moderately doped. It is collect charge supplied by the emitter and base.
Base: it is thinnest and lightly doped region. its function is to pass the majority charge carrier from emitter to collector.

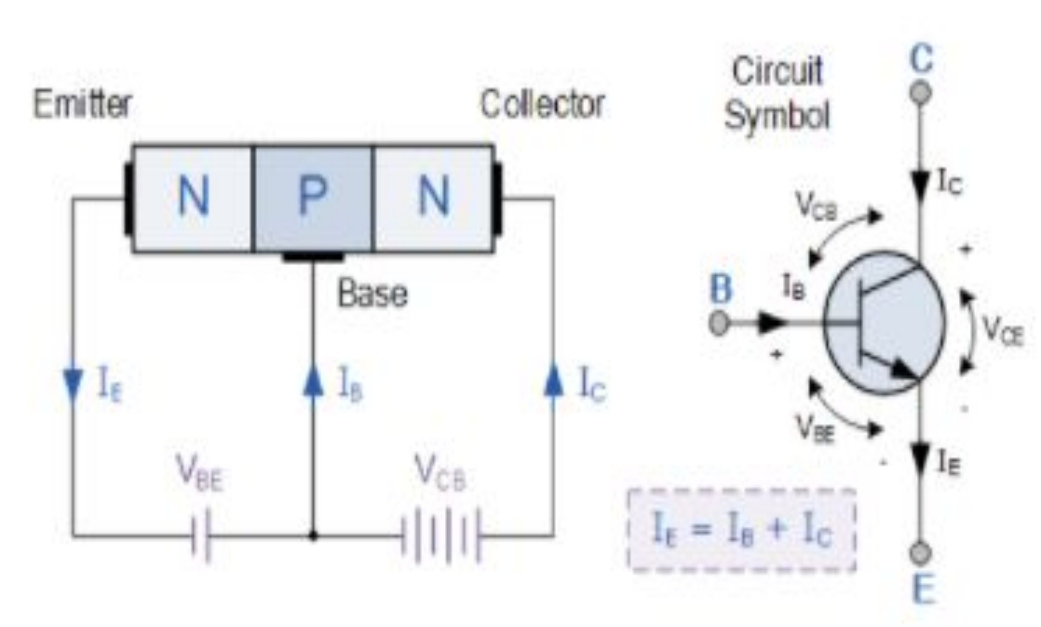
Types of transistor

- NPN: In this transistor, emitter and collector are N type semiconductor and base is P type semiconductor.
- PNP : In this transistor, emitter and collector are P type semiconductor and base is N type semiconductor.



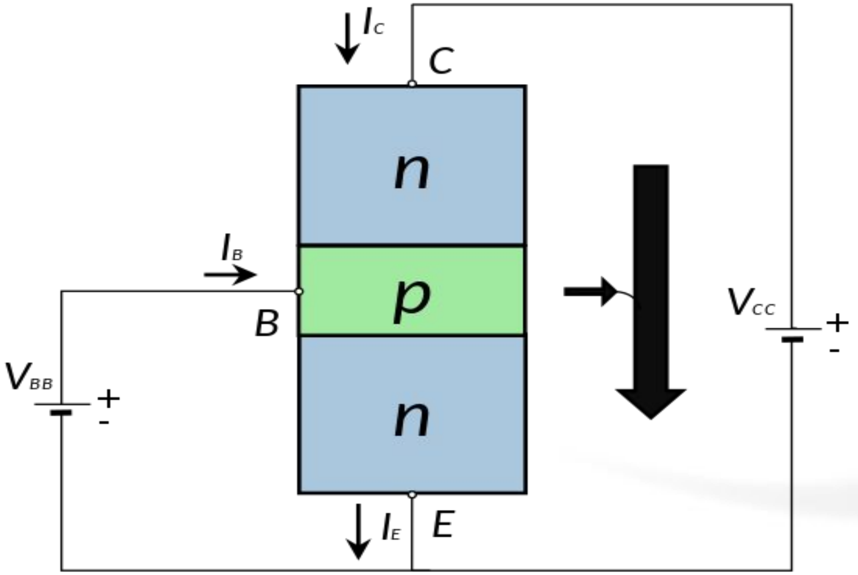
Transistor Configuration/Connection

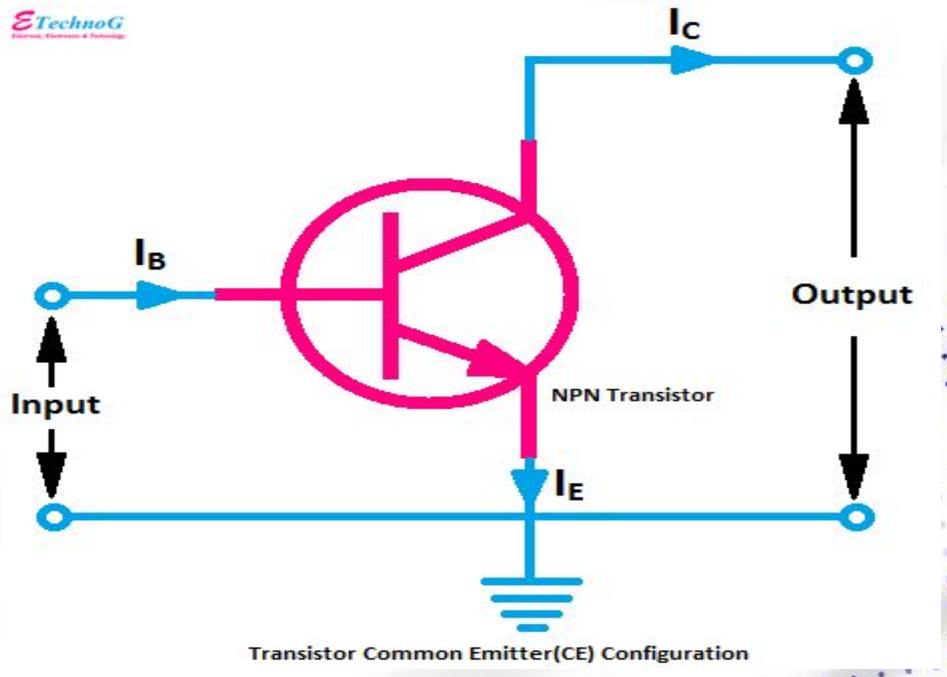
- 1. Common base configuration:
  - In this configuration the transistor is connected with base as common terminal, input is applied between emitter and base and output is taken between collector and base terminal.



Common Emitter Connection

- In this configuration the transistor is connected with emitter as common terminal, input is applied between emitter and base and output is taken between collector and base terminal.

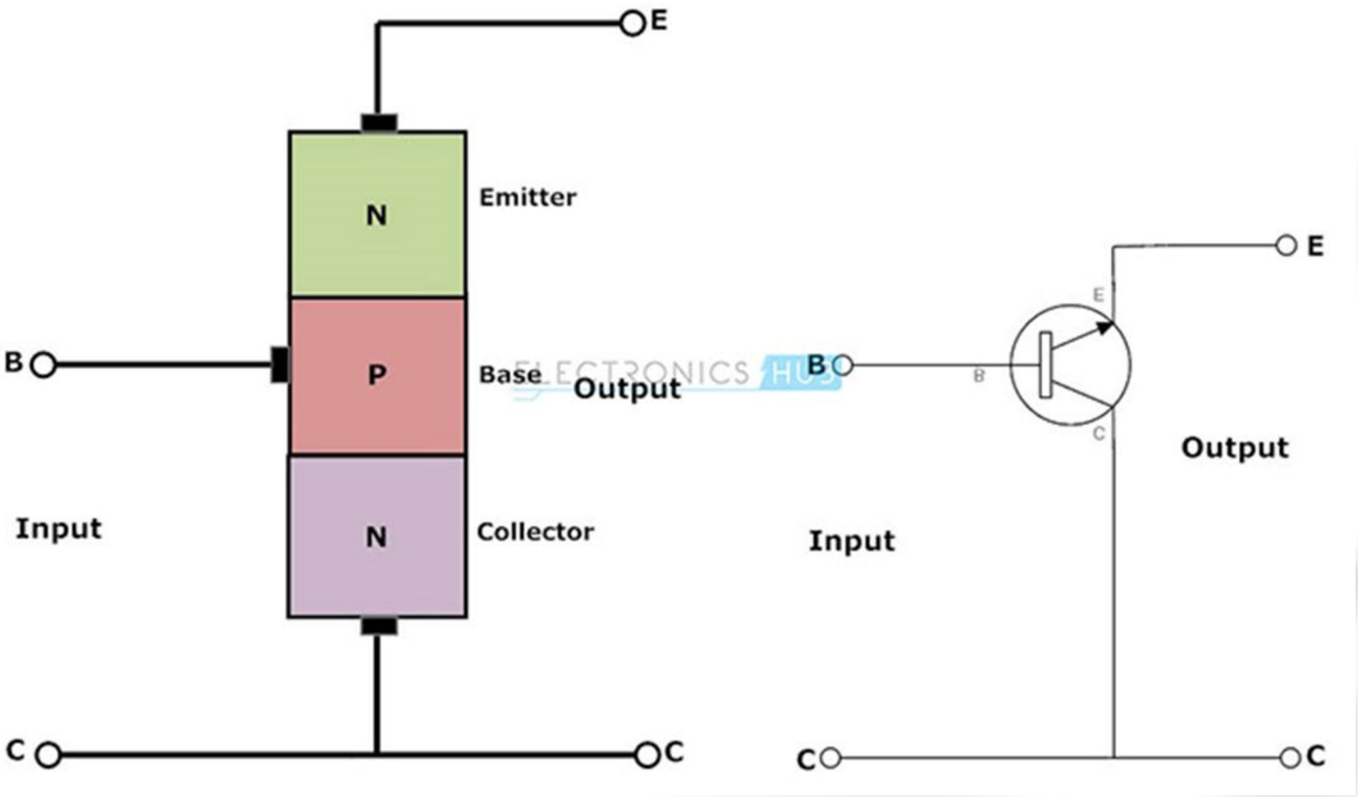




Transistor Common Emitter(CE) Configuration

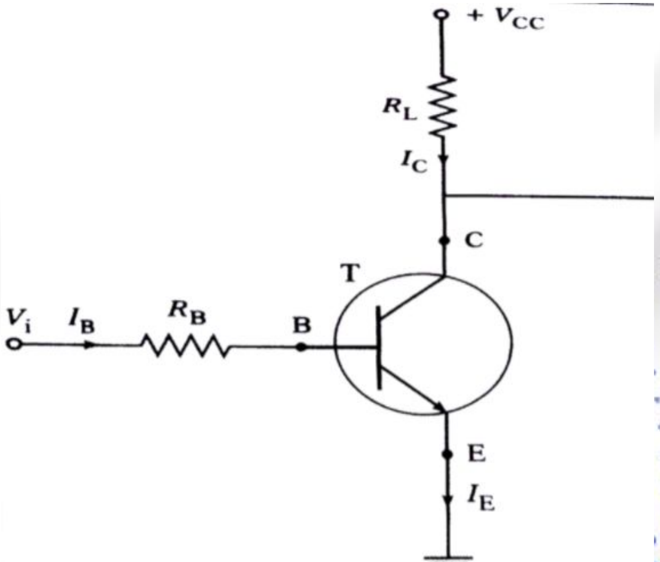
Common Collector Connection

- In this configuration the transistor is connected with collector as common terminal, input is applied between collector and base and output is taken between collector and emitter terminal.



Transistor as a switch

- A device which turn on and off the electric current in an electric circuit is called switch.
- The areas of operation for a transistor switch are known as the Saturation Region and the Cut-off Region.
- **Cut off region**: Here the operating conditions of the transistor are zero input base current (IB), zero output collector current (IC) and maximum collector voltage (VCE) which results in a large depletion layer and no current flowing through the device. Therefore the transistor is switched “Fully-OFF”.
- **Saturation Region:** Here the transistor will be biased so that the maximum amount of base current is applied, resulting in maximum collector current resulting in the minimum collector emitter voltage drop which results in the depletion layer being as small as possible and maximum current flowing through the transistor. Therefore the transistor is switched “Fully- ON”.



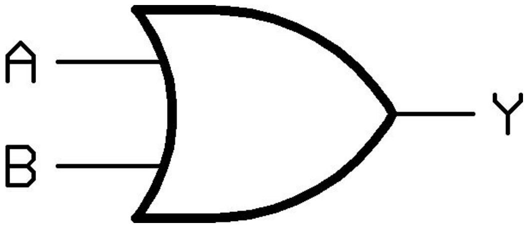
LOGIC GATES

- Logic Gates are electronic circuits which makes logic decision.
- It accepts two state input and gives two state output i.e. 0(low) and 1(high).
- Types of logic gates
- Simple Logic Gates:
  - OR Gate
  - AND Gate
  - NOT Gate
- Compound Logic Gates:
  - NOR Gate
  - NAND Gate
  - XOR
  - XNOR

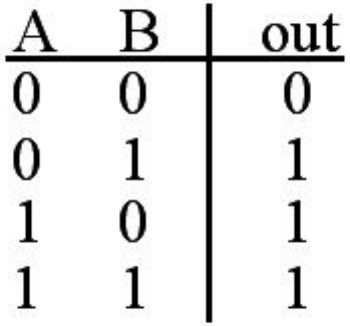
OR GATE

- **The OR gate** is a digital logic gate that implements logical disjunction - it behaves according to the truth table to the right. A HIGH output (1) results if one or both the inputs to the gate are HIGH (1). If neither input is high, a LOW output (0) results. In another sense, the function of OR effectively finds the maximum between two binary digits.
- Boolean expression – $Y = A + B$

Symbol-

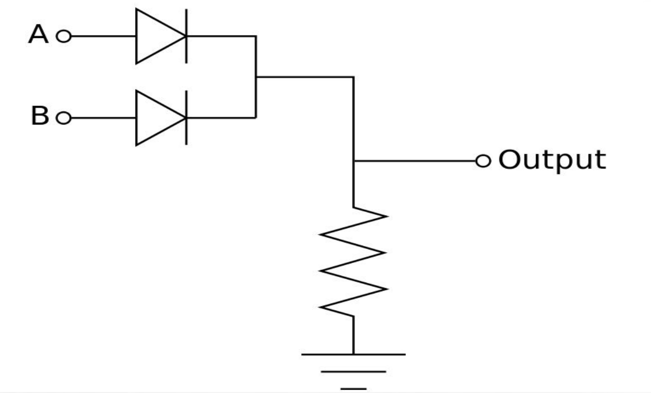


Truth table-

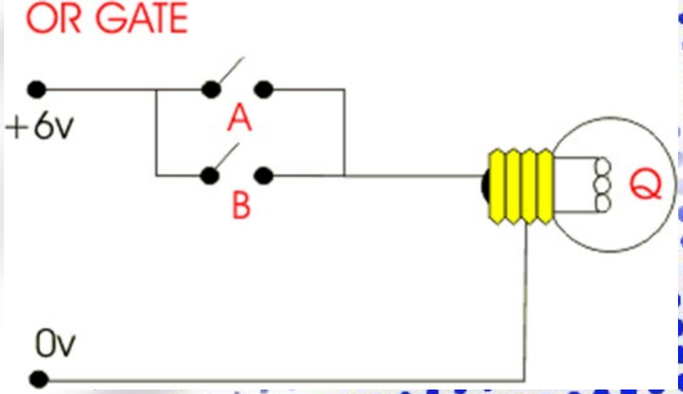


A	B	out
0	0	0
0	1	1
1	0	1
1	1	1

Or gate from diodes



Circuit diagram-



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Explanation of OR gate:

As seen in figure, the two input OR gate can be realized by two ideal diodes D1 and D2 and a resistor R. the following four cases are possible.

Case I: when A =0 and B = 0, both the diodes are not forward biased. They do not conduct output across R is zero, i.e. Y = 0.

Case II: when A =0 and B = 1, the diode D1 is not forward biased and diode D2 is forward biased and it conducts. Voltage drop across D2 is zero and full voltage(high) appears cross R , i.e. Y = 1.

Case III: when A =1 and B = 0, the diode D2 is not forward biased and diode D1 is forward biased and it conducts. Voltage drop across D1 is zero and full voltage(high) appears cross R , i.e. Y = 1.

Case IV when A =1 and B = 1, Both the diodes are forward biased and they conduct. Voltage drop across D1 and D2 are zero and full voltage(high) appears cross R , i.e. Y = 1.

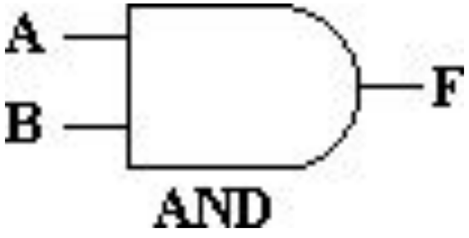
As we see truth table we found same as it is observation.

AND GATE

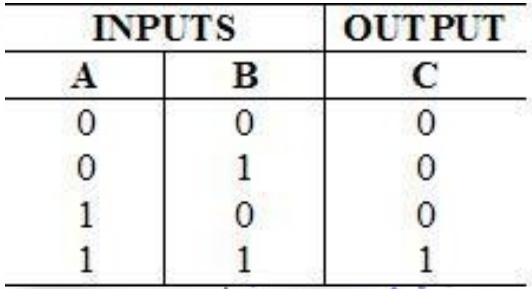
- The **AND gate** is a basic digital logic gate that implements logical conjunction - it behaves according to the truth table to the right. A HIGH output (1) results only if both the inputs to the AND gate are HIGH (1). If neither or only one input to the AND gate is HIGH, a LOW output results. In another sense, the function of AND effectively finds the minimum between two binary digits.

- Boolean expression – $Y = A.B$

Symbol-

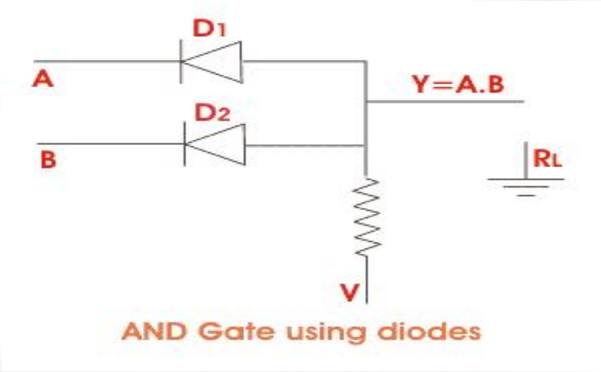


Truth table-



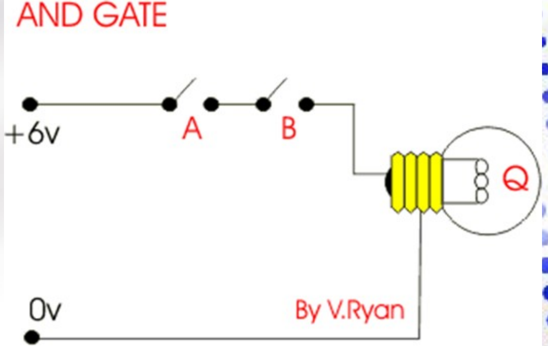
INPUTS		OUTPUT
A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

And gate from diodes



AND Gate using diodes

Practical circuit-



Contd...

Explanation of AND Gate

As seen in figure, the two input AND gate can be realized by two ideal diodes D1 and D2 and a resistor R connected to a battery. The following four cases are possible.

Case I: when A =0 and B = 0, both the diodes are forward biased so they conduct and are shorted. So the voltage drop across output is zero, i.e. Y = 0.

Case II: when A =0 and B = 1, the diode D2 is not forward biased and diode D1 is forward biased and it conducts and shorted. So the voltage drop across output is zero, i.e. Y = 0.

Case III when A =1 and B = 0, the diode D1 is not forward biased and diode D2 is forward biased and it conducts and shorted. So the voltage drop across output is zero, i.e. Y = 0.

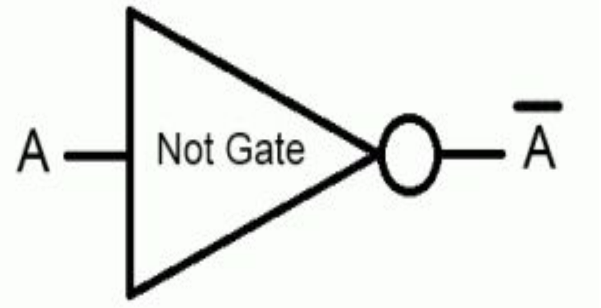
Case IV when A =1 and B = 1, Both the diodes are not biased biased and they do not conduct. and full voltage(high) appears cross the output , i.e. Y = 1.

As we see truth table we found same as it is observation.

NOT GATE

- A NOT gate (also often called Inverter) is a logic gate. It takes one input signal. In logic, there are usually two states, 0 and 1. The gate therefore sends 1 as output, if it receives 0 as input.
- Alternatively it received 1 as input, and sends 0 as output.
- Boolean expression – $Y = \overline{A}$

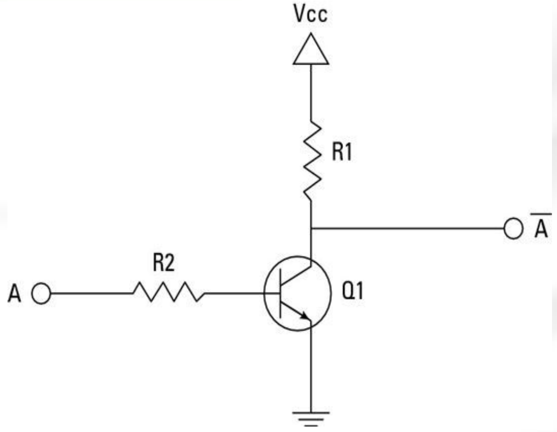
Symbol-



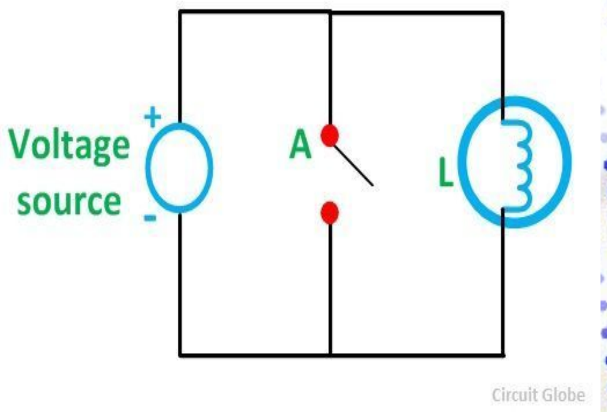
Truth table-

A (IN)	B (OUT)
0	1
1	0

Not gate using transistor



Practical circuit-



Circuit Globe

Contd…

Explanation of NOT gate.

NOT gate can be made using the transistor and resistors as shown in figure.

The following two cases are possible

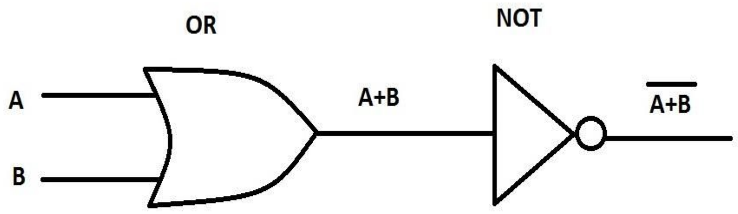
Case I when A = 0, the base of transistor is connected to earth. So it's base emitter junction is not forward biased. Hence base current and collector current is zero.

Now the transistor is said to be in cut-off mode. At this condition output voltage is the voltage of battery connected across the resistance R1. i.e. Y = 1.

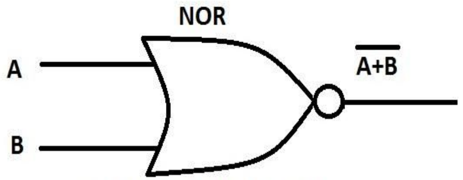
Case II when A = 1, base emitter junction is forward biased so transistor conducts and transistor is in saturation state. At this condition the battery voltage drop across resistor R1, and the output is low i.e. Y = 0.

NOR GATE

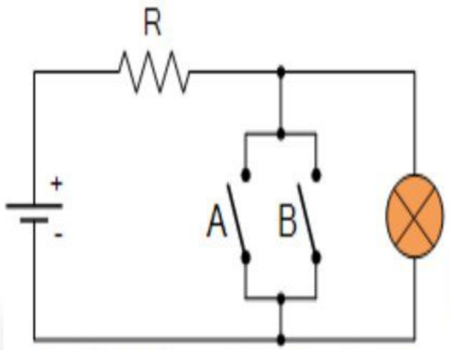
- The NOR gate represents the complement of the OR operation. Its name is an abbreviation of NOT OR. The graphic symbol for the NOR gate consists of an OR symbol with a bubble on the output, denoting that a complement operation is performed on the output of the OR gate.
- Boolean Expression : $Y = \overline{A + B}$



LOGIC CIRCUIT OF NOR GATE



SYMBOL OF NOR GATE



Lamp - ON = "1"
Lamp - OFF = "0

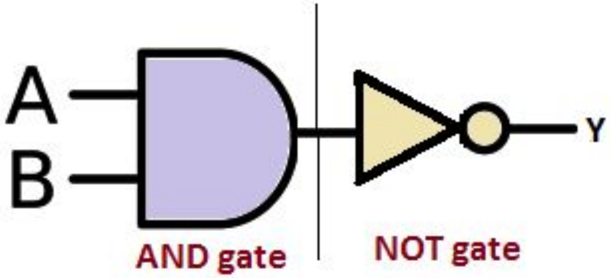
Switch A - Open = "0", Closed = "1"
Switch B - Open = "0", Closed = "1"

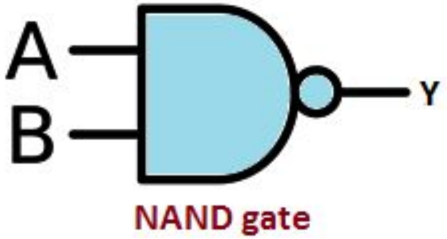
Input		Output
A	**B**	**Y**
0	0	1
0	1	0
1	0	0
1	1	0

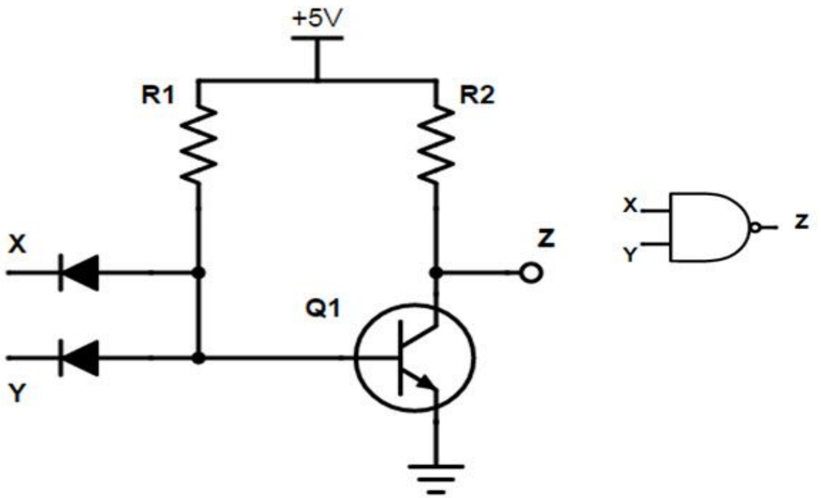
NAND GATE

- NAND Gate: The NAND gate represents the complement of the AND operation. Its name is an abbreviation of NOT AND. The graphic symbol for the NAND gate consists of an AND symbol with a bubble on the output, denoting that a complement operation is performed on the output of the AND gate.
- Boolean Expression :$Y = \overline{A.B}$

Input		Output
A	B	Y= $\overline{A.B}$
0	0	1
0	1	1
1	0	1
1	1	0

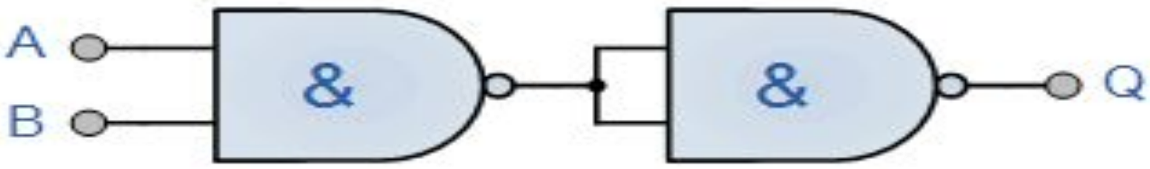






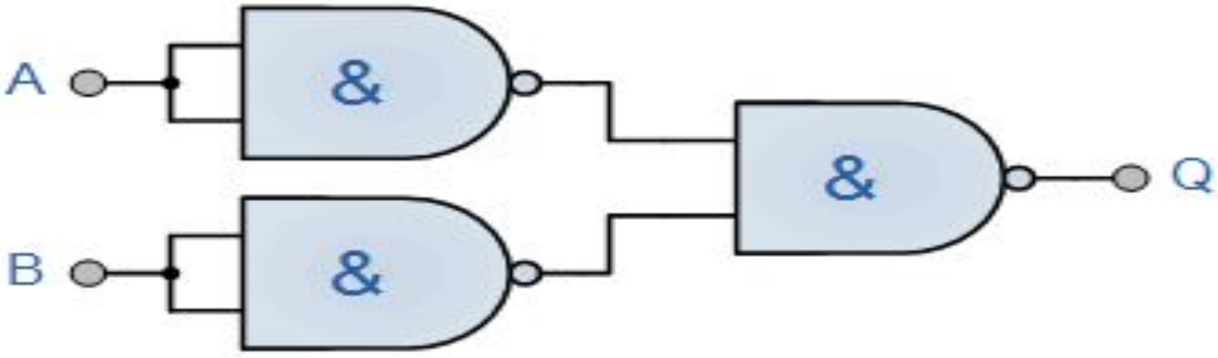
NAND Gate as a Universal Gate:

- Complete this using truth table



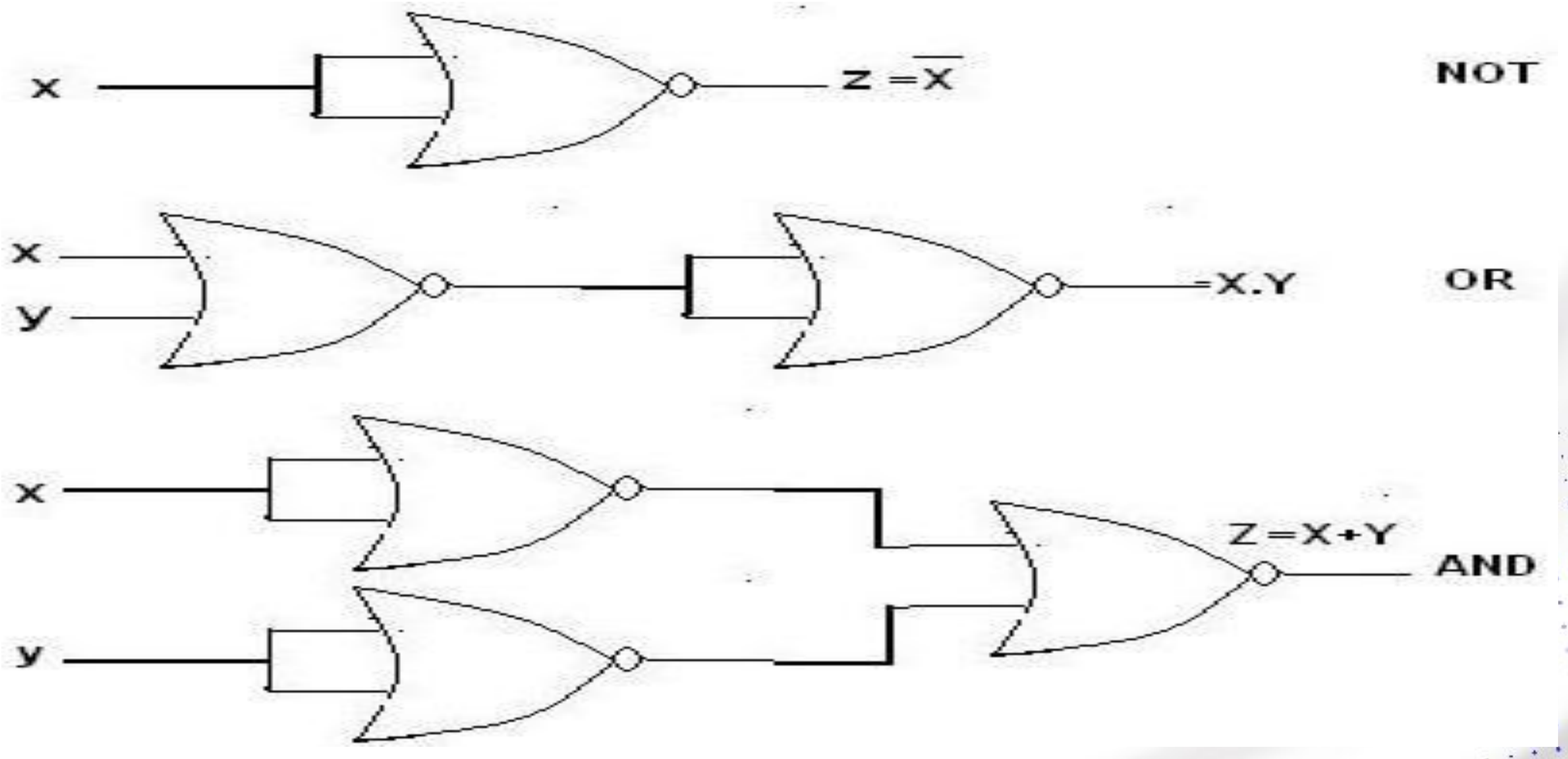
2-input AND Gate

NOT Gate



2-input OR Gate

NOR Gate as a Universal Gate:



Thank you!