Semiconductor

Syllabus :-

* Describe the formation of PN junction and semiconductor diode
* Plot forward and reverse characterstics of semiconductor diode. including the
* concept of zener diode
* Describe Rectifier
* Describe full wave rectification using semiconductor diodes
* Describe logic gates and explain operation of different logic gates OR, AND, NOT, NAND and NOR gates with their symbol, Boolean algebra and truth table.

Basic Introduction :- (out of syllabus)

Energy bands :

Range of energy possesed by an electron in a solid state.

1) Valance band :

Range of energies possed by valence electron is known as valence band.

2) conduction band :

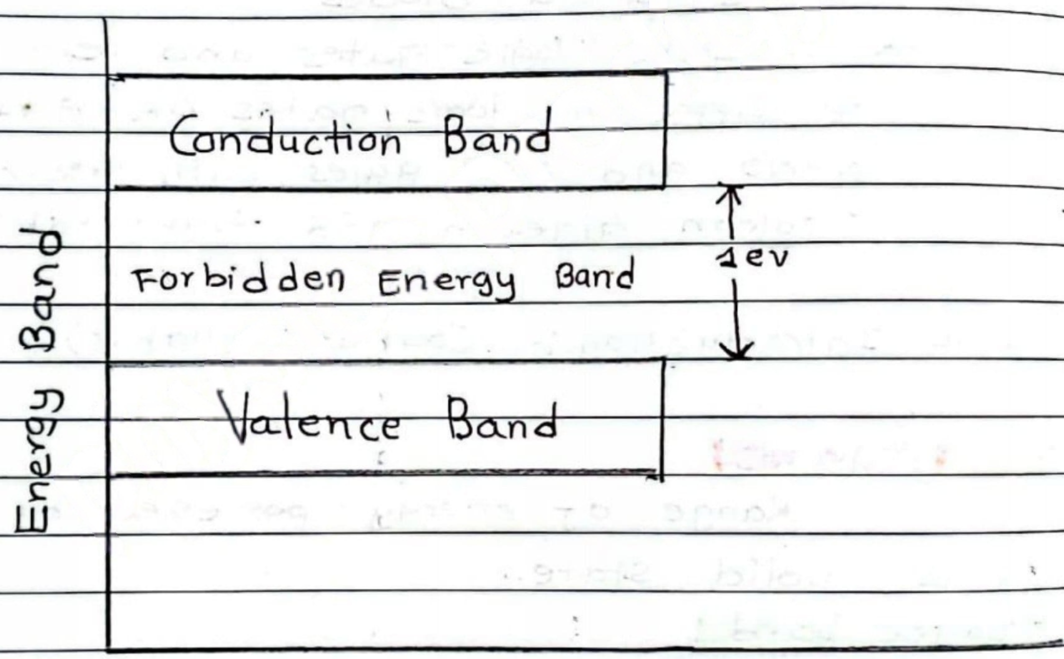
The band of electron orbitals that electrons can jump up into from the valence band when excited is called conduction band.

Simply :- The range of energy possed by free electrons so that they can conduct electricity is called conduction band.

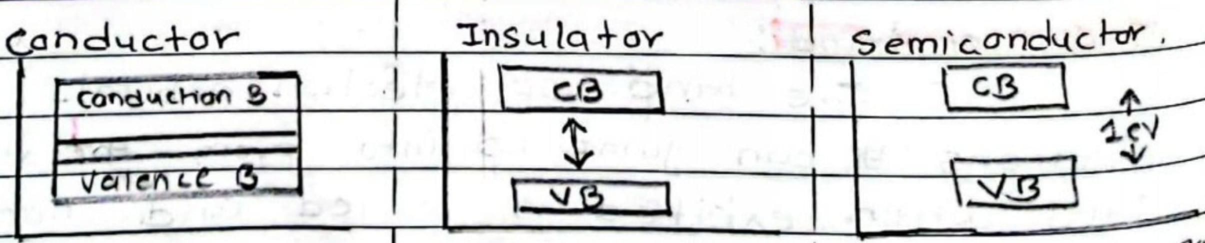
Forbidden Energy Band

The seperation between the valence band and conduction band is known as Forbidden Energy Band or Forbidden Energy gap.

Energy Band Diagram For semiconductor.



According to Energy band theory



Conductor	Insulator	Semiconductor
overlap	large FEB	less Energy gap VB electrons can easily jumps to CB by supplying little energy.

Doping :- process of adding impurity to the pure Form of semiconductor. It increses conduction.

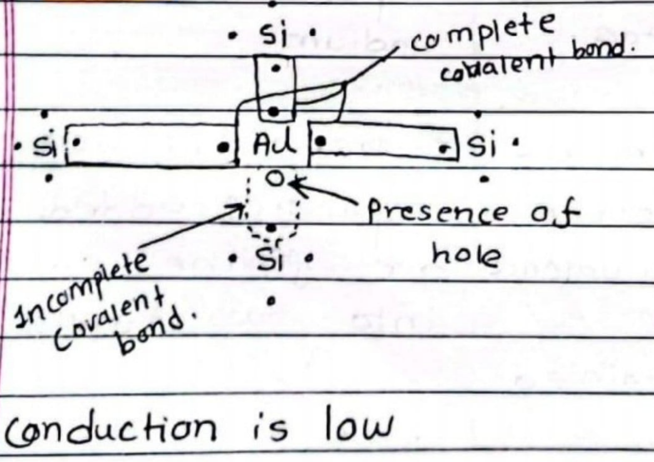
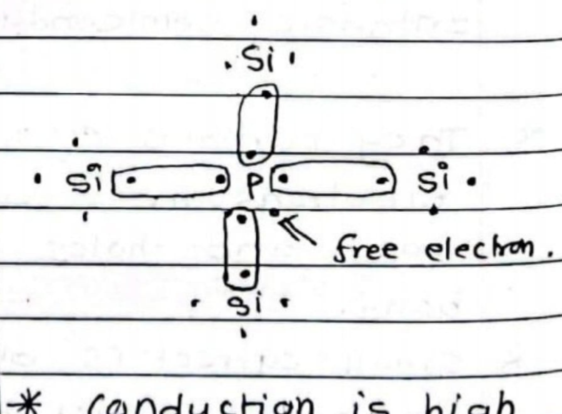
According to energy band theory semiconductors are defined as the substance whose forbidden energy gap is less and valence band electrons can easily jumps to conduction band by supplying little energy. At absolute 0 K they acts as Insulator. If we supply energy they behave as conductor.

Types of semiconductors

1) Intrinsic Semiconductors	2) Extrinsic Semiconductors.
* They are extermly pure semiconductors.	* They are impure semiconductors.
* No impurities	* Pure semiconductors doped with tetravalent or pentavalent impurities.
* Pure silicon or Germanium are the examples of Intrinsic semiconductors.	* Pure silicon or germanium doped with Arsenic or Indium
* They cointains equal no. of electrons in conduction band and holes in valence band.	* Depending upon the impurities added they are further classified into two types: N-type, P-type
* Small currect is obtained in such conductors.	
* Conductivity is low	→ conductivity in high bcoz of doping ↑

holes → +ve charge

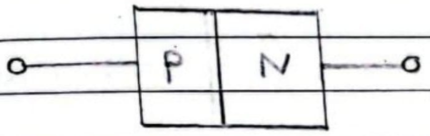
Extrinsic Semiconductor.

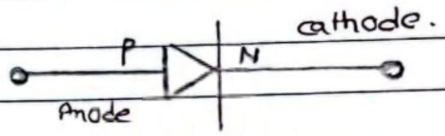
p-type semiconductor	N-type semiconductor.
* Pure semiconductor doped with trivalent impurities like galium , indium or Aluminium are called p-type semiconductor	* Pure semiconductors doped with pentavalent impurities like Antimony , phosphorous or Arsenic . are called N-type semiconductor.
* It is also known as acceptor type semiconductor.	* It is also known as donor type semiconductor.
* No. of holes > no. of e^-	* No. of e^- > no. of holes
* Net charge will be zero	* Net charge will be zero.
* Holes are the majority charge carrier	* e^- are the majority charge carrier
* There are very little thermally generated free e^- they are minority charge carrer.	* There are thermally generated holes. They are minority charge carrier.
	
* Conduction is low	* Conduction is high

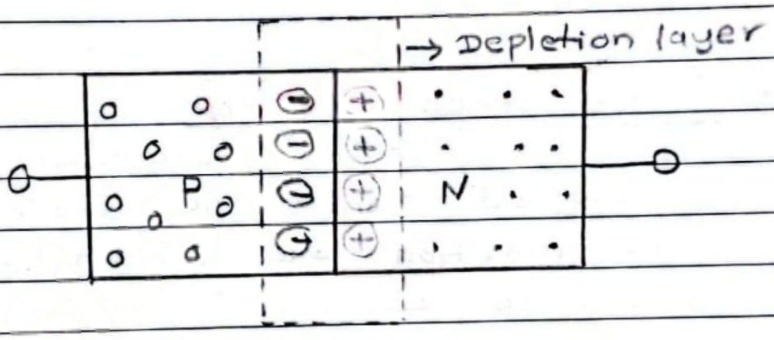
start From here,

PN-Junction

When a pure Form OF semiconductor is doped with p-type material at one end and n-type OF material at another, the resulting semiconductor material is called PN-Junction diode.







→ As we know the charge always Flows From higher concentration region to lower concⁿ region so negative charge (electron) From N-side diffuses towards p-side and positive charge (holes) diffuses From p-side to N-side. So positive ions are formed at N-side and -ve ions are Formed at P side near the junction.

Depletion layer :- The layer Formed due to the diffusion OF holes and electrons in P-N junction diode is called depletion layer.

V_B for Germinium → 0.3 V
V_B for Silicon → 0.7 V

Some important points about depletion layer

→ It acts like forbidden energy gap in semiconductor
→ It's width depends upon doping level.

$$\text{Depletion width} \propto \frac{1}{\text{doping level}}$$

For heavy doping, depletion layer is thin and viceversa.

Barrier potential (V_B)

→ The potential difference developed across the depletion layer of P-N junction due to immobile ions or charge carrier is called barrier potential. and corresponding field is called barrier field.

→ It's value depends upon doping level and tempeature ...

$$V_B \propto \frac{1}{\text{doping level}} \qquad V_B \propto 1/T$$

For each degree rise in tempeature V_B decreases by 2.5 mV.

uses of P-N junction diode.

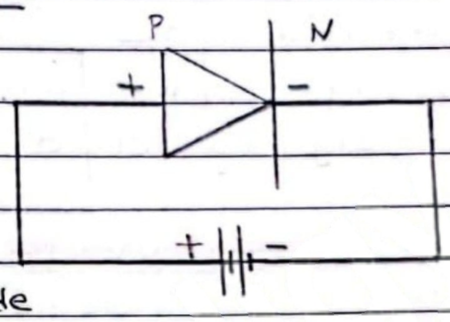
* used as rectifier device to convert Ac to dc.
* used as a switch in logic gates
*
*

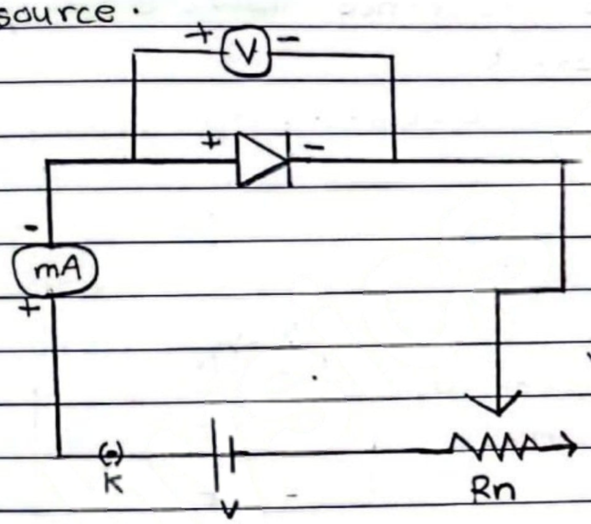
process of connection of external source of emf on a diode is known as biasing.

Working of P-N junction Diode (Imp) VV

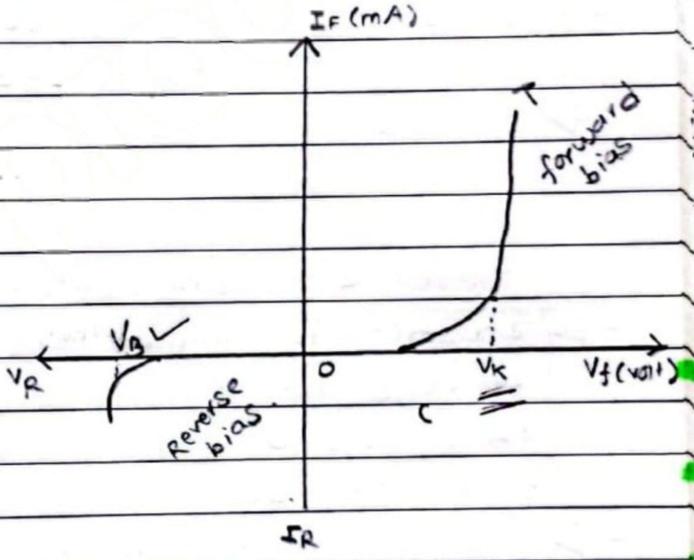
i) Forward biasing [PP – NN]

→ A P-N junction diode is said to be Forward biased if its p-side is connected to positive terminal and N-side is connected to negative terminal of the external source.





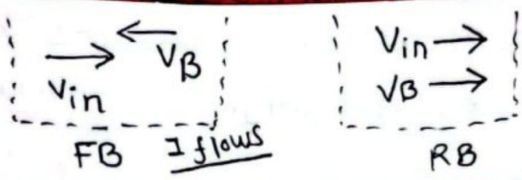
(Forward biased diode)



(I-V characterstics of diode)

→ The graph which shows variation of circuit current with forward biasing voltage is called forward bias characterstics.

→ For this, a circuit is made with Rheostat and mili Ammeter in order to vary voltage and note current.



I doesnot follows.

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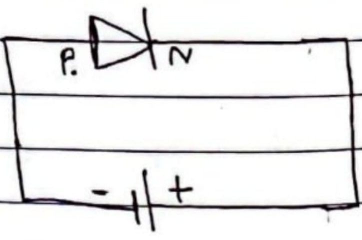
- When voltage is gradually increased, current also increases.
- When Forward voltage is greater than barrier potential, the current increases rapidly. The Voltage after which current is increased rapidly is called knee voltage (V_K)

Consequences of Forward biasing :-

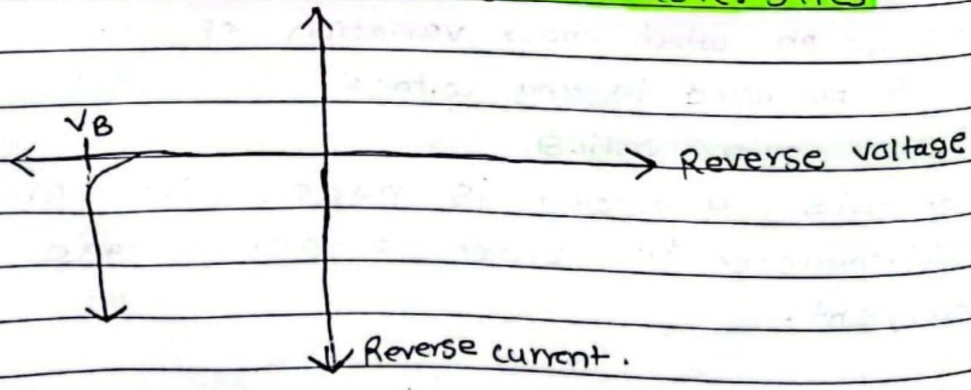
- The width of depletation layer decreases.
- Barrier potential (V_B) decreases.
- Diode offers very low resistance (Forward resistance) about (1-25)Ω.
- Diode acts as closed circuit.

(2) Reverse Biasing (PN-NP).

- In this biasing, +ve terminal of the battery is connected to N-side and -ve terminal with p-side.



- The graph which shows the variation of current with reverse biasing voltage is called Reverse Biasing characterstics.



[Reverse Saturation Current]

Causes Avalanche Breakdown.

- current gradually increases with reverse voltage
- very low current flows due to minority charge carrier (e⁻ in
- At a point, current is rapidly increased The crossponding voltage is called Breakdown Voltage.
-

Consequences of Reverse biasing:

- Width of depletation layer increases.
- Barrier potential increases.
- Offers very high resistance.
- Acts as open circuit.

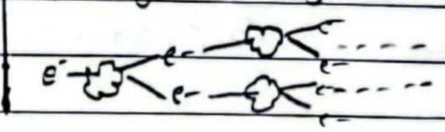
Junction Break-down (or Reverse Breakdown)

The limiting value of reverse bias potential that cause junction breakdown of diode with production of large electron-hole pair and sharp increase in current is called junction Breakdown voltage.

There are two types of junction Breakdown. They are:-

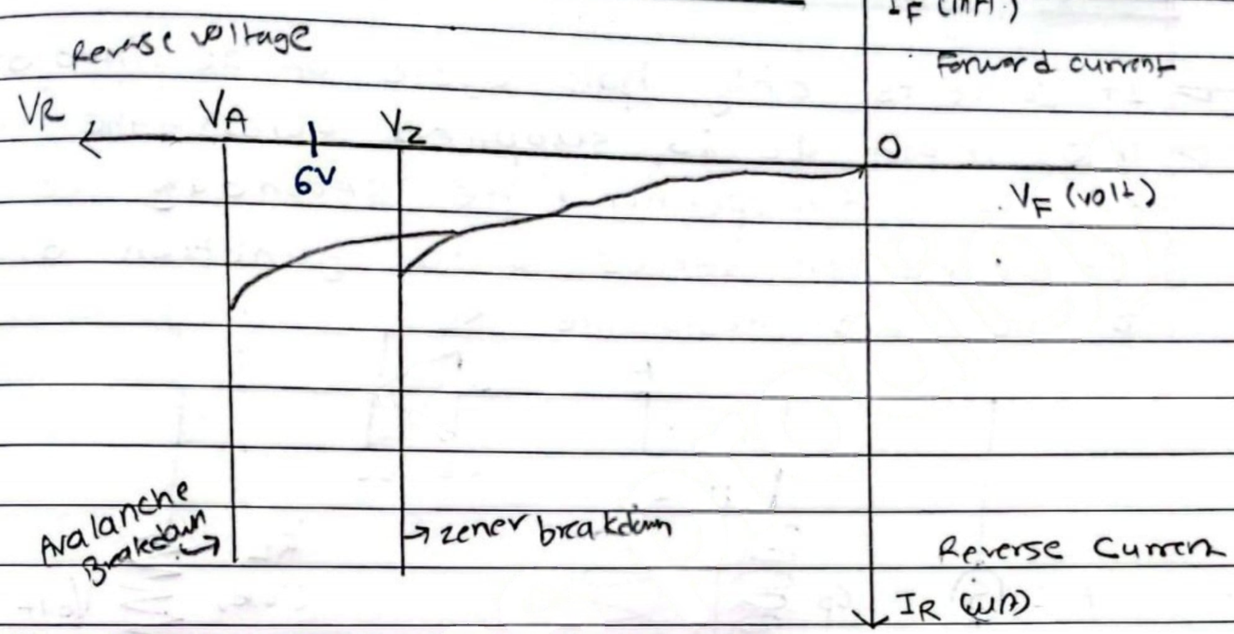
- Zener Breakdown
- Avalanche Breakdown.

$V_B < 6V$	$V_B > 6V$
Zener Breakdown	**Avalanche Breakdown.**
→ Both sides of P-N Junction are heavily doped.	→ Both sides of P-N junction are lightly doped.
→ A strong electric field is produced.	→ A weak electric field is produced.
→ Large no. of electrons and holes are produced.	→ small no. of electron-hole pairs are generated.
→ zener effect is the type of electrical breakdown in a reverse biased P-N junction diode in which the electric field enables the tunneling of electrons from valance Band to conduction band of a semiconductor, leading a large no. of free electrons (minority carriers) which suddenly increases reverse current.	→ Avalanche breakdown is the sudden rapid increase in current in semiconductor material when sufficient amount of electric force is applied to the material.
→ Small voltage sets large EF which is sufficient to break covalent bonds of Depletation layer.	→ This effect can be used to control voltage more precisely in various electronic devices.
→ Reverse voltage ↑↑, large current flows in reverse direction.	→ Reverse electric field accelerates minority charge carrier and they collide with depletation layer and is able to break covalent bond of the layer and electron hole pair are generated and process continuous with production of large charge carrier



$V_R \uparrow\uparrow \rightarrow$ Velocity $\uparrow \rightarrow KE \uparrow \rightarrow$ e collide layer $\rightarrow$ continuously

Zener and Avalanche effect



Rectification and Rectifier

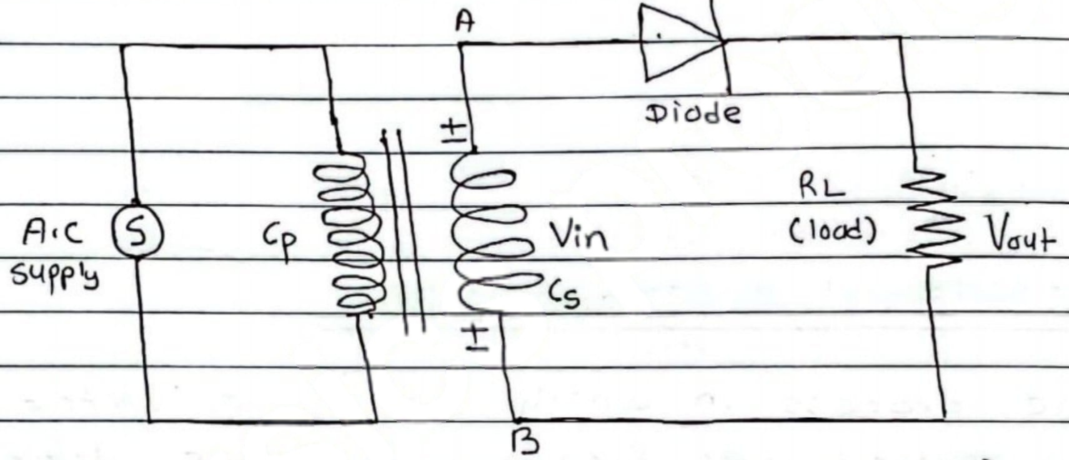
→ The process in which AC is converted into DC is called Rectification and the device used to do so is called Rectifier.

There are two types of Rectifier.

- Half-wave Rectifier
- Full wave Rectifier
  - Centre Tapped Rectifier
  - Bridge Rectifier

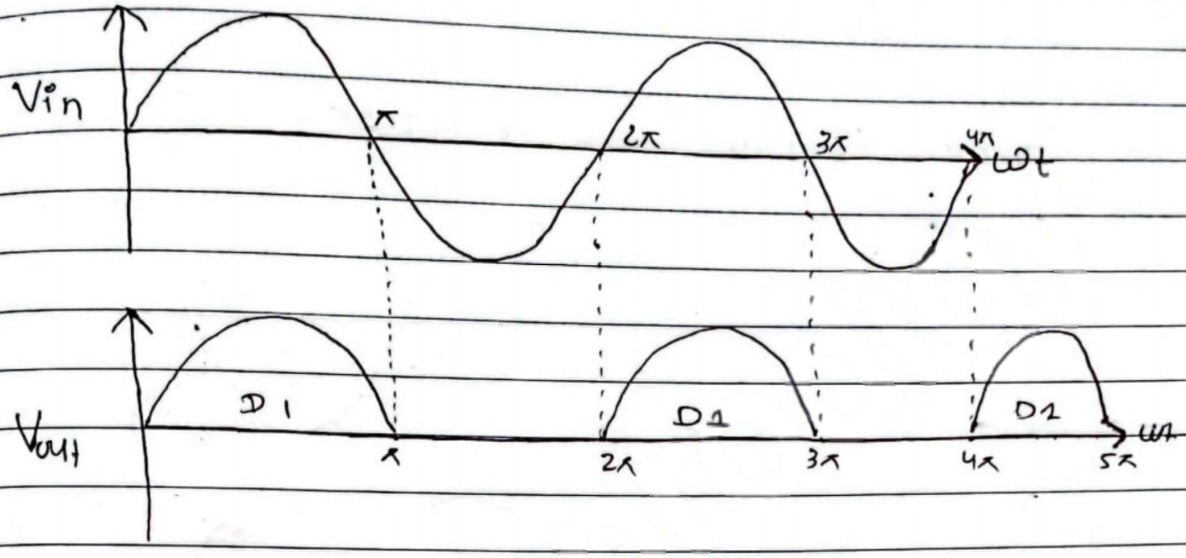
1) Half-wave Rectifier

- It converts only half cycle of ac into dc.
- The input ac is supplied across the primary coil of a transformer. The secondary coil is connected in series with junction diode D and load Resistance R_L.



- When ac input is applied to primary coil (Cp), a voltage is induced in secondary coil (Cs) due to mutual inductance.
- During the positive half cycle of ac, one terminal say A becomes +ve. Then the diode is forward biased and current flows through R_L.
- In next cycle the diode is reverse biased and no current flows through R_L.
- So only unidirectional current flows through Resistance (R_L) and it acts as half wave rectifier.

Output of Half-wave Rectifier

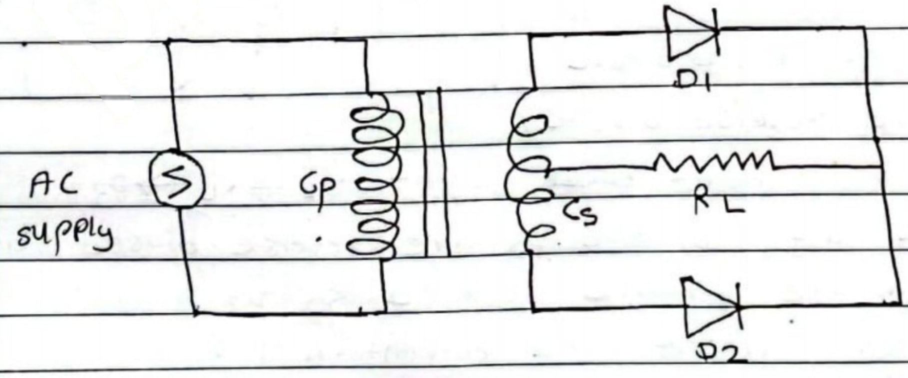


2) full wave Rectifier

- They are of two types:-

i) Central Tapped full wave Rectifier

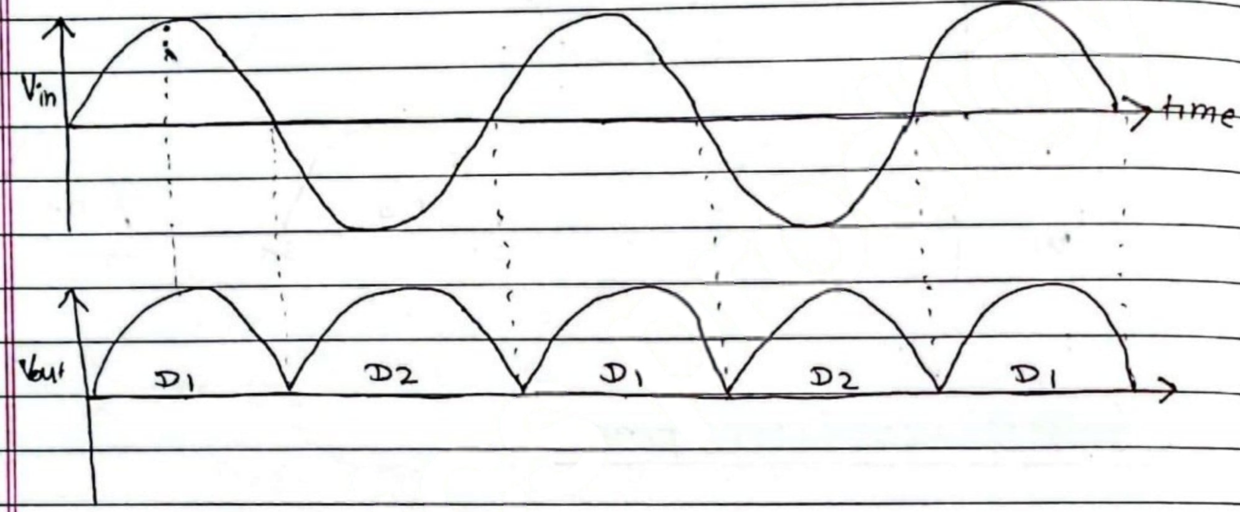
→ full wave rectifier is a device that converts full cycle of ac into dc.



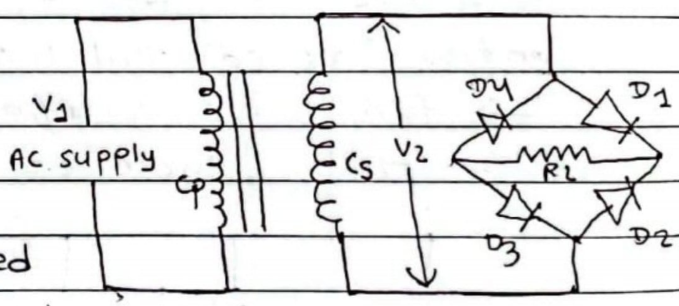
- During +ve half cycle D1 acts as forward biasing and it conduct current and it flows through R_L.
- During -ve half cycle D1 is reverse biased but D2 is forward biased and current is conducted through the D2 and it flows through R_L.

→ Thus combination of D1 and D2 acts as Full wave rectifier.

output of full wave rectifier.



ii) Bridge Rectifier



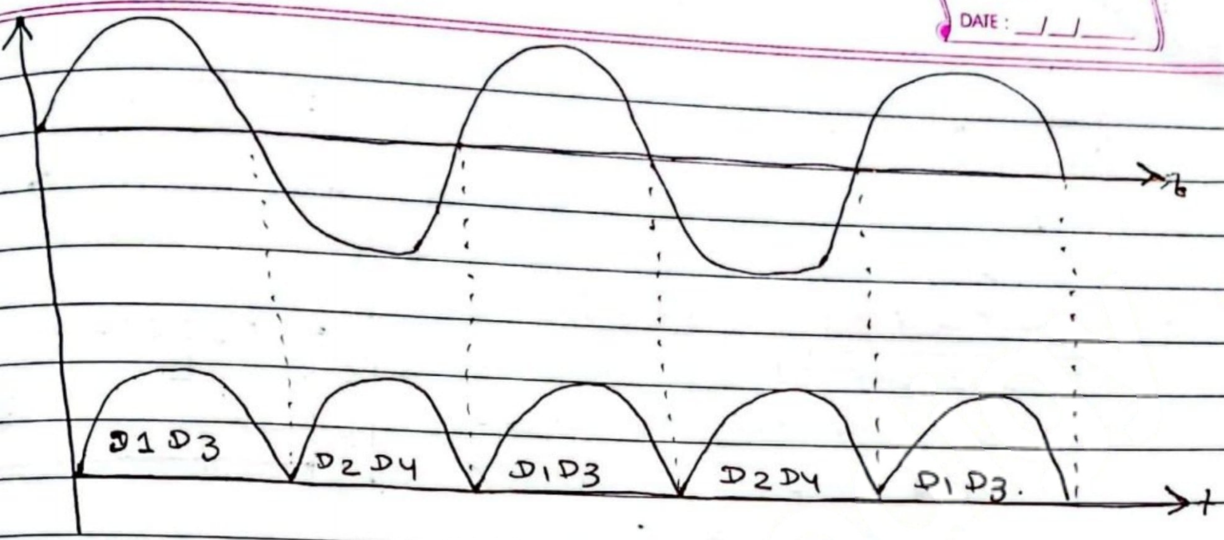
→ During +ve half

D1 & D3 are Forward biased

And D2 & D4 are Reverse biased.

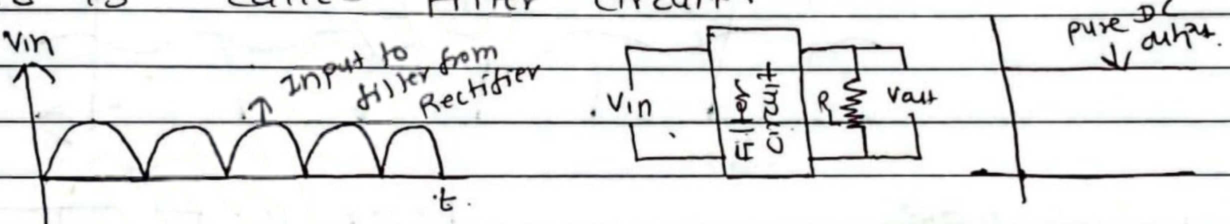
So, D1 and D3 conduct ~~elect~~ current $D_1 \rightarrow R_L \rightarrow D_3$

→ During -ve half, D1 and D3 are reverse biased and D2 and D4 are forward biased so D2 and D4 will conduct current and current will flow throuwh R_L.



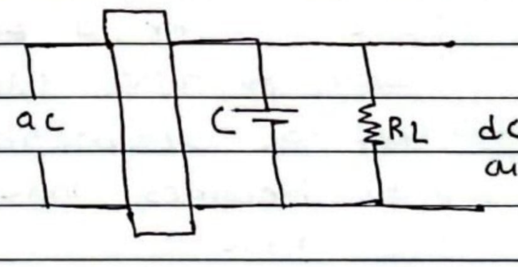
Filter Circuit

→ The circuit connected b/n rectifier and load to convert pulsating dc into steady dc is called Filter circuit.



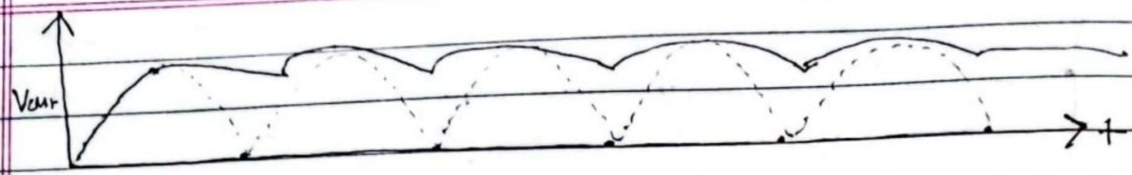
Conversion of pulsating dc into pure dc.

i) Capacitor filter (C-filter)

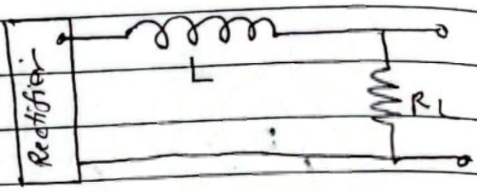


→ A capacitor of capacitance C is connected in parallel with RL as shown in fig

→ During increasing output voltage of rectifier the capacitor is charged up to its peak output voltage and during decreasing voltage it supply the stored energy. Then the output becomes as shown in the figure.

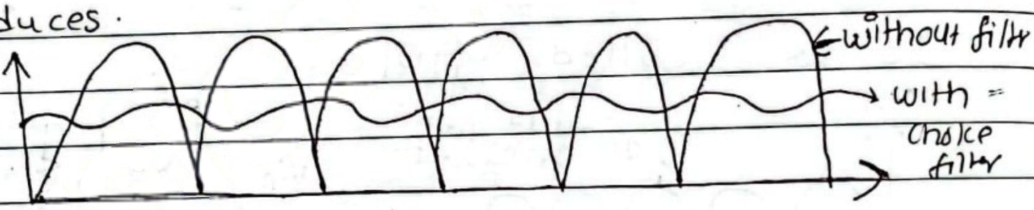


ii) Inductor Filter (L Filter)

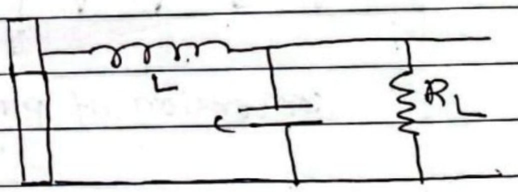


→ An inductor having inductance 'L' is connected in series with the output of Rectifier and load resistor.

→ An inductor opposes the changing current passing through it, so current through R_L becomes less fluctuating as a result voltage fluctuation also reduces.



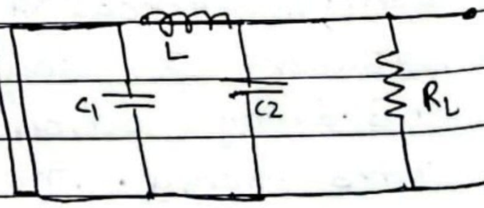
iii) LC Filter



→ one inductor in series and one capacitor in parallel with Rectifier and R_L are connected

→ Due to combination of L and C the output in R_L becomes more smooth than using L or C alone.

iv) π filter



→ Two capacitors C_1 and C_2 in parallel and one inductor L in series are connected in like π shape.

Action of each component is ;

a) Capacitor (C_1)

→ It offers low resistance for ac and high resistance for dc component. so it pass appreciable amount of ac to ground and dc to inductor.

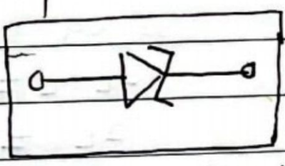
b) Inductor (L)

→ It offers high Resistance of ac and very low resistance for dc so it blocks ac and let dc pass easily through it.

c) Capacitor (C_2)

→ It behaves as C_1. It bypass ac component to rectifier output which could not be blocked by inductor 'L'. As a result only steady dc is available to output

Zener Diode :-



→ It is the special kind of junction diode which is heavily doped and and works in reverse bias condition.

→ It's depletation is very thin (depletation layer)

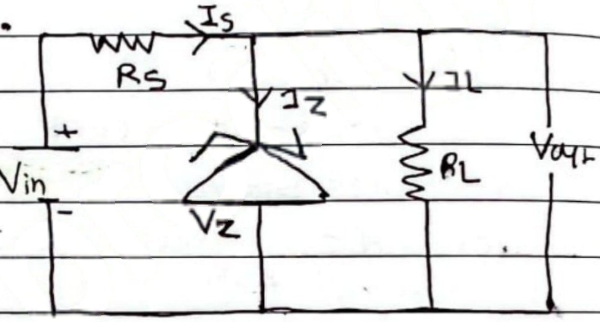
→ It works as voltage Regulator.

→ Electric Field produced is greater than PN-Junction

Zener Diode as Voltage Regulator (Imp)

→ The device which is used to regulate constant voltage is called voltage regulator.

→ Zener diode can be used as voltage regulator by keeping in parallel with load Resistance in reverse biased condition.



Let V_{in} be input voltage and R be resistor.

when, $V_{in} > V_Z$

Applying KCL, we get

$$I_S = I_Z + I_L \quad \text{— (1)}$$

$$V_{in} = V_{out} + I_S R_S$$

$$V_{out} = V_{in} - I_S R_S \quad \text{— (2)} \qquad [V = \varepsilon - IR]$$

$$V_o = V_Z = I_L R_L$$

so equation (2) becomes

$$I_L R_L = V_{in} - I_S R_S \qquad (V_S = I_S R_S)$$

$$I_L = \frac{V_{in} - V_S}{R_L}$$

Working in detail :-

- When input Voltage increases beyond a certain limit the current through the circuit rises sharply causing a sufficient increase in the voltage drop across the Resistance Rs.
- Thus the voltage across zener diode remains Constant and also the output voltage remain constant at Vout.
- When input voltage decreases, then the current through the circuit goes down sharply causing sufficient decrease in voltage across Rs. As a result output voltage will again remains constant.

* zener diode works only if $V_{in} > V_Z$
* when $V_{in} < V_Z$ no current pass through diode (i.e $I_Z = 0$) and all input voltage drop across the load Resistance R_L. $\boxed{V_{out} = V_{in} \text{ at } I_Z = 0}$
* when $V_{in} = V_Z$, the breakdown point is reached and voltage across the diode is constant.
* When $V_{in} > V_Z$, the output remains constant but there is increase in Voltage across Rs. Hence the voltage is regulated.

Here, $V_{in} = V_Z + V_S = V_Z + I_S R_S$

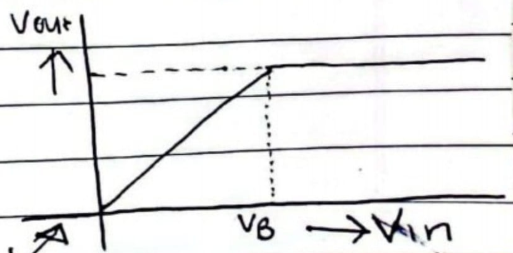
$$\therefore I_S = \frac{V_{in} - V_Z}{R_S}$$

The current through load Resistance (R_L) is I_L

So, $I_S = I_Z + I_L$

or, $I_L = I_S - I_Z$

or $I_Z = I_S - I_L$.



Voltage Regulation curve

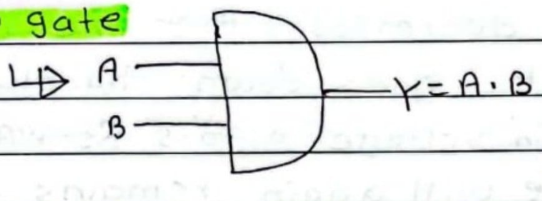
Logic Gate

→ They are electronic circuit used to make logical decisions. They are of two types.

i) Simple logic gates
- → AND gate
- → OR gate
- → NOT gate

(ii) Compound logic gates
- → NAND
- → NOR
- → XNOR etc.

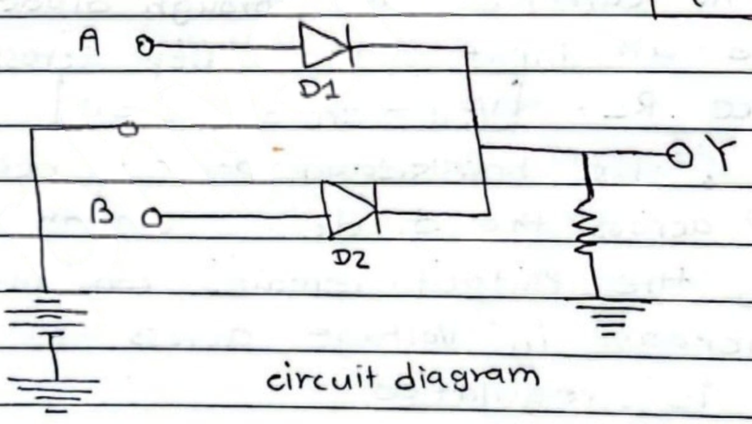
AND gate



output is ON, if all inputs are on

Truthtable.

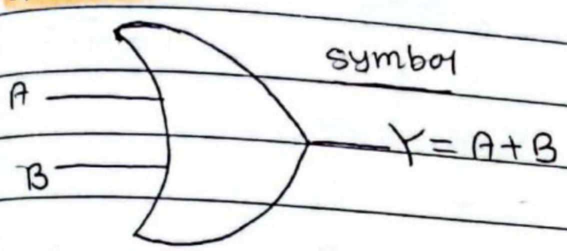
Input		output
A	B	Y = A·B
0	0	0
0	1	0
1	0	0
1	1	1



circuit diagram

OR Gate:

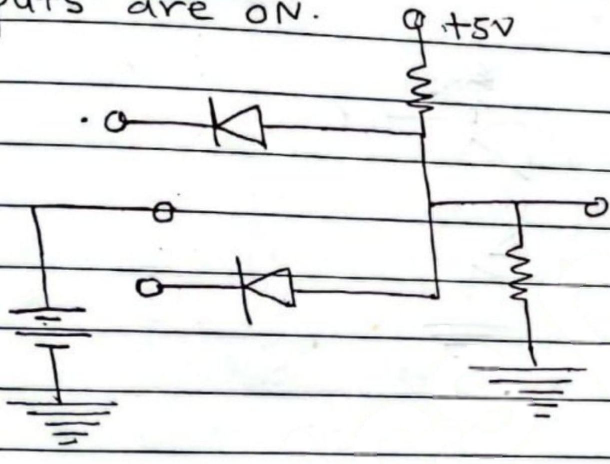
symbol



INPUT		Output
A	B	Y=A+B
0	0	0
0	1	1
1	0	1
1	1	1

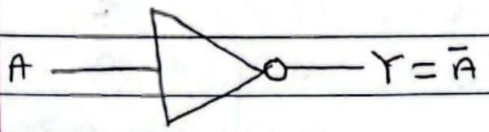
Truth table.

output ON, if either or all inputs are ON.



circuit diagram.

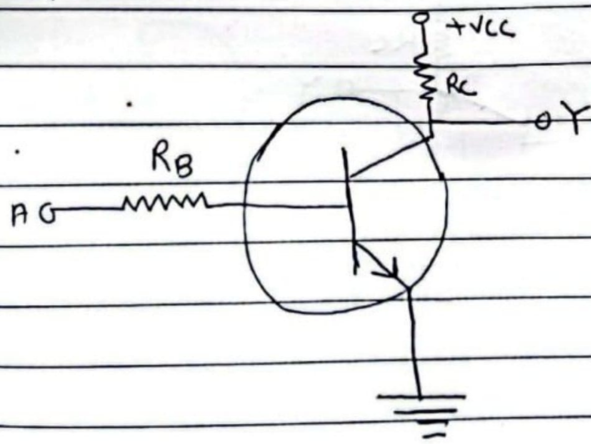
NOT Gate



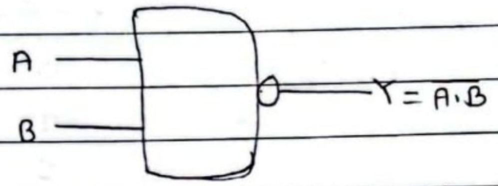
Truth table

Input	output
A	$Y=\bar{A}$
1	1
0	0

output is OFF, if input is on and viceversa.

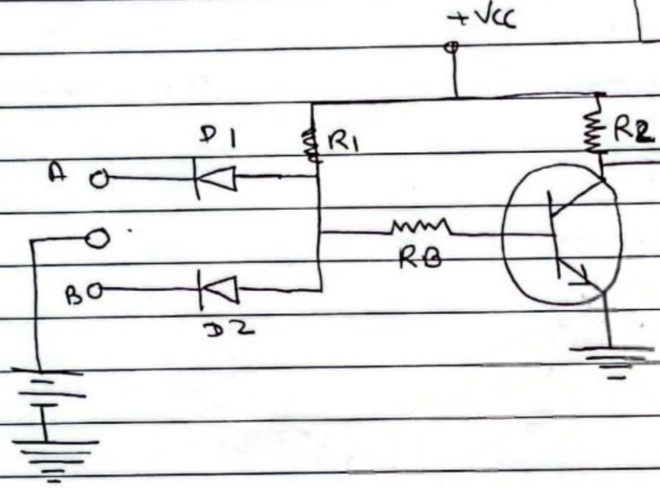


NAND Gate.

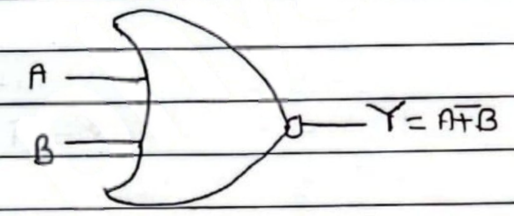


INPUT		OUTPUT
A	B	$Y = \overline{A \cdot B}$
0	0	1
0	1	1
1	0	1
1	1	0

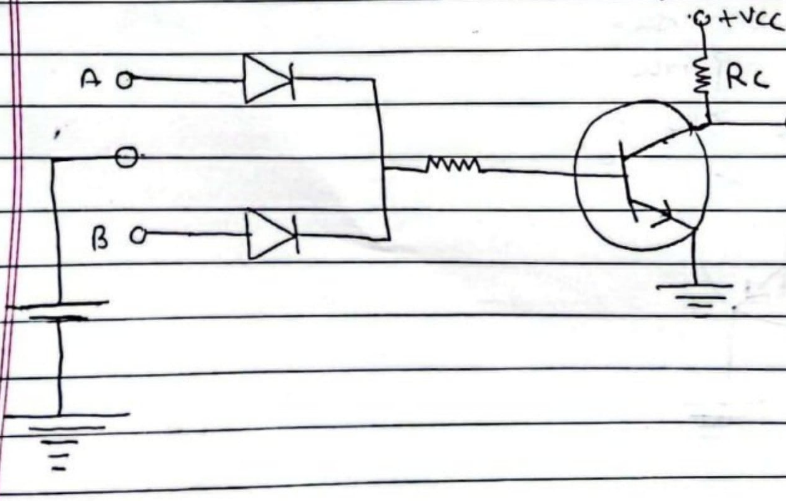
Truth table



NOR Gate



INPUT		OUTPUT
A	B	$Y = \overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0



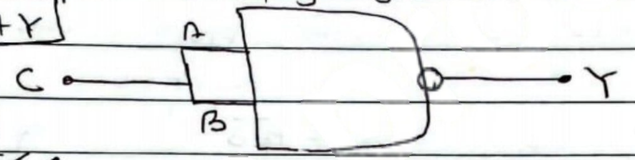
NAND Gate as Universal gate

NAND gate is called as universal gate because all other gate can be made from NAND gate. When it is combined with other types of gates, NAND gate can be used to design all three basic gates.

i) NOT gate from NAND gate.

A NAND gate serves as a NOT gate, when its input are simply joined together.

INPUT	OUTPUT Y
0	1
1	0



(A=B=C)

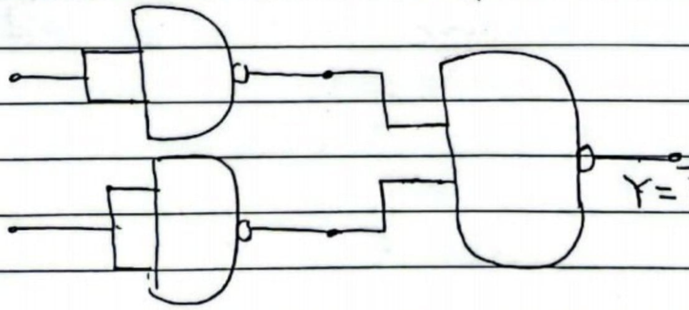
Fig :- NOT gate by NAND gate.

since, both the input of AND gate are joined together, there is only one input.

Above ~~throut~~ truth table justifies that the combination is NOT gate.

ii) OR Gate from NAND gate.

→ OR gate can be obtained from NAND gate when output of two NOT gates formed by NAND gates are connected to two inputs of a NAND gate as shown:



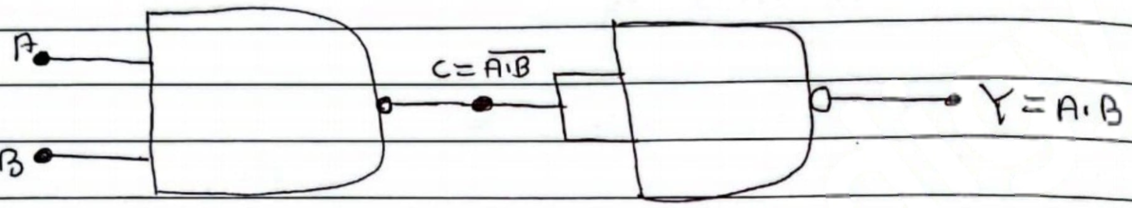
$Y = \overline{\overline{A} \cdot \overline{B}} = A+B$.

A	B	A+B
0	0	0
0	1	1
1	0	1
1	1	1

Output of truthtable looks like OR gate.

iii) AND gate from NAND gate.

→ When the output of a NAND gate is connected to input of a NOT gate formed from NAND gate. Then we get AND gate.



The truthtable of obtaining from above figure is given below ;-

A	B	C = $\overline{A \cdot B}$	Y = A·B
0	0	1	0
0	1	1	0
1	0	1	0
1	1	0	1

Questions

1) Blah Blah Blah - - - - .

(a) What is p-n junction diode? How do free electrons and holes flow in p-n junction diode?

→ In p-side of p-n junction diode there are holes and in n-side there are large number of free electrons. As we know, charge flows from higher concentration to lower concentation so electrons from n-sides flow towards holes in p-side and viceversa.

(b) Explain the mechanism of formation of positive and negative ions at p-n junction.

→ The electrons from p-side flow to n-side and fill the holes present so there is formation of positon ions. Similarly when e from p-side fallow to n-side there is formation of hole which forms positive ion at n side.

2a) Explain what is the necessity of reverse biasing in zener diode.

→ zener diode is special type of p-n junction diode which is heavily doped and desighed to work in reverse biasing voltage. Reverse biasing controls the output voltage at specific value. If voltage increases above zener voltage, it controls and provides constant output voltage. so reverse ~~b~~ biasing plays vital role in zener diode.

(b) .