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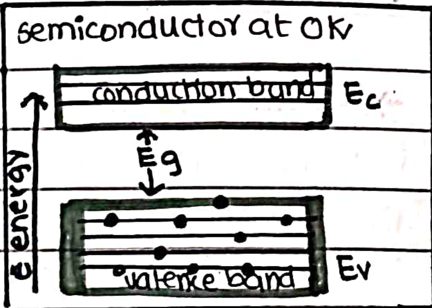
ELECTRONICS

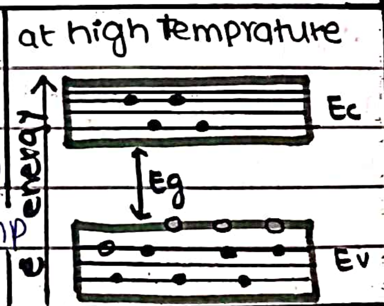
"Electronics is the science that deals with electronic circuits that operate by controlling the flow of electrons or other electrically charged particles or electronics deals with flow of charge (electron) through non-metal conductors (semiconductors)."

→ **Semiconductor:** "A perfect, pure semiconductor containing no impurities is called an intrinsic semiconductor. Semiconductors have an intermediate electric conductivity b/w conductors and insulators."

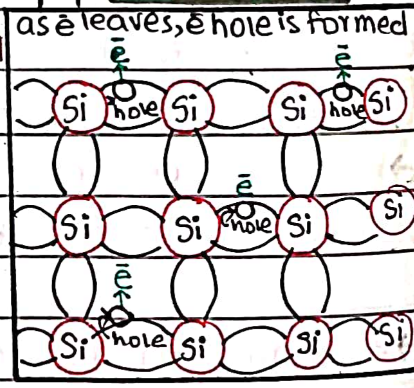


→ **Energy band structure:** For a semiconductor, valence band and conduction band are separated by an energy gap less than that of insulators and more than conductors.

→ **at 0K:** at 0K, electrons in valence band do not possess enough energy to jump into conduction band thus semiconductor behaves like an insulator as applied electric field can not cause electrons to flow.



→ **At high temprature:** When energy is provided, ēs jump from valence to conduction band leaving electron holes in valence band. Those electrons which acquire potential energy equal to or in excess of the bandgap energy Eg are excited from valence band to conduction band.



→ **Electron holes:** When ēs jump from valence band they leave holes. Nature of these holes is such that it attracts other neighbouring ēs to enter the hole (just like +ve attracts -ve). As neighbouring electron enters the hole, it leaves another hole in its place. Thus electron holes travel oppositely to electrons.

→ **Doping of Impurities:** "An addition of impurity into an intrinsic semiconductor is called doping. The impurity added is called dopant"

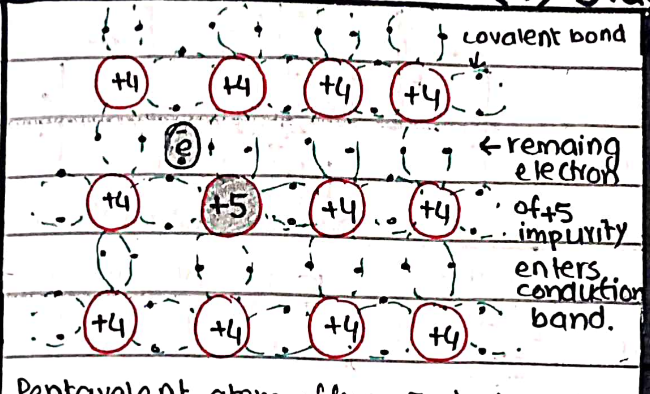
→ **Why are dopants used:** Dopants are used to increase conductivity of intrinsic semiconductors. Once impurity is added they are termed as extrinsic semiconductors

→ **What kind of dopants are used and why?** Pentavalent elements from Group V and trivalent elements from group III are used because they are nearly of same size as silicon or germanium atoms and do not manipulate the crystal structure of host semiconductors.

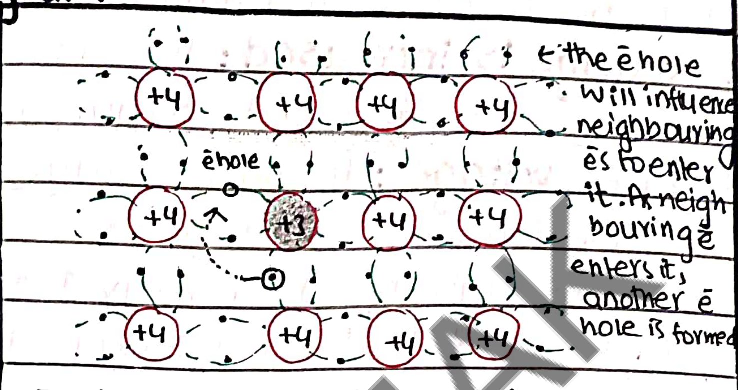
Depending upon dopant, there are two types of extrinsic semiconductors :-

N-TYPE SEMICONDUCTOR	P-TYPE SEMICONDUCTOR
(i) Production	
→ Produced when pure semiconductor is doped with pentavalent impurity like [Phosphorous, Arsenic] dopants.	→ Produced when pure semiconductor is doped with trivalent impurity example: Boron, Aluminum] dopants
(ii) Role of impurity atoms	
→ Impurity atoms act as donors this is because they donate ē's to the conduction band. Suppose 'Phosphorous' is doped with 'Si' 'Si' forms 4 bonds, 'P' forms 5. Thus 1ē is donated by each 'P'.	→ Impurity atoms act as acceptors they attract ē's from valence band to complete their 4 bonds as they can only form 3 due to only having 3 valence electrons.
(iii) Mechanism of conduction	
→ Free negative ē's in C band conduct at high T. (No electron holes present)	→ Electron holes attract ē's and this motion of ē is responsible for conduction.
(iv) Majority carriers/reason behind name	
→ As negative charge carriers (majority carriers) i.e ē's are responsible for current, these are called 'N-Type' → Here electron holes are minority carriers	→ As positively charge carriers (majority carriers) i.e electron holes are responsible for current, they are called 'P-Type' Here free electrons are minority carriers

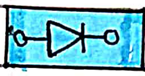
(V) Diagram



▲Pentavalent atom offers 5 electrons for bonding but Si only makes 4 bonds



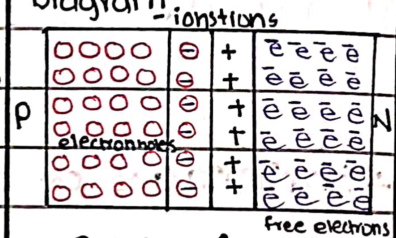
▲Trivalent atom offers 3 ēs for bonding but Si makes 4 bonds thus ē hole is formed.

➡ PN Junction: 

→Construction: When P-type crystal with in contact with N-Type crystal is subjected to high pressure, it becomes a single piece called as PN Junction

→Depletion layer formation: P type crystal contains electron holes and N type contains free electrons due to trivalent and Pentavalent valency of impurity respectively. At the region of contact, free ēs flow from N-type to the electron holes in nearby area of P type. This causes a layer of negative ions in P type facing the N-Type and a layer of positive ions in N Type adjacent to layer of negative ions. This region containing +ve and -ve ions is called depletion layer.

Diagram



▲PN Junction

→ Potential wall: Potential wall is established at junction which doesn't allow movement of any more free electrons from N-Type to P Type.

→Connection with variable voltage: When P-Type is connected to +ve terminal and N-Type is connected to -ve terminal flow of charges through junction can be made possible.

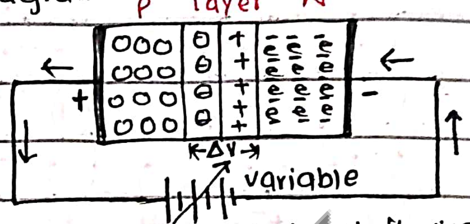
Initially: charge in the circuit when arrives at N-Type terminal it will be repelled because overall nature of N-crystal is negtive due to free electrons at terminal site.

As voltage is increased: As voltage is increased, ēs in the circuit obtain energy.

At 'knee voltage': At knee voltage which is 0.3V for germanium and 0.7V for silicon, ēs gain enough kinetic energy to flow through the P-N diode and through the Depletion barriers. When

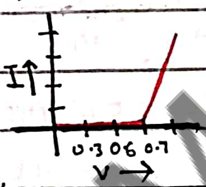
Current through the junction: After crossing the barrier, charges enter ē holes and jump from hole to hole. Thus we can say that motion of electrons is opposite to that of electron holes. Finally current leaves the PN-Type and flows through the circuit back to the battery. This forward motion is forward bias and current is called forward current

Diagrams



▲ at knee voltage, current starts flowing

graph



← this IV graph shows that at 0.7 volts for silicon junctions, the current starts flowing. Before that no current flows through circuit

motion of ēs through ēholes

as electron moves forward, it leaves ~~an empty electron hole behind it.~~ Thus we can say that if motion of ē is towards left, motion of ēhole is towards right.

→ Shrinkage of depletion layer: When P-type region is connected with positive potential with respect to N-Type, the depletion layer shrinks

→ Bulking of depletion layer: When N-Type region is made positive with respect to P-Type, depletion layer thickens. This is called reverse bias and the current (a very small amount as very less charge carriers cross the junction in this case) is called reverse current.

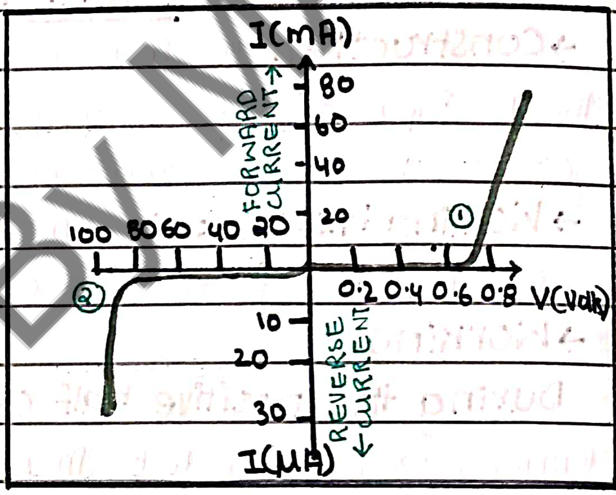
→ Important point: Thickness of depletion layer ∝ Resistance to current

→ leakage current in reverse bias: The small amount of current called leakage current gets an oppurtunity to flow because despite the N side containing majority free electrons, it also has electron holes. And the P side contains minority free electrons similarly. These free electrons are attracted by the electron holes of the N side. This causes leakage current of the order of a few micro amperes.

→ **Zener effect:** In reverse bias, if voltage is increased, a few bonds (covalent) break in the junction releasing electrons which flow through the junction.

→ **Avalanche effect:** This is the last extreme voltage is increased to such a high level that maximum covalent bonds break due to high energy which causes a rapid rush of electrons. (electrons ka (طوفان)) beyond this, the junction is destroyed.

→ **IV graph of silicon diode:**



① Voltage keeps on increasing but current does not increase till voltage reaches 0.7 volts or knee voltage at which the graph dramatically turns upward showing increase in current. This is for forward bias.

② Unlike forward bias, some leakage current flows before graph changes dramatically. At 90 volts, avalanche effect is depicted. Maximum current flows. This is reverse bias.

→ DRIFT OF MINORITY CARRIERS:

→ **Minority carriers in P-region:**
Minority carriers in P region are electrons (free)

→ **Minority carriers in N-region:**
Minority carriers in N-region are electron holes

→ **Drift:** Electric field assists the minority carriers to flow across the junction from their respective regions. This flow is very minute. Free electrons move to N region whereas holes move to P region. (Note: holes aren't positive like protons. holes just have a positive effect as an electron hole attracts electrons)

→ **Drift current:** "Current constituting minority carriers aided by electric field is drift current."

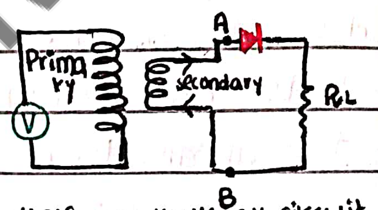
$$I_{drift} = I_e + I_h$$

→ **Rectification**: "The conversion of A.C (alternating current) into D.C (direct current) is called rectification and the device used is called rectifier."

→**Use:** Some electronic devices use DC for their operation and DC supplies are expensive, low power and short lived thus a DC supply is generated by using an AC supply which is inexpensive and not short lived. Diodes are used for this purpose as rectifiers.

HALF WAVE RECTIFIER

Diagram



▲Halfwave rectifier circuit

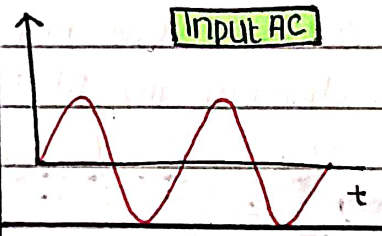
→**Construction:** This circuit uses a transformer to couple the AC input voltage. Secondary coil is joined with diode and load resistance in a series circuit.

→ **Working Principle:** Converts half wave of the AC into DC through forward and reverse bias.

→**Working**

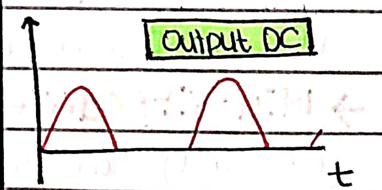
During the positive half cycle: If point A is at +ve terminal with respect to B, then diode is forward biased so it offers low resistance and current flows through it and through load resistance.

Input voltage across A



During the negative half cycle: Point A is now at -ve potential as current switches polarity diode is reverse biased so it offers very high resistance and no current flows through R.

Output voltage across RL



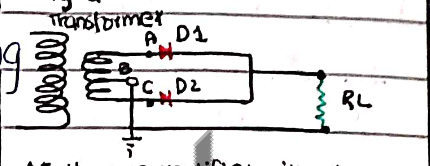
→ **Net result:** This procedure carries on for next half cycles. Diode allows positive half cycle through it and stops the negative half cycle. Net result is that current flows in only one direction and that is Direct current.

The direct current has pulses thus it is called as pulsating DC.

FULL-WAVE RECTIFIER

→ Construction: A transformer with centre-tapped secondary winding and two diodes in alternate switching mode along with a load resistance R_L.

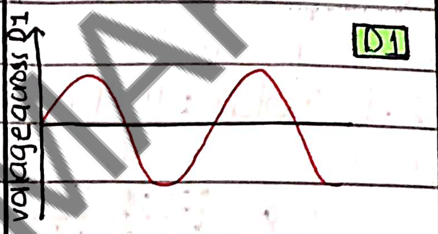
Diagram



▲Full wave rectifier circuit

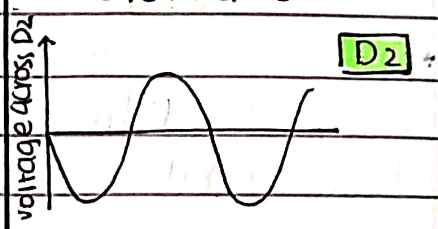
→ Working: Converts both the half cycles of input A.C signal into the D.C signal.

Wave form at A



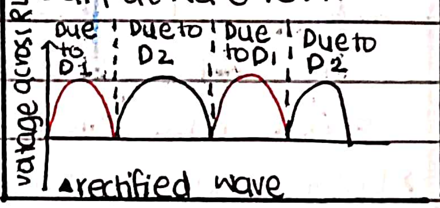
- **During 1st half cycle of AC:** Point A becomes positive and point B becomes negative thus D1 becomes forward biased, D2 becomes reverse biased. No current flows through D2

Wave form at B



- **During 2nd Half cycle of AC:** Point C becomes positive and A becomes negative thus D2 becomes forward biased. D1 becomes reverse biased. No current flows through D1, it is said to be switched off while D2 is turned on.

Out put wave form



▲rectified wave

- **Role of R_L:** load resistance enables the current to adopt an alternative path when one of the diodes isn't switched off. If R_L isn't present, current wont be able to flow back to the battery.

→ Net result: For first half cycle, the current is due to D1 and for 2nd half cycle, current is due to D2. In one complete cycle, the direction of current through R_L is same. Thus full wave is rectified.

→ Which rectifier is more efficient: Full wave rectifier is more efficient as it converts entire AC wave into DC whereas half wave rectifier converts half AC wave into DC.

→ Bridge Rectifier: Full wave rectifier consisting of four diodes is called bridge rectifier.

→ Transistor:

"A transistor consists of two back to back PN-junctions made in a single piece of semi-conductor crystal. The word transistor is short form of transference of signal across a resistor."

TYPES

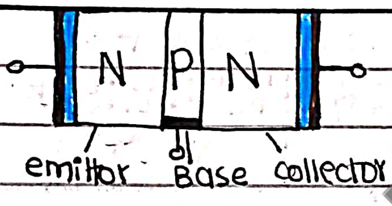
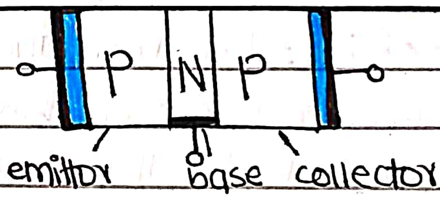
1. Bipolar: Its function depends upon both minority and majority charge carriers. Sometimes they are called Bipolar Junction Transistors (BJTs)

2. Unipolar: Its function depends upon majority charge carriers. It is also called field effect transistor (FET)

→ FURTHER TYPES OF BIPOLAR TRANSISTOR

NPN	PNP
→ When P-Type substance is sandwiched between two P-Type substances, then device formed is called NPN transistor.	→ When N-Type substance is sandwiched between two P substances, then device formed is called NPN transistor

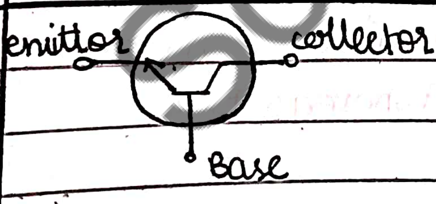
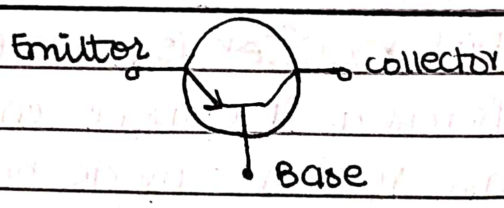
Diagram

NPN	PNP
 → Emittor and collector are N-Type → Common base is P-Type.	 → Emittor and collector are P-Type → Common base is N Type.

Majority Carriers

NPN	PNP
Electrons	Electron holes

Symbol

NPN	PNP
	

→ **Which transistor is more preferred?** In most cases NPN because mobility of electrons is three times more than that of holes and thus operation is fast

PARTS OF TRANSISTOR

→Emitter: The emittor has greater concentration of impurity atoms as compared to collector. so it has more charge carriers than collector. Emitter emits the majority charge carrier. Emitter is smaller in size than collector.

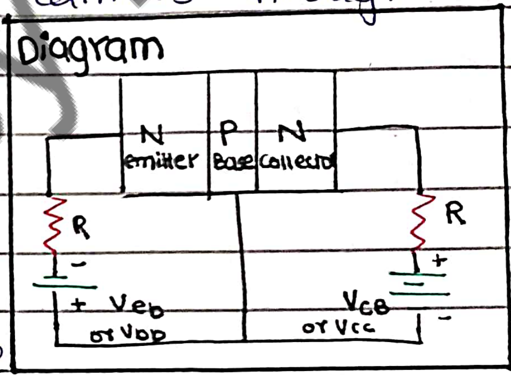
→ Base: central region is called base. It has low conc. of impurity as compared to emittor and collector. It controls flow of current from emitter to collector.

→Collector: collector collects majority charge carriers through base. it has less impurity than emittor.

→ Biasing of a transistor

- Emitter base junction is forward biased
- collector base junction is reverse biased
- Emitter base junction offers low resistance
- Collector base junction offers high resistance

Diagram



→Grounding base: Collector current is almost equal to emittor current. since base is lightly doped, minute current retains in base this is why base is grounded.

We can write $I_E = I_B + I_C$

WORKING OF TRANSISTOR

→Forward bias: Emittor base junction

→Reverse bias: Collector base junction

→Application of voltage: $V_{CC} > V_{BB}$. Electrons flow from N (emittor) region to base region. Here they can opt two paths; either flow to the +ve terminal of Vcc or flow from the base to positive terminal of VBB. As Vcc is greater than VBB, most electrons flow to collector region from base due to very high potential of Vcc and very less doping of base. A few electrons still flow to VBB's +ve terminal.

→ **Emittor Current:** Total current arriving at emmitor

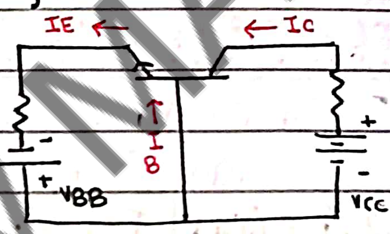
→ **Base Current:** Current exiting base to flow towards VBB. (or current formed due to combining of ē holes and electrons

→ **Collector current:** Remaining current flowing out from collector.

$I_E = I_B + I_C$

→ **How to assign directions of current in circuit?** Direction of conventional current is opposite to the flow of electrons. Thus conventional base current flows from +ve terminal of VBB into base and conventional collector current flows from +ve of Vcc to collector.

Diagram



NOTE: ‖|⊢ as compared to ⊣⊢ shows ‖|⊢ is greater than ⊣⊢

→ **Types of configurations:** Configuration refers to methods of connecting transistor in circuit. As each transistor has three terminals thus in all configurations, one of its terminal is common to both input and output circuits of transistor. There exist three types of configurations: common base (CB), common emittor (CE), and common collector (CC).

COMMON BASE

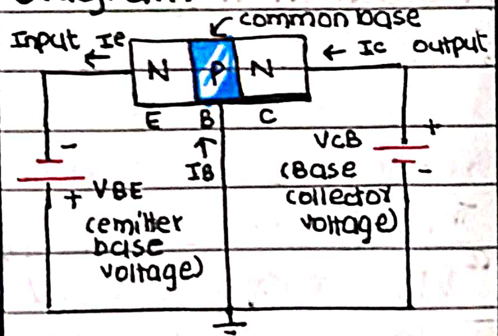
"When a base of transistor is common to both input and output circuits, then it is called common base configuration."

→ **Input terminal:** Emitter and common base terminal

→ **Output terminal:** Collector and common base terminals

→ **Common Base** Base is grounded so common base configuration is also called grounded base configuration

Diagram



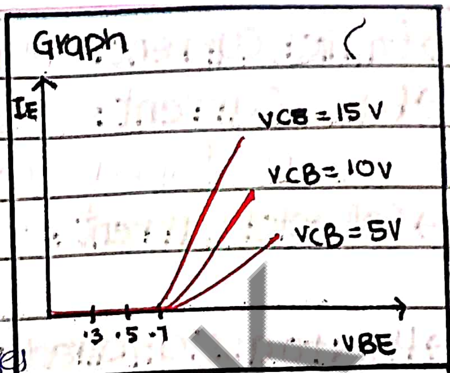
▲CB configuration.

→ **Supply voltage:** supply voltage b/w base and emitter is V_{BE} while b/w collector and base is V_{CB}

INPUT CHARACTERISTICS:

"To study from graph the variation of I_E (input current) with input voltage (V_{BE}) while output voltage is kept constant"

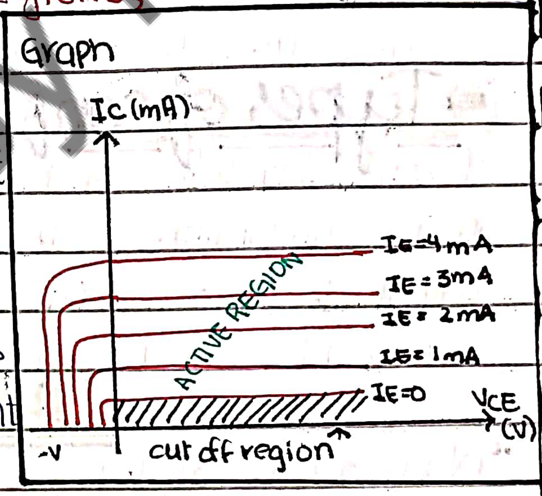
→ **Knee voltage:** At knee voltage maximum current flows (I_E) while keeping V_{CB} constant.



→ **Why are curves different for different values of VCB?**
3 different curves are obtained at 3 different constant values of VCB. As VCB increases, emitter current IE also increases and vice verse. This is because $V_{CB} \propto I_E$ (strength of VCE has effect on I_E)

OUTPUT CHARACTERISTICS:

"To study from graph of the variation of output current Ic with output voltage VCE while input current is kept constant. Output characteristics have 3 regions;"



→ **Active Region** F | R : When base emitter junction is forward biased and collector base junction is reverse biased. Here emitter current is considered nearly equal to collector current

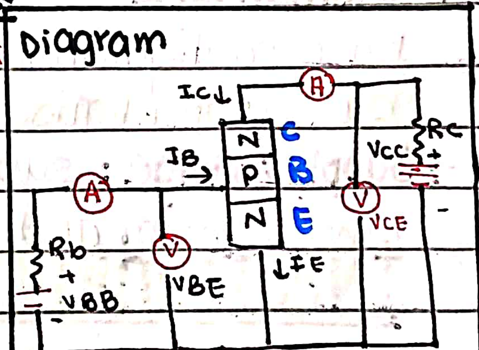
→ **Cutoff Region** R | R : When both junctions are reverse biased. This means emitter current is almost zero and thus output or collector current will be zero as well. Transistor is fully OFF

→ **Saturation** F | F : When both junctions are forward biased it is saturation region. In this case as polarity of output voltage source is reversed, -ve terminal will repel charges and thus collector current reaches to zero and all current is trapped within transistor
Transistor is fully ON.

COMMON EMITTER

" When emitter of transistor is common to both input and output circuits then it is called common emitter configuration."

→ **Input terminals:** Base and common emitter
→ **Output terminals:** Collector and common emitter



CE config.

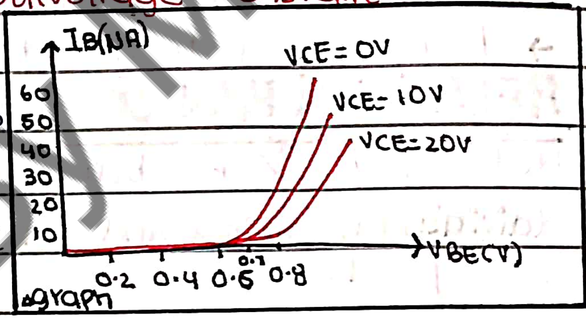
→ **Grounded portion:** Emitter terminal is grounded so it is also called as grounded emitter configuration (Note: the common region b/w both junctions is grounded).

→ **supply voltage:** supply voltage between base and emitter is denoted VBE while the supply voltage b/w collector and emitter is ~~denoted~~ denoted by VCE.

INPUT CHARACTERISTICS

"To study from graph of the variation of input current IB with the input voltage VBE while keeping VCE (output voltage constant."

→ **Effect of VCE:** If VCE is maintained at a high value, IB will be less as compared to IB for a comparitively lower VCE value. This is because VCE will attract electrons and base current will decrease.

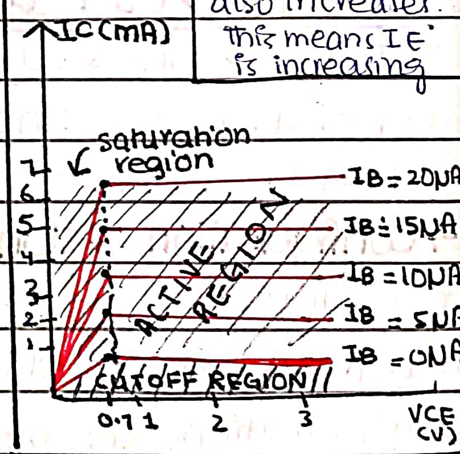


OUTPUT CHARACTERISTICS:

"Input or base current is kept constant and output voltage VCE is increased from zero volts to different voltage levels and the corresponding output current (Ic) is recorded"

→ **Active region** F | R : First junction is forward biased and other is reverse biased. Keeping input current (IB) fixed at different levels by adjusting input voltage (VBE), for each level output voltage (VCE) and the correspon ding output current (Ic) is recorded.

as Base current increases, Ic also increases. This means IE is increasing



→ **Cut off region** R | R : Both emittor and collector-base junctions are reverse biased. The input current (IB) is 0μA, transistor operates in cutoff region.

→ **Saturation Region** F | F : Both junctions are forward biased at knee voltage charges get trapped as they have no path to flow.

→ **Important points:** In saturation region, transistor is fully OFF while in cut-off region, transistor is fully ON.

ALPHA FACTOR: "Ratio of collector current Ic to emitter current IE is called alpha factor. It is an amplification factor"

→ **Mathematically**:

$\alpha_{static} = I_C/I_E$	(when current is fixed)
$\alpha_{dynamic} = \Delta I_C/\Delta I_E$	(when current is changing)

as $I_C \approx I_E$, $\alpha \approx 1$.

→ α-factor tells us how much emitter current is converted into collector current.

BETA FACTOR: "Ratio of collector current Ic to base current IB is called current gain beta factor."

→ **Mathematically**: $\beta_{static} = I_C/I_B$ $\beta_{dynamic} = \Delta I_C/\Delta I_B$

→ β factor ranges from 50 to 400.

RELATION B/W α & β-FACTOR:

we know $\beta = I_C/I_B$ but $I_B = I_E - I_C$ thus $\beta = \frac{I_C}{I_E - I_C}$

(dividing nominator and denominator by IE to achieve α-factor)

$$\beta = \frac{I_C/I_E}{(I_E - I_C)/I_E} \qquad I_C/I_E = \alpha$$

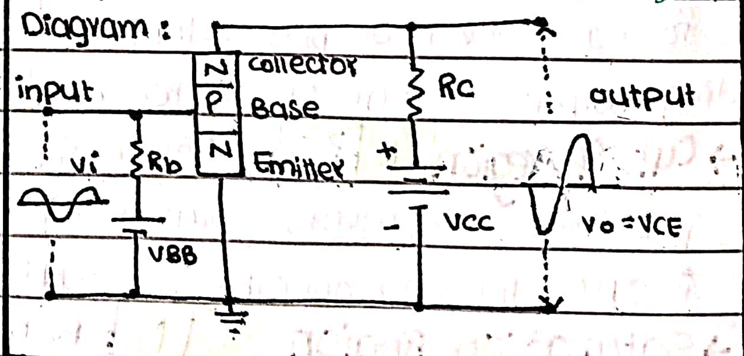
Thus $\boxed{\beta = \frac{\alpha}{1-\alpha}}$ or $\boxed{\alpha = \frac{\beta}{1+\beta}}$

$$\beta = \frac{\alpha}{1-\alpha}$$
$$\beta(1-\alpha) = \alpha$$
$$\beta - \beta\alpha = \alpha, \quad \beta = \alpha + \beta\alpha$$
$$\beta = \alpha(1+\beta)$$

→ **Transistor as an amplifier**: "Amplification is the process of increasing the strength of a signal. An amplifier is the device that provides amplification of a signal (the increase in current voltage or power of a signal) without changing the original signal."

→ **Configuration of transistor**: All three configurations i.e CE, CB, CC can be used as transistor amplifier but C-E configurations are most commonly used.

Diagram:



→ **Basic working**: (considering a C-E amplifier). Input signal is given through Base-Emitter terminal. Output amplified signal is obtained at collector-Emitter terminal. 'VBB' forward biases base emitter junction.

'VCC' reverses base-collector junction. (VCC >> VBB). VBE is input voltage and VCE is output voltage.

→ As the input signal voltage adds up with 'VBE', the emitter current and the base current increases. As a result collector current also increases and an amplified signal is obtained at output terminal.

→ **Mathematically:**

- INITIALLY WHEN INPUT SIGNAL IS NOT INVOLVED:

Input current → $I_B = V_{BE}/r_i$ (By ohm's law where 'ri' is internal resistance offered by transistor)

Output current → $\beta = I_C/I_B$, $I_C = \beta(\text{gain}) \cdot I_B$

Output voltage → $V_{CC} = V_{CE}$ (collector emitter) + V_R (voltage across resistance)

$V_{CC} = V_o$ (output voltage or V_{CE}) + $I_C R_C$ where $V_R = I_C R_C$

$V_o = V_{CC} - I_C R_C$

[here $I_C = \beta \cdot I_B$ where $I_B = V_{BE}/r_i$ thus $I_C = \beta \cdot V_{BE}/r_i$]

thus $$V_o = V_{CC} - \left(\frac{\beta V_{BE} \times R_C}{r_i}\right) \quad (A)$$

- WHEN INPUT SIGNAL IS INVOLVED:

(i) V_{BE} changes to $V_{BE} + \Delta V_{in}$ (input signal voltage)

(ii) I_B changes to $I_B + \Delta I_B$

(iii) I_C changes to $I_C + \Delta I_C$

(iv) V_o changes to $V_o + \Delta V_o$

} since increase in I_B causes an increase in I_C, $\uparrow I_C = \beta \cdot I_B \uparrow$

Putting change values in eq. (A) we get

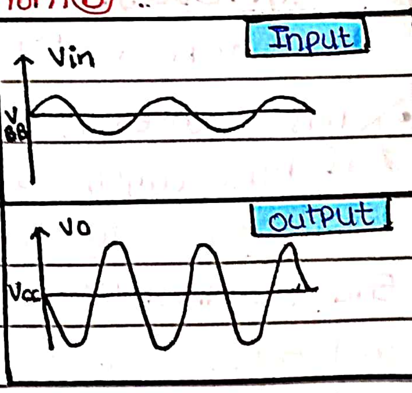
$$V_o + \Delta V_o = V_{CC} - \frac{\beta(V_{BE} + \Delta V_{in}) R_C}{r_i} \quad (B)$$

calculating change in voltage by subtracting (A) from (B)

$$(V_o + \Delta V_o) - V_o = V_{CC} - \beta\frac{(V_{BE} + \Delta V_{in})}{r_i} R_C - \left(V_{CC} - \beta\frac{V_{BE}}{r_i} R_C\right)$$

$$\cancel{V_o} + \Delta V_o - \cancel{V_o} = \cancel{V_{CC}} - \cancel{\frac{\beta V_{BE} R_C}{r_i}} - \beta\frac{\Delta V_{in}}{r_i} R_C - \cancel{V_{CC}} + \cancel{\frac{\beta V_{BE}}{r_i} R_C}$$

$$\Delta V_o = -\beta \frac{\Delta V_{in}}{r_i} R_C \quad \text{or} \quad \frac{\Delta V_o}{\Delta V_{in}} = -\beta \frac{R_C}{r_i}$$



→ **gain of amplifier is:** $A = -\beta \frac{R_C}{r_i}$. This factor is in the order of hundreds thus input voltage is amplified.

→ **negative sign:** shows there is a phase shift of 180° between input and output signals.

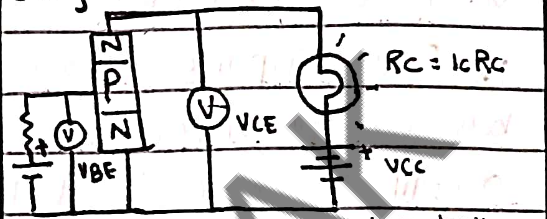
Side box: Here's what notations for voltage stand for :)

- VBE → Emitter base voltage (common to E & B)
- VCE → Collector emitter voltage
- VCC → High voltage connected with resistance 'R_C'
- VCB → Collector base voltage
- VBB → voltage at terminal with resistance 'R_B'

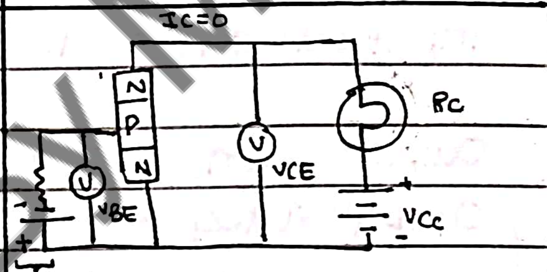
→ Transistor as a switch :

"Transistor switches form the basis of all electronic computers."

Diagram



▲ at first bulb doesn't light up but as I_C increases so much that $V_{CE} \approx 0$ bulb lights up. switch is ON.



polarity reversed.

▲ as there is no current through bulb $V_{CC} = V_{CE}$ and switch is OFF or open.

→ Transistor switch ON: When PN junction is forward biased, depletion region becomes very thin thus base current increases. As base current increases, collector current I_C also increases. There comes a point when maximum current flows through load due to great increase in I_C such that V_{CE} becomes approximately zero. Transistor is saturated.

Mathematically:

$V_{CC} = V_{CE} + V_\gamma$ (across resistance / bulb)

$V_{CC} = V_{CE} + I_C R_C$ $\quad V_{CE} \approx 0$

$V_{CC} = V_\gamma$

→ Transistor switch OFF: If emitter base junction is reverse biased, no base current will be present and along with that no collector current I_C will be present either. Thus no current flows through load. Transistor is said to be cut-off.

Mathematically

$V_{CC} = V_{CE} + V_\gamma$

$V_{CC} = V_{CE} + I_C R_C$ $\quad$ But $I_C = 0$ (as $I_C = \beta I_B$ where $I_B = 0$)

$V_{CC} = V_{CE}$

→ Conclusion: When transistor is used as a switch, its activity as a switch is determined by base current I_B through transistor. If base current is zero, no collector current is there and thus switch is OFF. If base current is increased by increasing VBB voltage, collector current develops significantly and switch is ON.

End of Chapter Note: When attempting the paper draw both diagrams for junctions and transistor i.e., ① having symbol ⊳|, (transistor symbol with B, E) as well as ② conventional representation eg. (NPN block).