UNIT-IV

Fundamentals of semiconductor devices and digital circuits

Lecture 28

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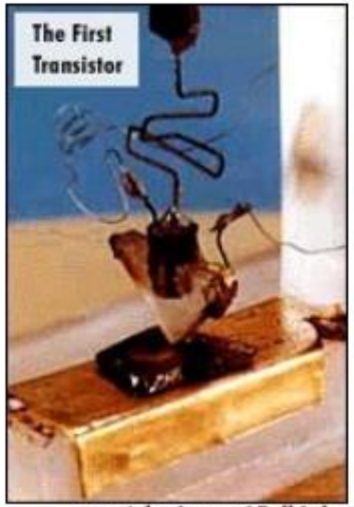
Transistors

- The scientists that were responsible for the 1947 invention of the transistor were: John Bardeen, Walter Brattain, and William Shockley.
- In 1956, the group was awarded the Noble Prize in Physics for their invention of the transistor.



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BJT Transistor Structure

BJT (Bipolar Junction Transistor) is bipolar because both holes (+) and electrons (-) will take part in the current flow through the device

– N-type regions contains free electrons (negative carriers)

– P-type regions contains free holes (positive carriers)

- 2 types of BJT

– NPN transistor

– PNP transistor

- The transistor regions are:

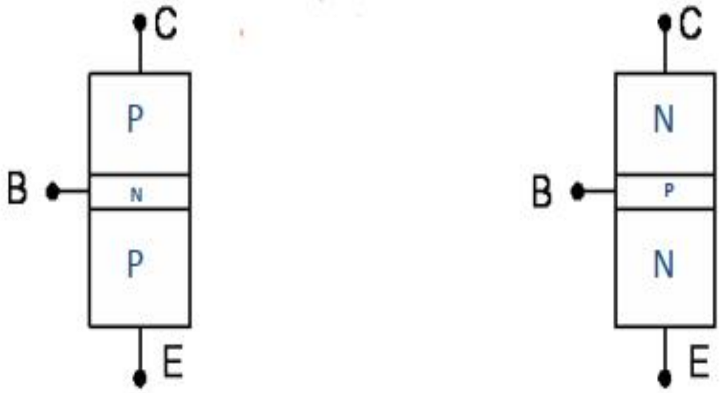
– Emitter (E) – send the carriers into the base region and then on to the collector

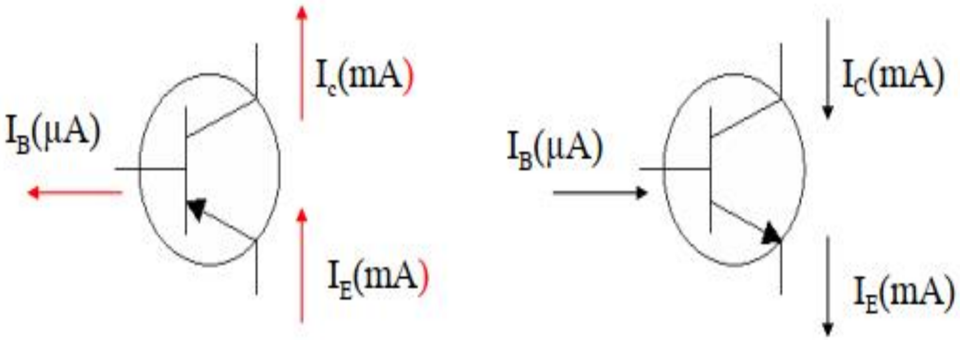
– Base (B) – acts as control region.

– Collector (C) – collects the carriers

BJT Transistor Structure

How many junction?
Terminals ?
Which current arrow represents ?

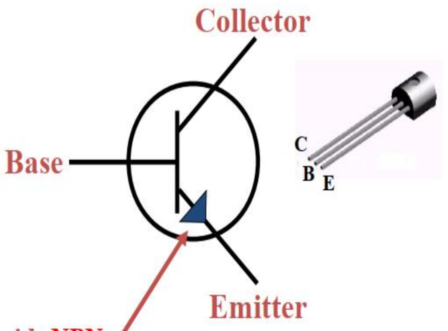




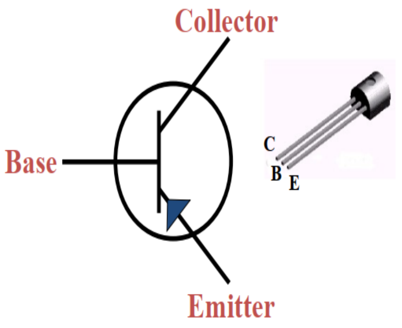
Arrow shows the current flows

ANALOGY

BJT Schematic Symbol



Memory aid: NPN means Not Pointing iN.



Memory aid: NPN means Pointing iN Properly.

Please come IN

Explanation Slide

QUICK QUIZ (POLL)

A transistor has …………………

A. one pn junction

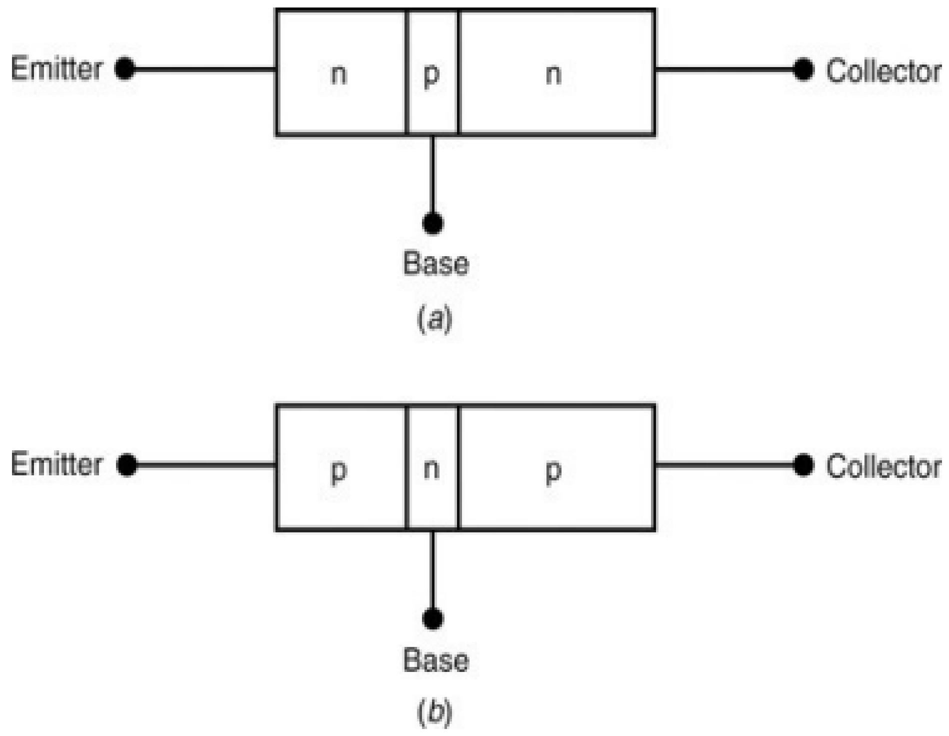
B. two pn junctions

C. three pn junctions

D. four pn junctions

BJT Transistor Construction

- A transistor has three doped regions.
- For both types, the base is a narrow region sandwiched between the larger collector and emitter regions.



- The emitter region is heavily doped and its job is to emit carriers into the base.

- The base region is very thin and lightly doped.
- Most of the current carriers injected into the base pass on to the collector.

- The collector region is moderately doped and is the largest of all three regions.

QUICK QUIZ (POLL)

The base of a transistor is …………. doped

A. heavily
B. moderately
C. lightly
D. none of the above

QUICK QUIZ (POLL)

The element that has the biggest size in a transistor is ……………….

A. collector
B. base
C. emitter
D. collector-base-junction

QUICK QUIZ (POLL)

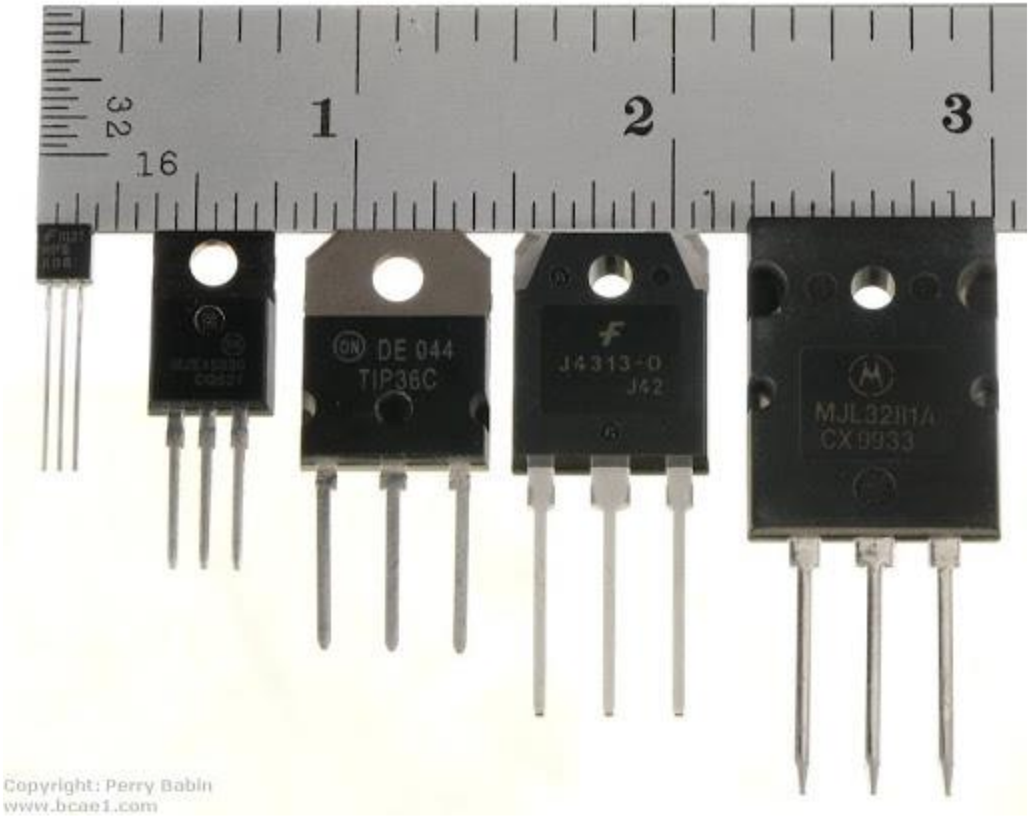
A heat sink is generally used with a transistor to ………..

A. increase the forward current

B. decrease the forward current

C. compensate for excessive doping

D. prevent excessive temperature rise



Modes of Operation in a BJT

<table>
<tr><th>Modes</th><th>EBJ</th><th>CBJ</th><th>Application</th></tr>
<tr><td>Cutoff</td><td>Reverse</td><td>Reverse</td><td rowspan="2">Switching application in digital circuits</td></tr>
<tr><td>Saturation</td><td>Forward</td><td>Forward</td></tr>
<tr><td>Active</td><td>Forward</td><td>Reverse</td><td>Amplifier</td></tr>
<tr><td>Reverse active</td><td>Reverse</td><td>Forward</td><td>Performance degradation</td></tr>
</table>

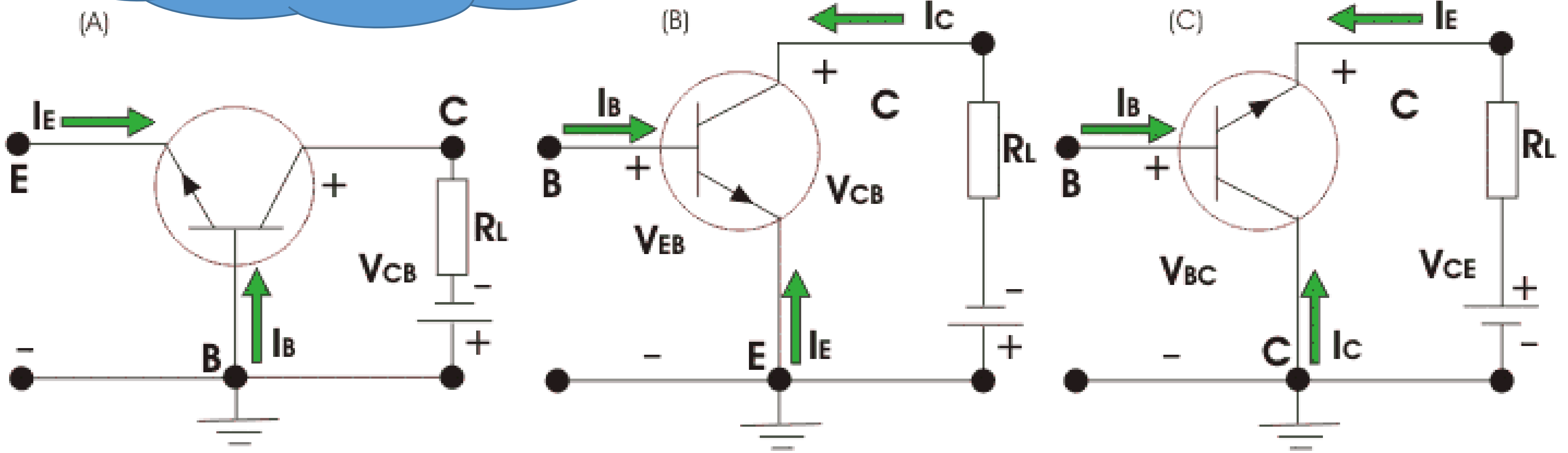
Configuration of a Transistor

- Depending on the possibilities of circuit configurations transistor connections are of three types.
  - A. Common Base Transistor
  - B. Common Emitter Transistor
  - C. Common Collector Transistor.

Input and output current and voltages

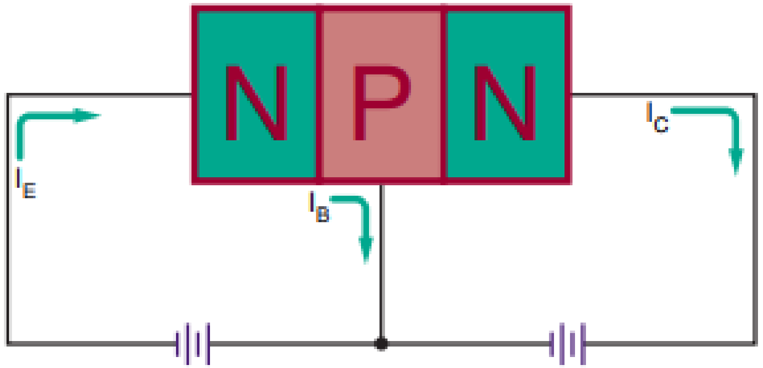
Current controlled Device

Arrow shows Direction of conventional current ???

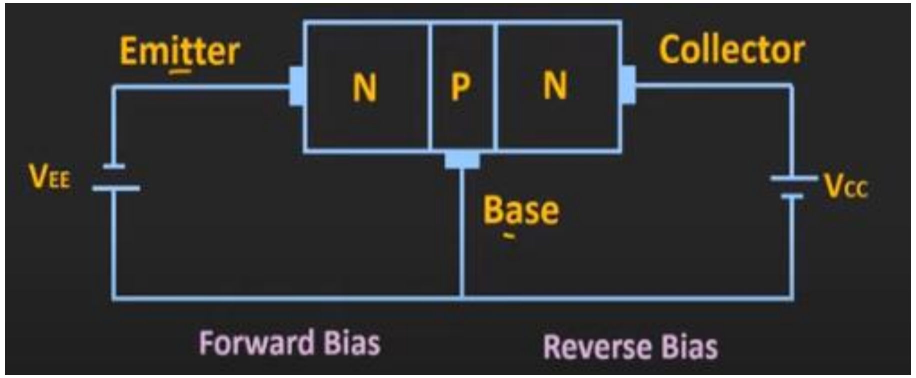


Transistor Operation (NPN)

- The BE junction is forward biased whereas the CB junction is reversed biased. The width of the depletion region of the BE junction is small as compared to that of the CB junction.
- The forward bias at the BE junction reduces the barrier potential and causes the electrons to flow from the emitter to the base.
- As the base is thin and lightly doped it consists of very few holes so some of the electrons from the emitter (about 2%-5%) recombine with the holes present in the base region and flow out of the base terminal.
- The remaining large number of electrons will cross the reverse-biased collector junction to constitute the collector current.
- Therefore, KCL , $I_E = I_B + I_C$
- $I_C = \alpha I_E + I_{CO}$

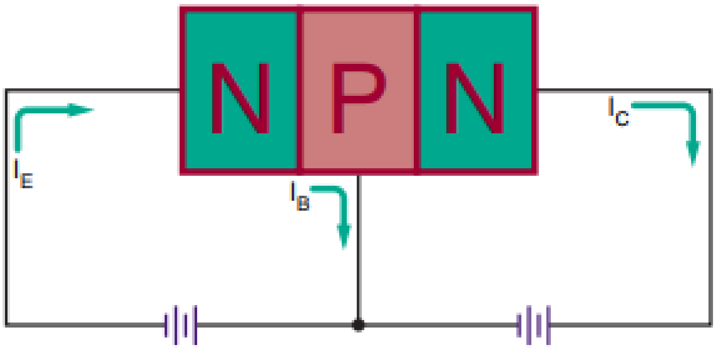


EXPLANATION

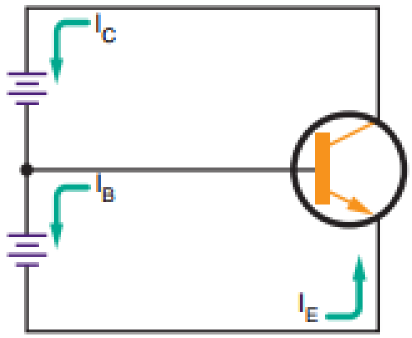


Common Base Configuration

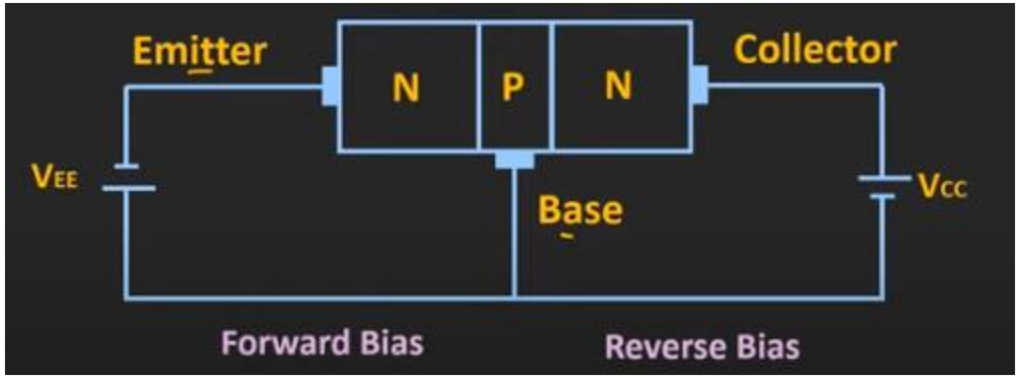
- Base is common to both the input and output sides of the configuration.

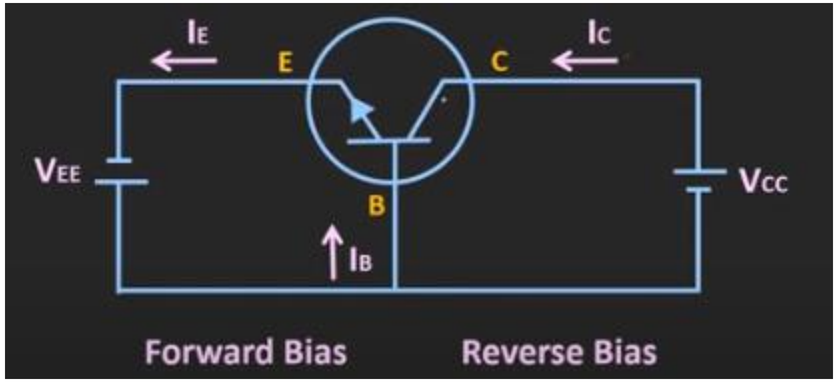


(A) BLOCK DIAGRAM OF A BIASED NPN TRANSISTOR



(B) SCHEMATIC DIAGRAM OF A BIASED NPN TRANSISTOR





Direction of electron flow ??

Schematic of NPN Transistor

QUICK QUIZ (POLL)

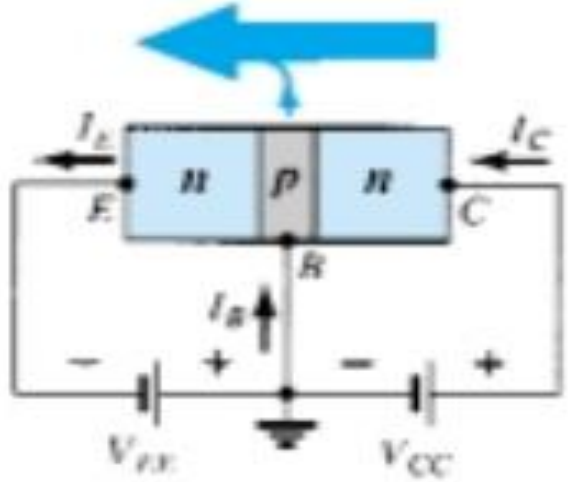
Most of the majority carriers from the emitter ………………..

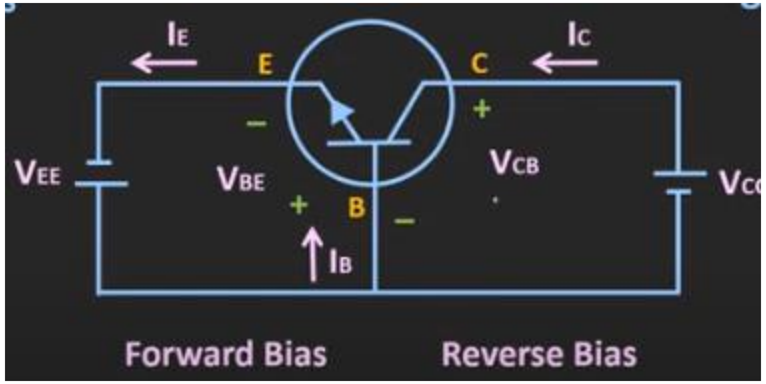
A. recombine in the base
B. recombine in the emitter
C. pass through the base region to the collector
D. none of the above

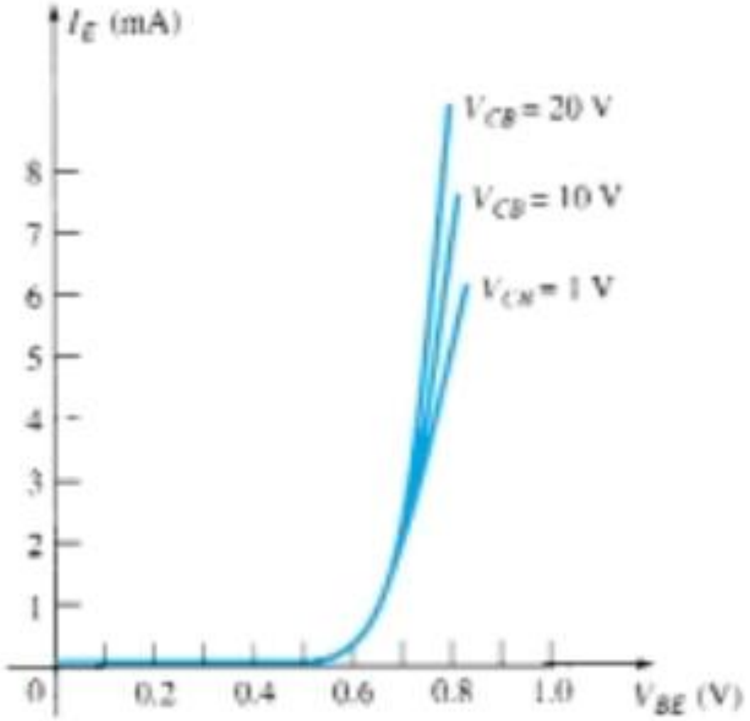
Common Base Configuration

CB Input Characteristics:

- As the emitter-base junction is forward biased, therefore the graph of $I_E\ vs\ V_{BE}$ is similar to the forward characteristics of a p-n diode.
- I_E increases when V_{CB} increases (for a fixed V_{BE}).

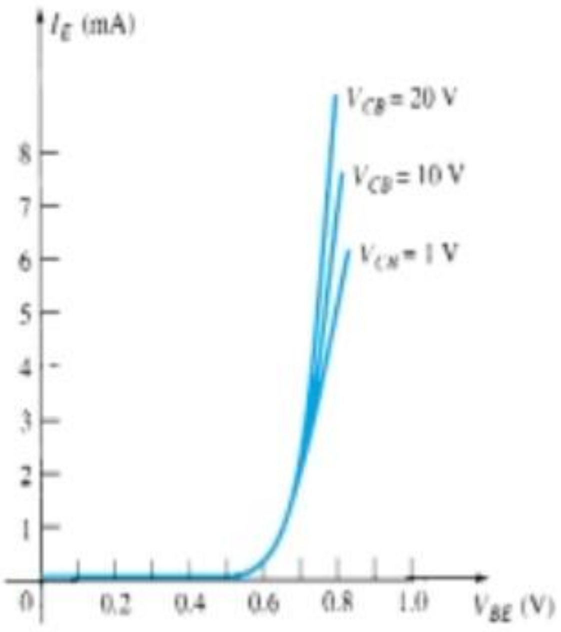






Explanation Slide

Early effect or base width modulation (Effect due to VCB)



FB Characteristics of DIODE

More penetration of the depletion region in the base thus effective width reduces ,results less recombination ,also more external field attract more electrons from base thus …………IE .

IE=IB + IC

Input resistance ?

QUICK QUIZ (POLL)

A transistor is a …………… operated device

A. current

B. voltage

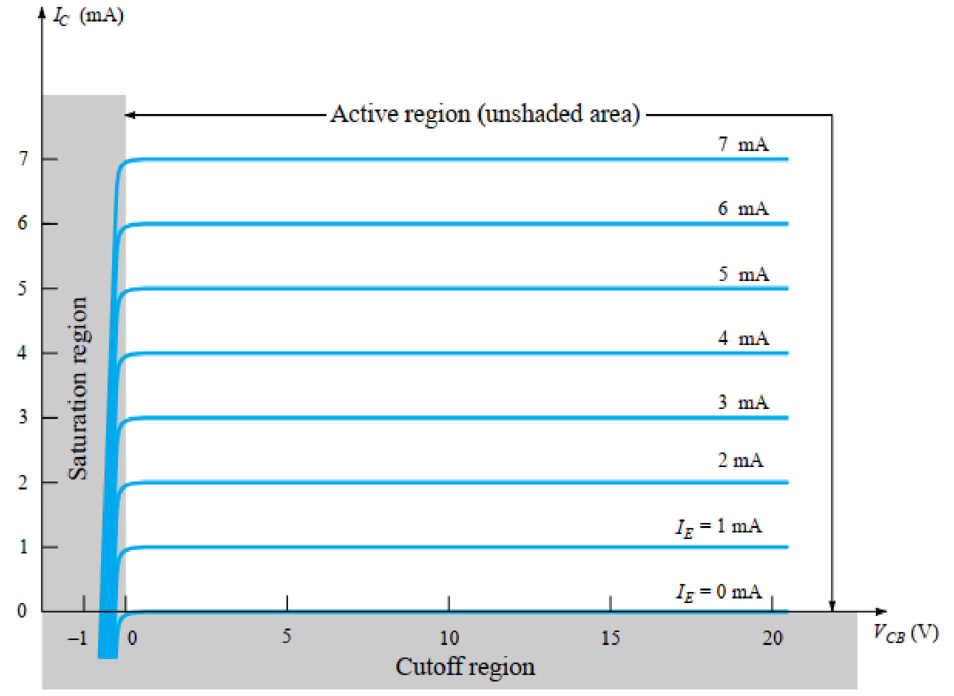
C. both voltage and current

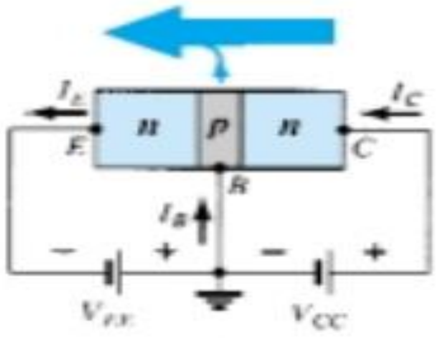
D. none of the above

Common Base Configuration

CB Output Characteristics:

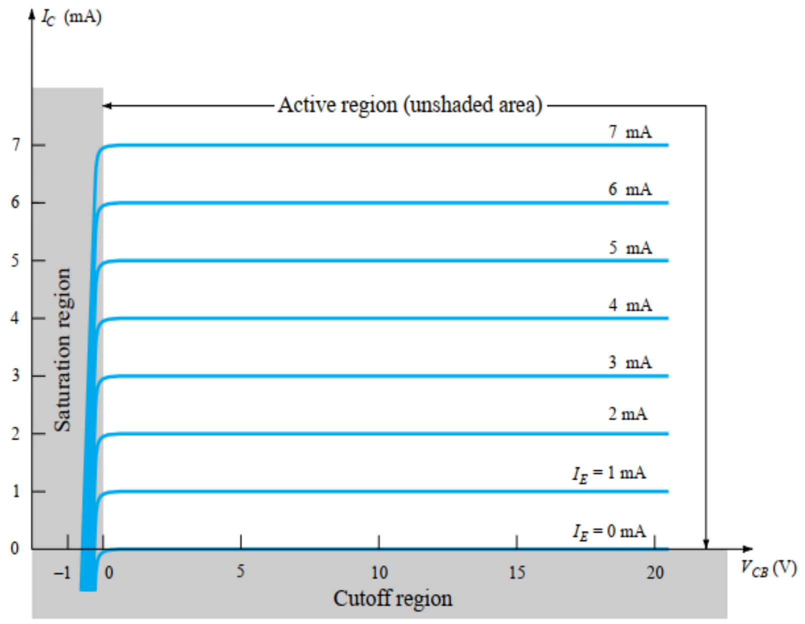
- The output or collector set of characteristics has three basic regions of interest, as indicated in Fig., *active, cutoff, and saturation regions.*
- As the emitter current increases above zero, the collector current increases to a magnitude essentially equal to that of the emitter current.
- Increasing levels of VCB have a small effect on the characteristics





Explanation Slide

What happened if VCB Increases too high ???



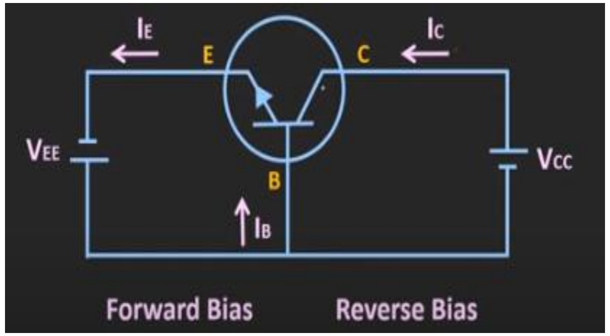
Decreasing VCB thus results RB junction becomes ……….? Thus which region operation ………,what happened to depletion region ,IC

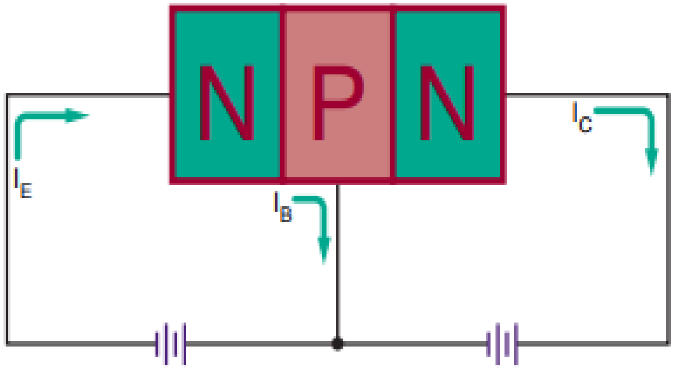
Common Base Amplification Factor

- For a common base amplifier configuration, current gain, is given as ${i_{out}}/{i_{in}}$ which itself is determined by the formula ${i_C}/{i_E}$.
- The current gain for a CB configuration is called Alpha, (α).

  i.e, $\alpha = \frac{I_C}{I_E}$

- Thus the CB amplifier attenuates the current, with typical values of alpha ranging from between 0.95 to 0.998





QUICK QUIZ (POLL)

When transistors are used in digital circuits they usually operate in the ………….

A. active region

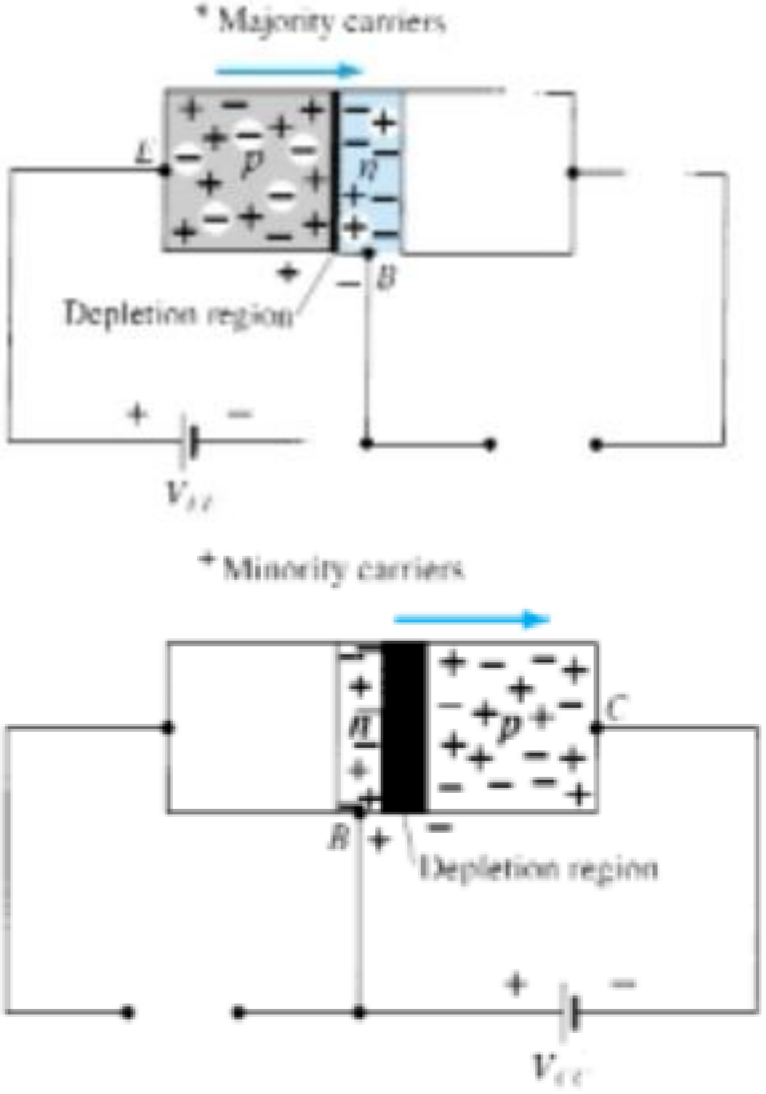
B. breakdown region

C. saturation and cutoff regions

D. linear region

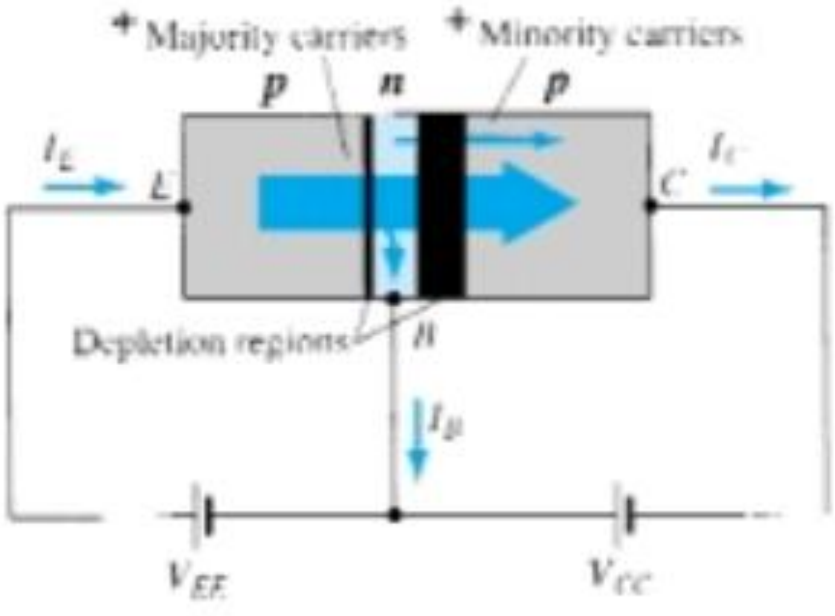
Transistor Operation (PNP)

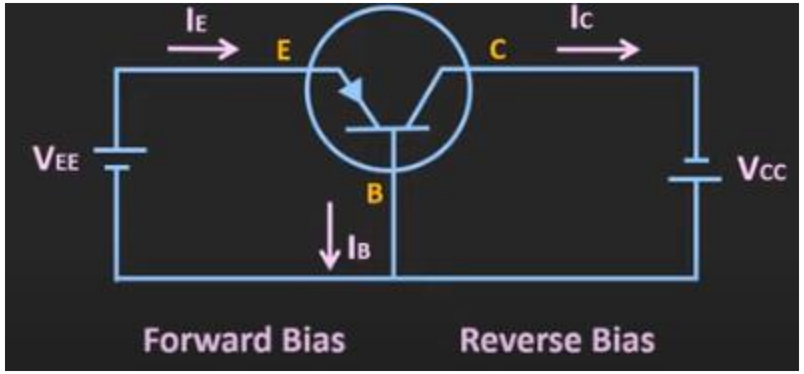
- The operation of the pnp transistor is exactly the same if the roles played by the electron and hole are interchanged.
- During forward bias, the depletion region has been reduced in width due to the applied bias, resulting in a heavy flow of majority carriers from the p- to the n-type material.
- During reverse bias, flow of majority carriers is zero, resulting in only a minority-carrier flow.
- Therefore, from KCL: $I_E = I_B + I_C$



Transistor Operation (PNP)

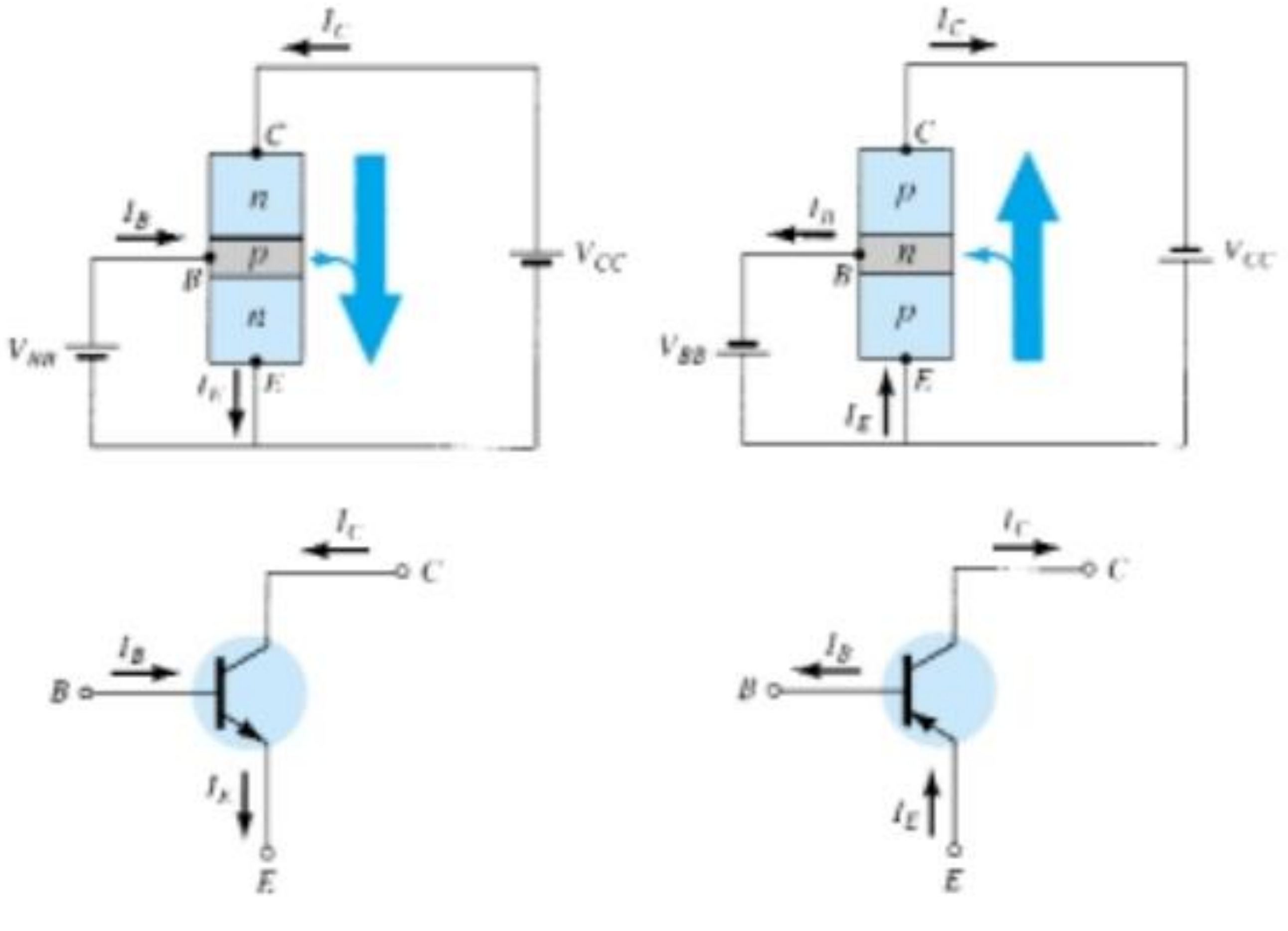
- The operation of the pnp transistor is exactly the same if the roles played by the electron and hole are interchanged.
- From KCL: $I_E = I_B + I_C$
- The collector current, however, is comprised of two components—the majority and minority carriers.
- The minority-current component is called the leakage current and is given the symbol I_{CO} (I_C current with emitter terminal Open).
- The collector current, therefore, is determined in total by:
- $I_C = I_{C_{majority}} + I_{CO_{minority}}$





Common Emitter Configuration

- Emitter is common to both the input and output sides of the configuration.



(a) (b)

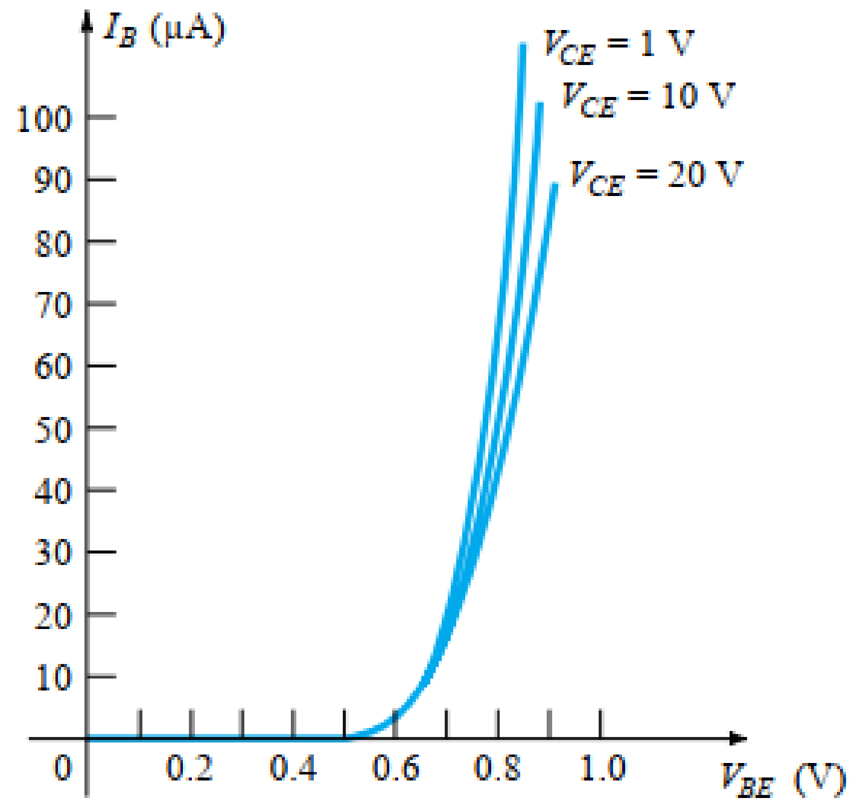
Explanation Slide

Base width modulation makes IB …….?

Common Emitter Configuration

CE Input Characteristics:

- The curve for common emitter configuration is similar to a forward diode characteristics.
- The base current I_B increases with the increase in the base-emitter voltage V_{BE}.
- With an increase in V_{BE}, the base current decreases.



Relation between $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$

QUICK QUIZ (POLL)

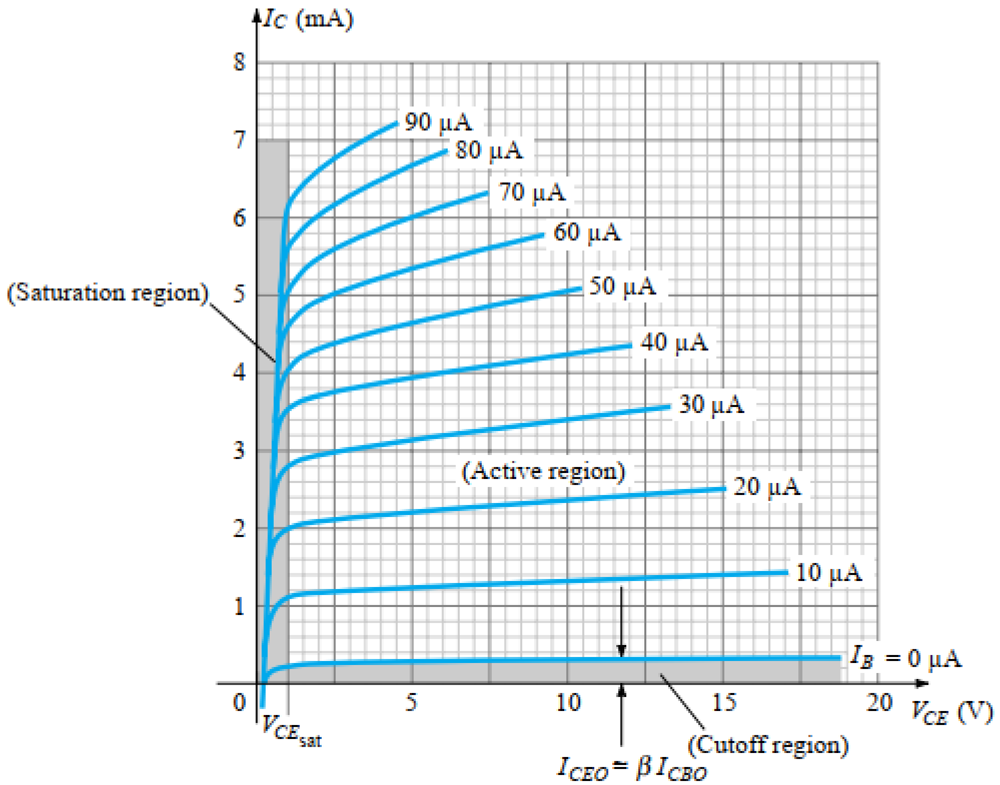
If the value of α is 0.9, then value of β is ……….

A. 9
B. 0.9
C. 900
D. 90

Common Emitter Configuration

CE Output Characteristics:

- In the active region, the collector current increases slightly as collector-emitter V_{CE} current increases.
- The slope of the curve is quite more than the output characteristic of CB configuration.
- The value of the collector current IC increases with the increase in VCE at constant voltage I_E, the value β of also increases.



Common Emitter Amplification Factor

- The current in a bipolar NPN transistor is the ratio of these two currents $^{i_C}/_{i_E}$ called the Current Gain of the device and is given the symbol of h_{fe}or nowadays Beta, (β).

i.e, $\beta = \frac{I_C}{I_B}$

- For practical devices the level of typically ranges from about 50 to over 400, with most in the midrange.
- For a device with a of 200, the collector current is 200 times the magnitude of the base current.

Relation between $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$

$$I_E = I_C + I_B$$

we have

$$\frac{I_C}{\alpha} = I_C + \frac{I_C}{\beta}$$

and dividing both sides of the equation by I_C will result in

$$\frac{1}{\alpha} = 1 + \frac{1}{\beta}$$

or

$$\beta = \alpha\beta + \alpha = (\beta + 1)\alpha$$

so that

$$\boxed{\alpha = \frac{\beta}{\beta + 1}}$$

or

$$\boxed{\beta = \frac{\alpha}{1-\alpha}}$$

QUICK QUIZ (POLL)

In a transistor, IC = 100 mA and IE = 100.2 mA. The value of β is ....

A. 100

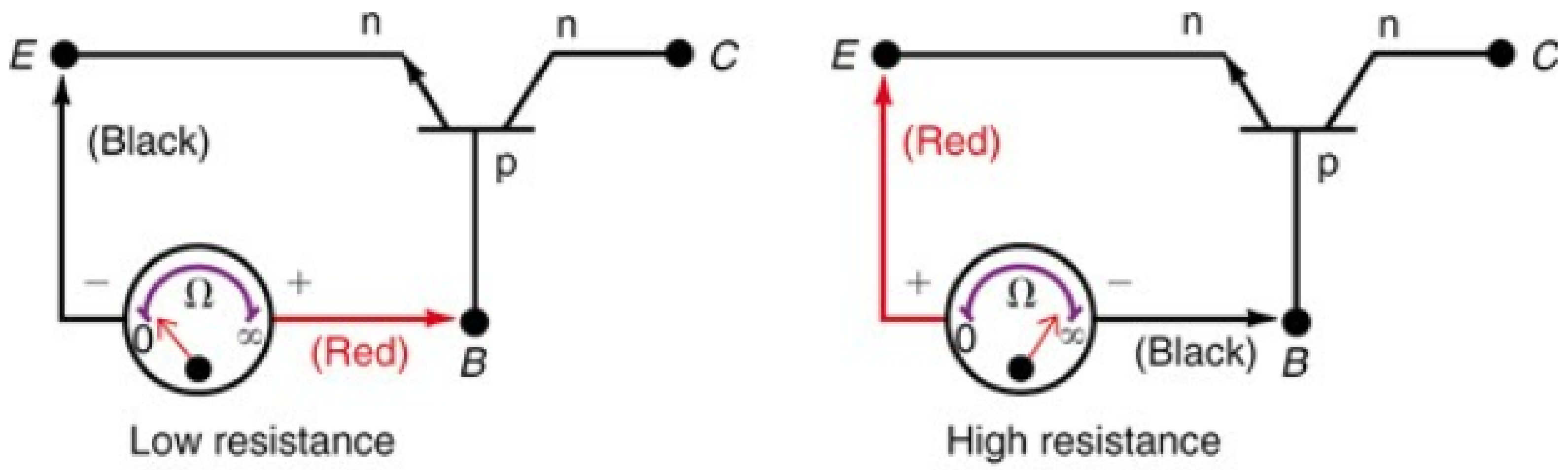
B. 500

C. about 1

D. 200

Transistor Testing

- To check the base-emitter junction of an npn transistor, first connect the ohmmeter as shown in Fig. 28-9 (a) and then reverse the ohmmeter leads as shown in (b).
- For a good p-n junction made of silicon, the ratio R_R/R_F should be equal to or greater than 1000:1.

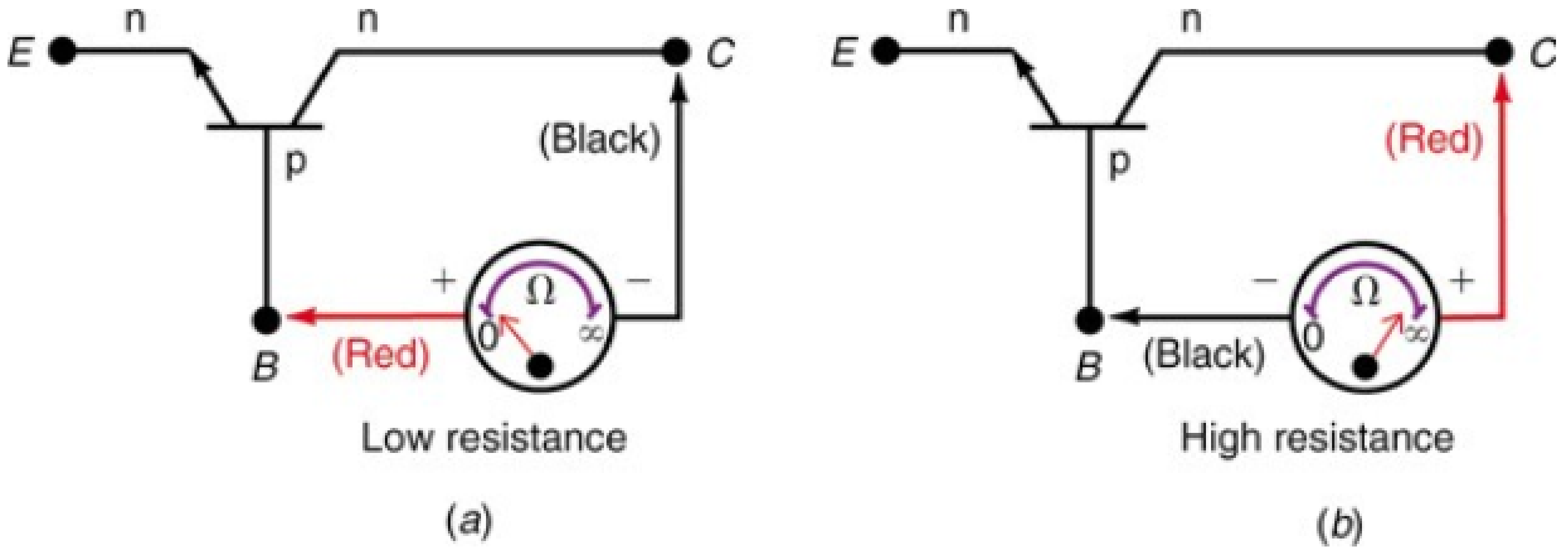


(a)

(b)

Transistor Testing

- To check the collector-base junction, first connect the ohmmeter as shown in Fig. 28-10 (a) and then reverse the ohmmeter leads as shown in (b).
- For a good p-n junction made of silicon, the ratio R_R/R_F should be equal to or greater than 1000:1.
- The resistance measured between the collector and emitter should read high or infinite for both connections of the meter leads.



Explanation Slide

Explanation Slide