Helwan University - Faculty of Engineering (Helwan)
Electronics and Communications Engineering Department

Lec-4 Bipolar Junction Transistors (BJTs)

Presented By:

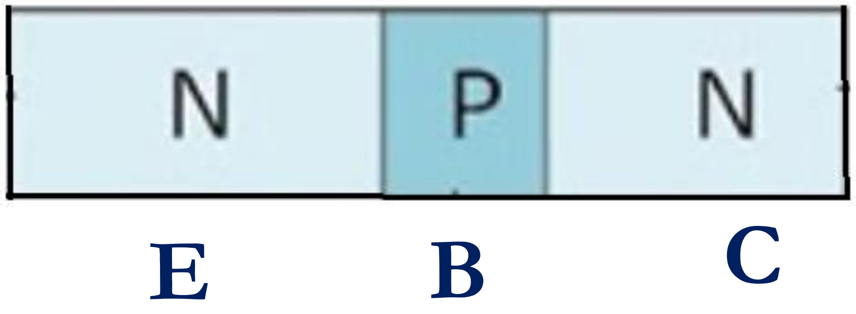
Azza Mohamed Anis

Bipolar Junction Transistor (BJT)

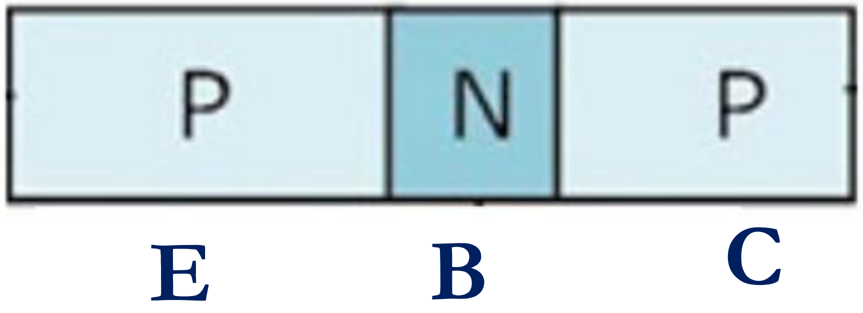
The term bipolar refers to the use of both holes and free elections as current carriers.

BJT consists of three doped semiconductor regions:

[1] **NPN** BJT: has two n regions separated by p region.



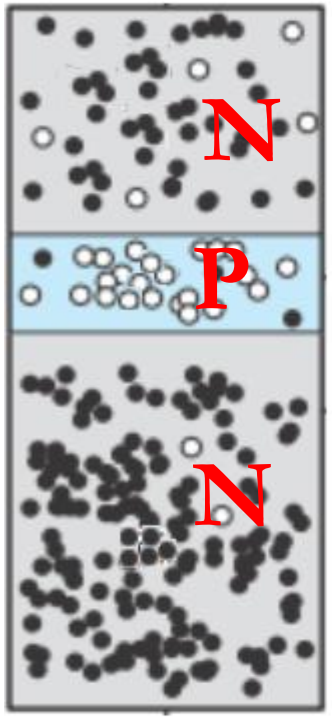
[2] **PNP** BJT: has two p regions separated by n region.



The three regions are called emitter (E), base (B), and collector (C).

The emitter region is heavily doped.

Collector



Base

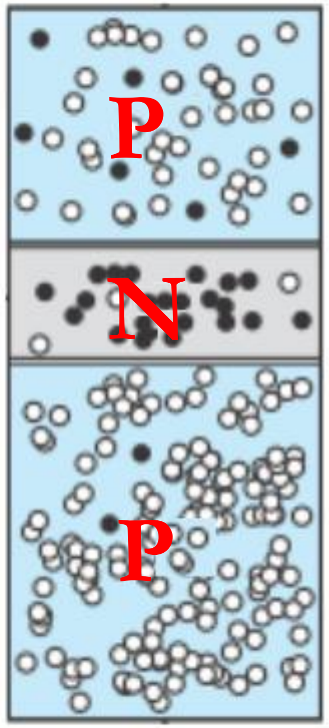
Emitter

NPN BJT

The collector region is moderately doped.

The base region is lightly doped and very thin.

Collector

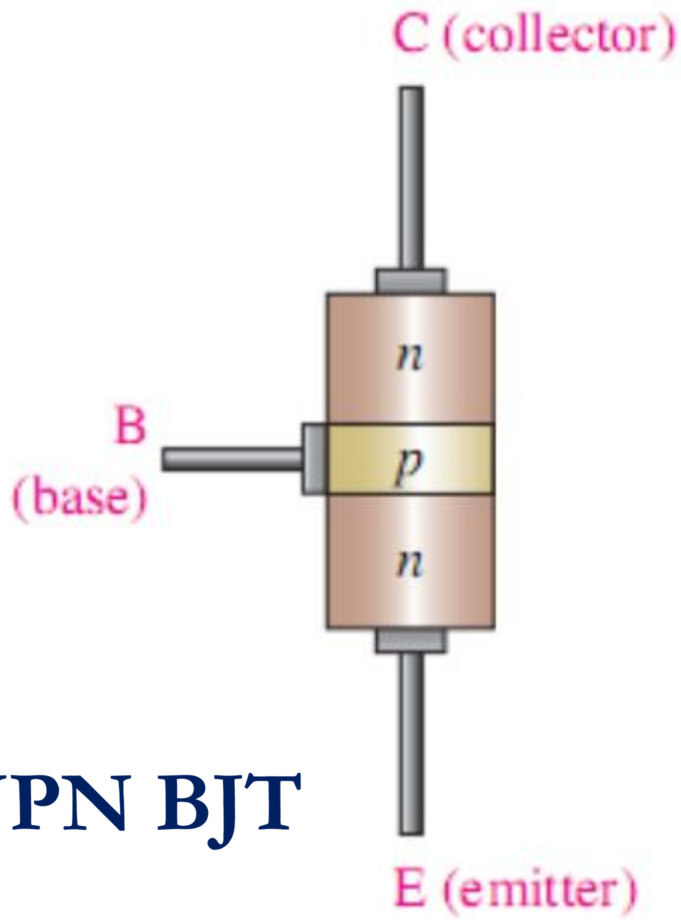


Base

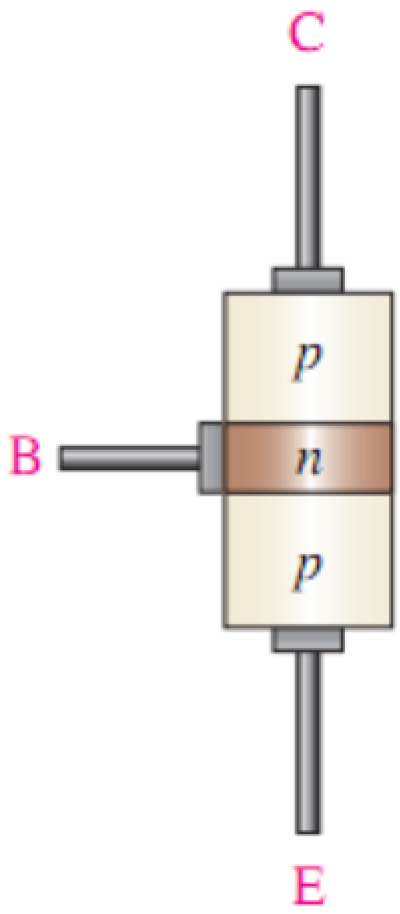
Emitter

PNP BJT

Each region is connected to a conductive terminal (metallic lead). These metallic leads are labeled E, B, and C for emitter, base, and collector.



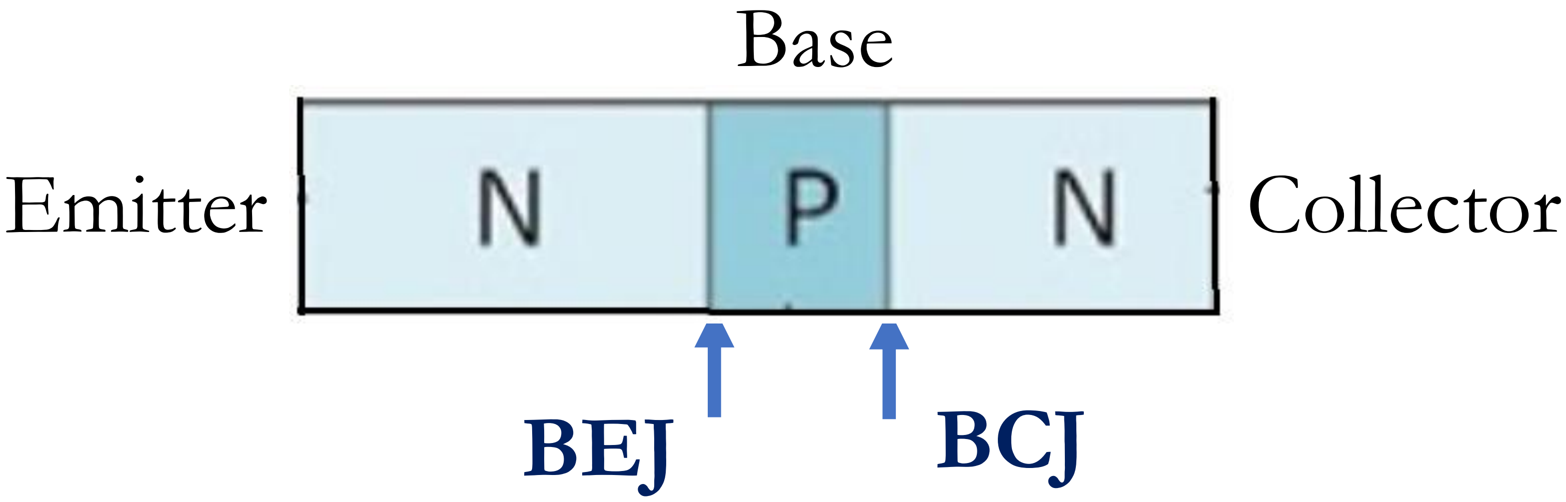
NPN BJT



PNP BJT

Junctions of NPN BJT

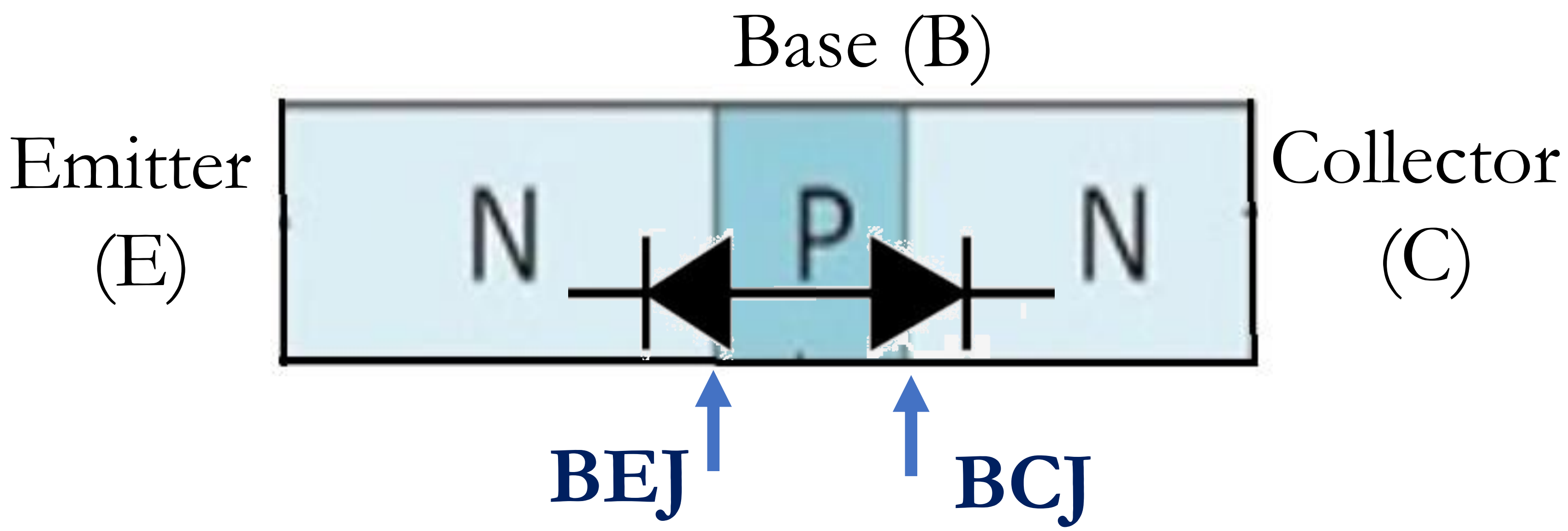
NPN BJT has two pn junctions.



The pn junction joining the base region and the emitter region is called the base-emitter junction (**BEJ**).

The pn junction joining the base region and the collector region is called the base-collector junction (**BCJ**).

Modes (Operation Regions) of NPN BJT



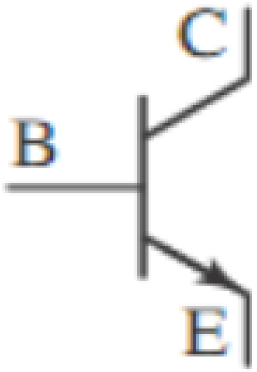
Modes	BEJ	BCJ	Applications
Active	Forward	Reverse	Amplifier
Saturation	Forward	Forward	Closed Switch
Cutoff	Reverse	Reverse	Open Switch

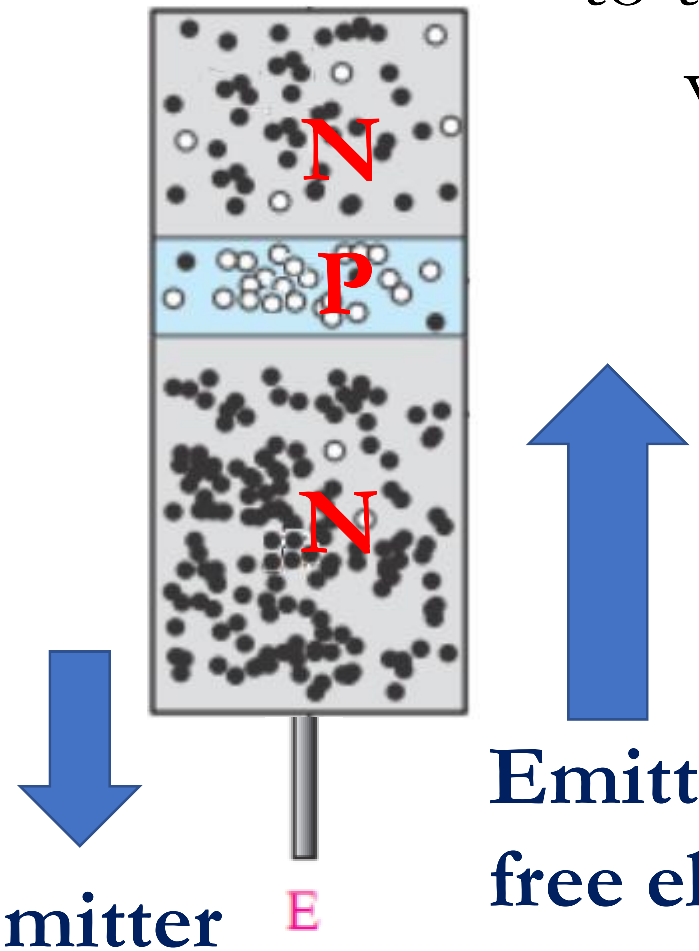
Digital Circuits

Symbol of NPN BJT

The arrow on the emitter terminal refers to the flow direction of emitter current when the emitter-base junction is forward-biased.

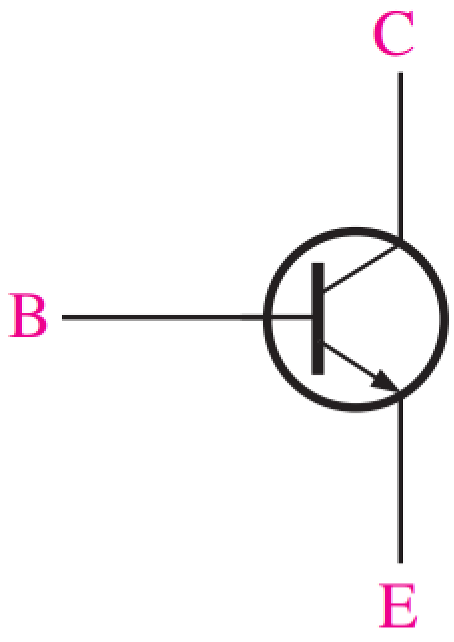
NPN Symbol





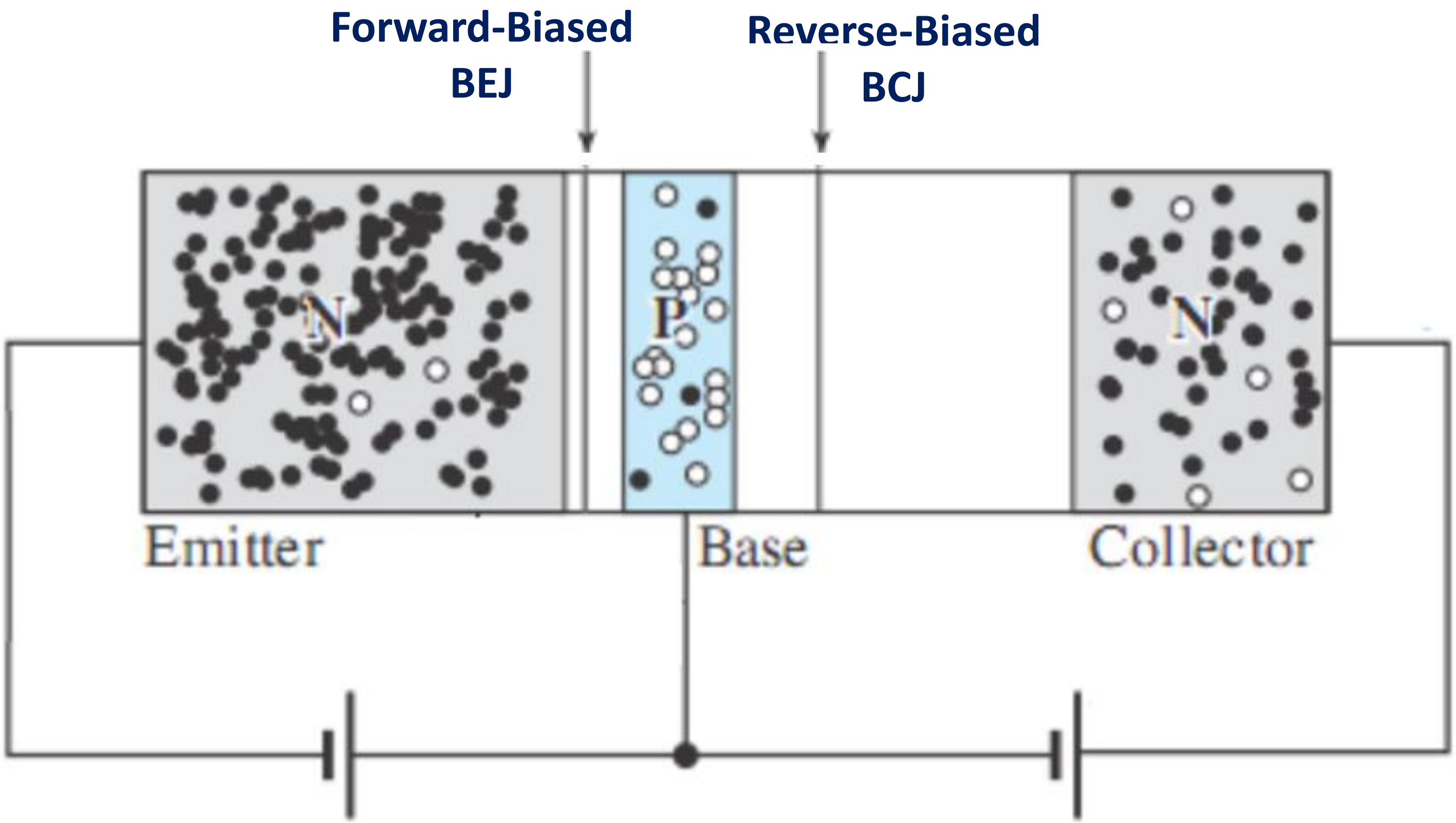
Emitter Current

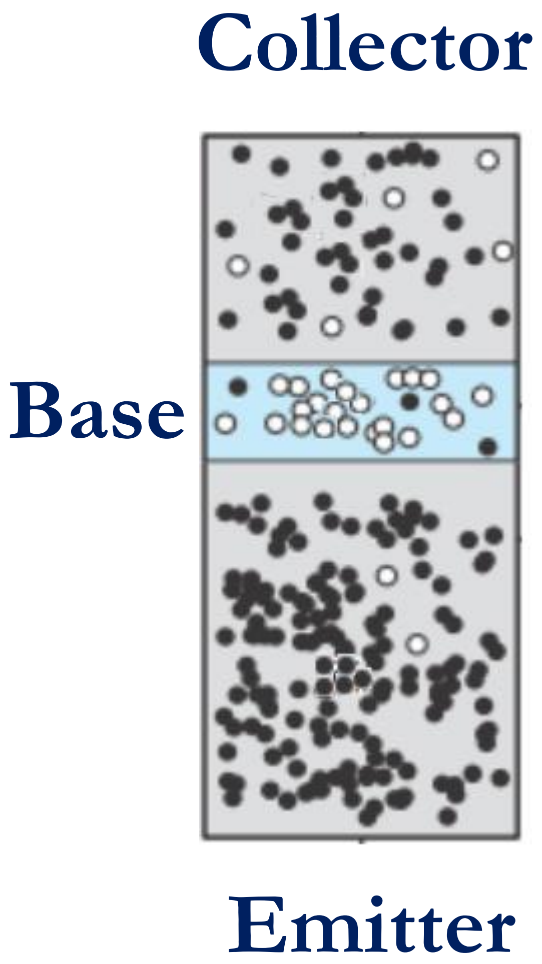
Emitter injects free electrons



Active Mode of NPN BJT

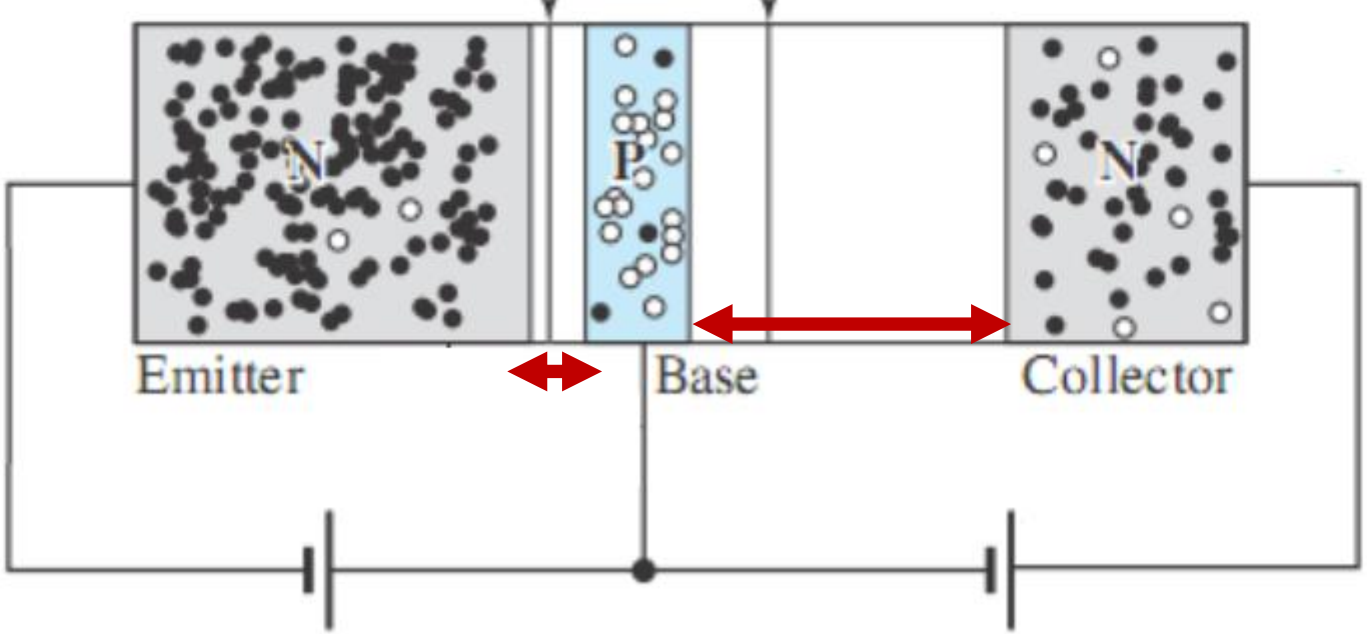
In active mode, external dc voltages are applied to set BEJ is forward-biased and BCJ is reverse-biased.



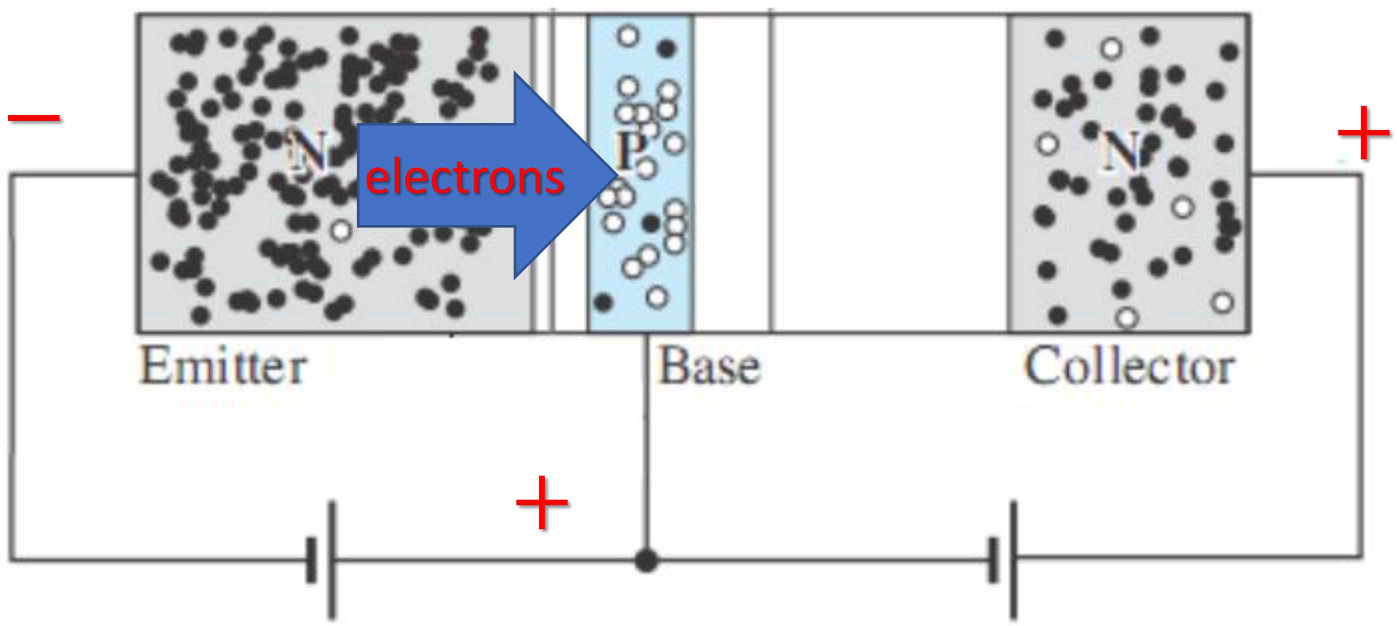


The **forward biasing** between base and emitter **narrows** the base-emitter **depletion region**

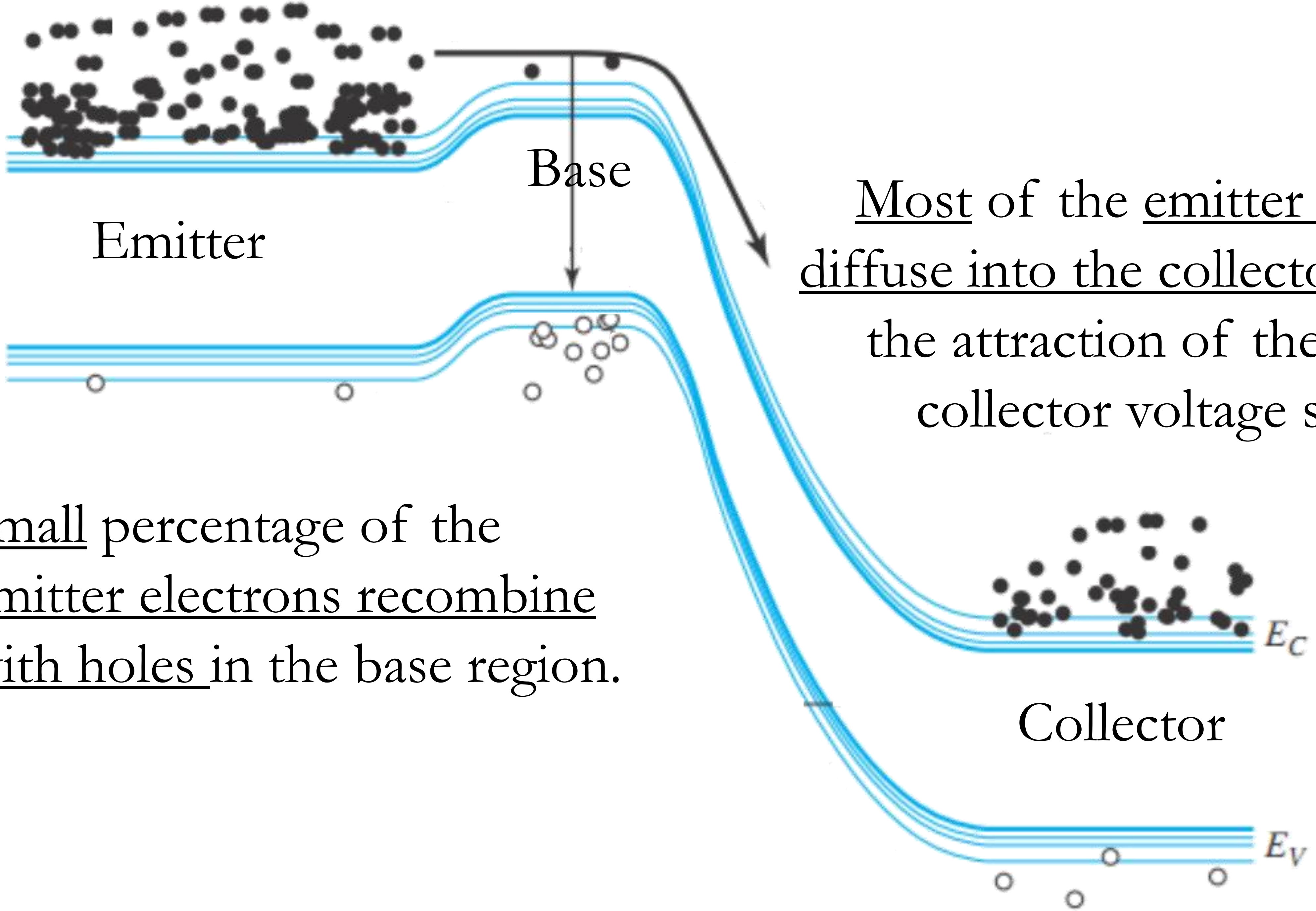
The **reverse biasing** between base and collector **widens** the base-collector **depletion region**



In npn BJT, the heavily doped n-type emitter region has a very high density of free electrons.

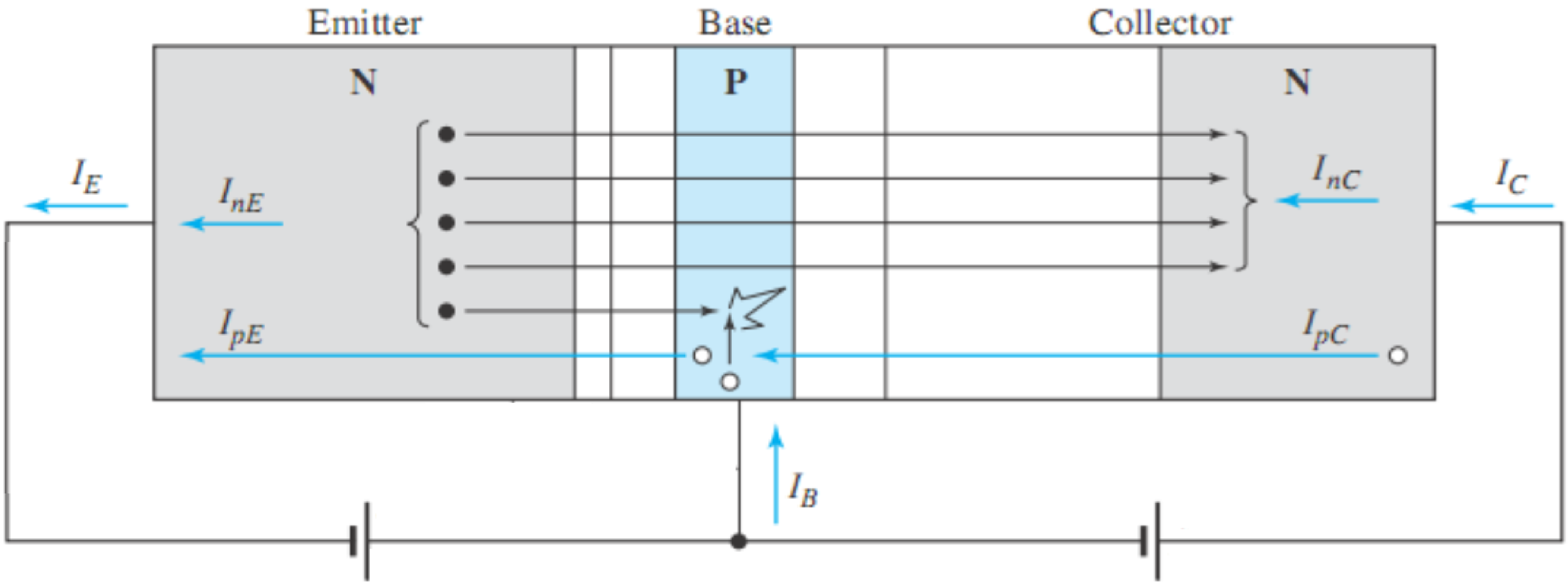


These free electrons easily diffuse (move) into the p-type base region.



Most of the emitter electrons diffuse into the collector region by the attraction of the positive collector voltage source.

Small percentage of the emitter electrons recombine with holes in the base region.

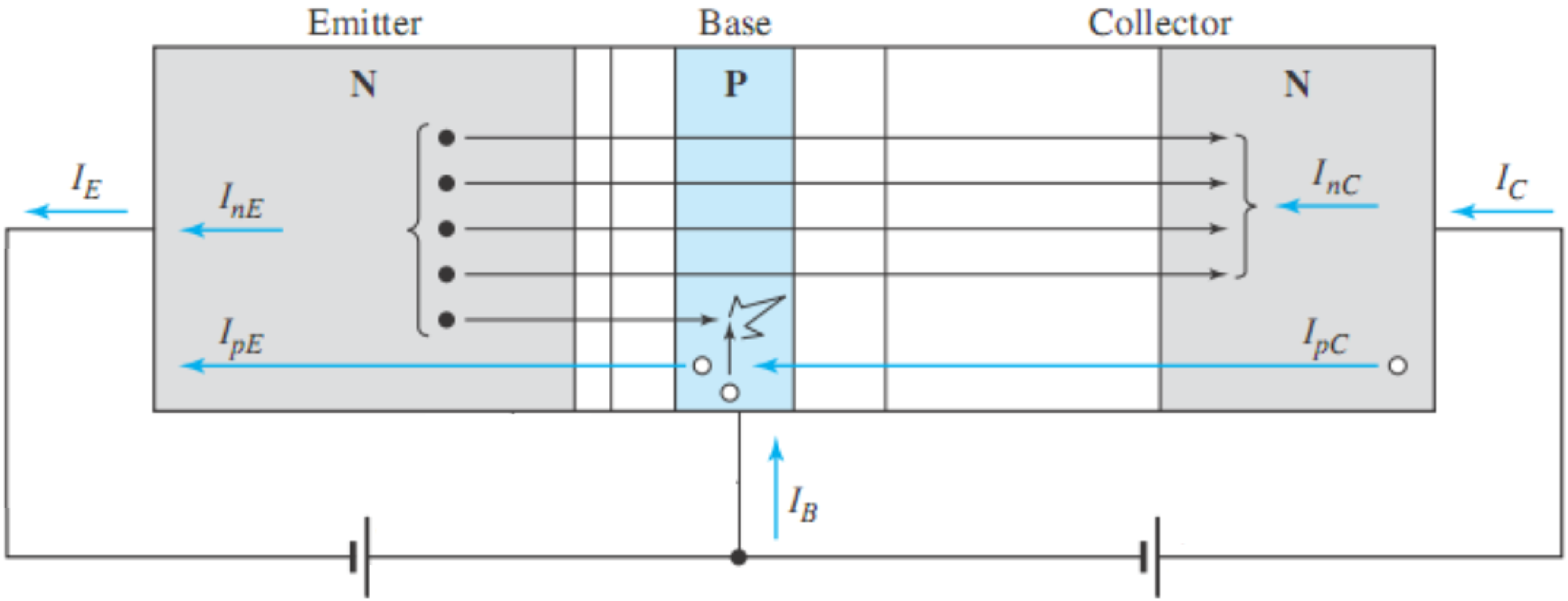


Just as in a forward-biased diode:

The flow of electrons from emitter into base results in **electron current** $\boldsymbol{I_{nE}}$

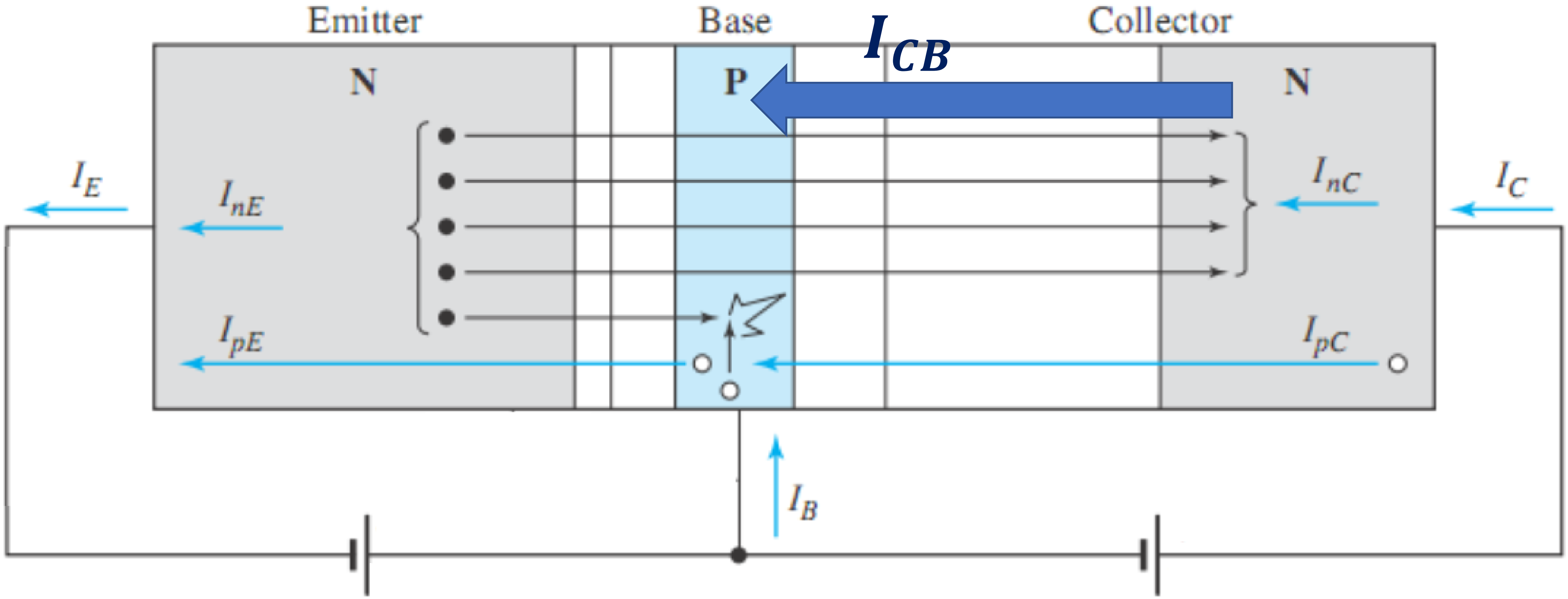
The flow of holes from base into emitter results in **hole current** $\boldsymbol{I_{pE}}$

The total **emitter current** is the sum of these two currents: $\boldsymbol{I_E = I_{nE} + I_{pE}}$



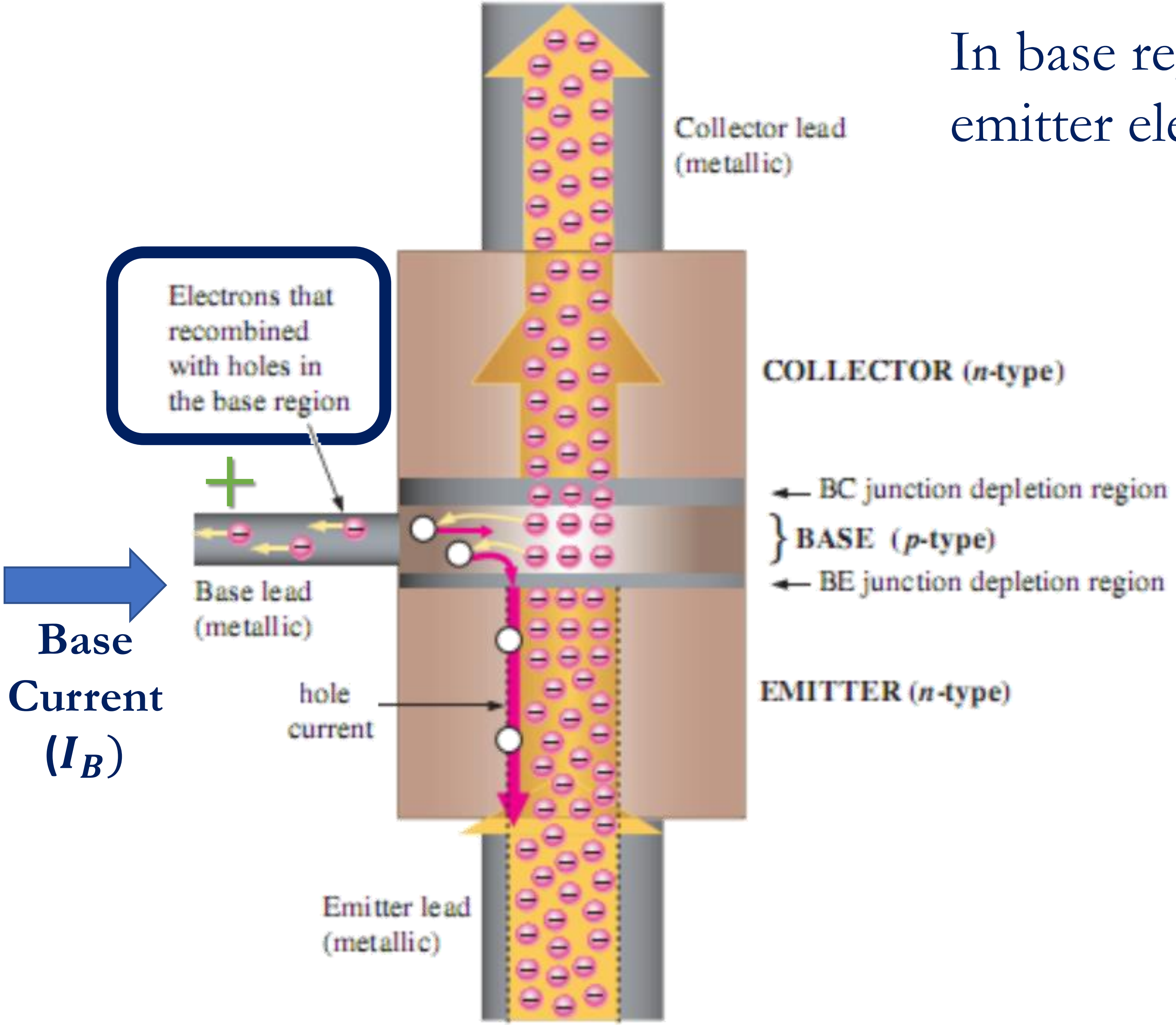
The flow of the emitted electrons from emitter into collector results in **electron current I_{nC}**

The flow of minority holes from collector into base results in **hole current I_{pC}**



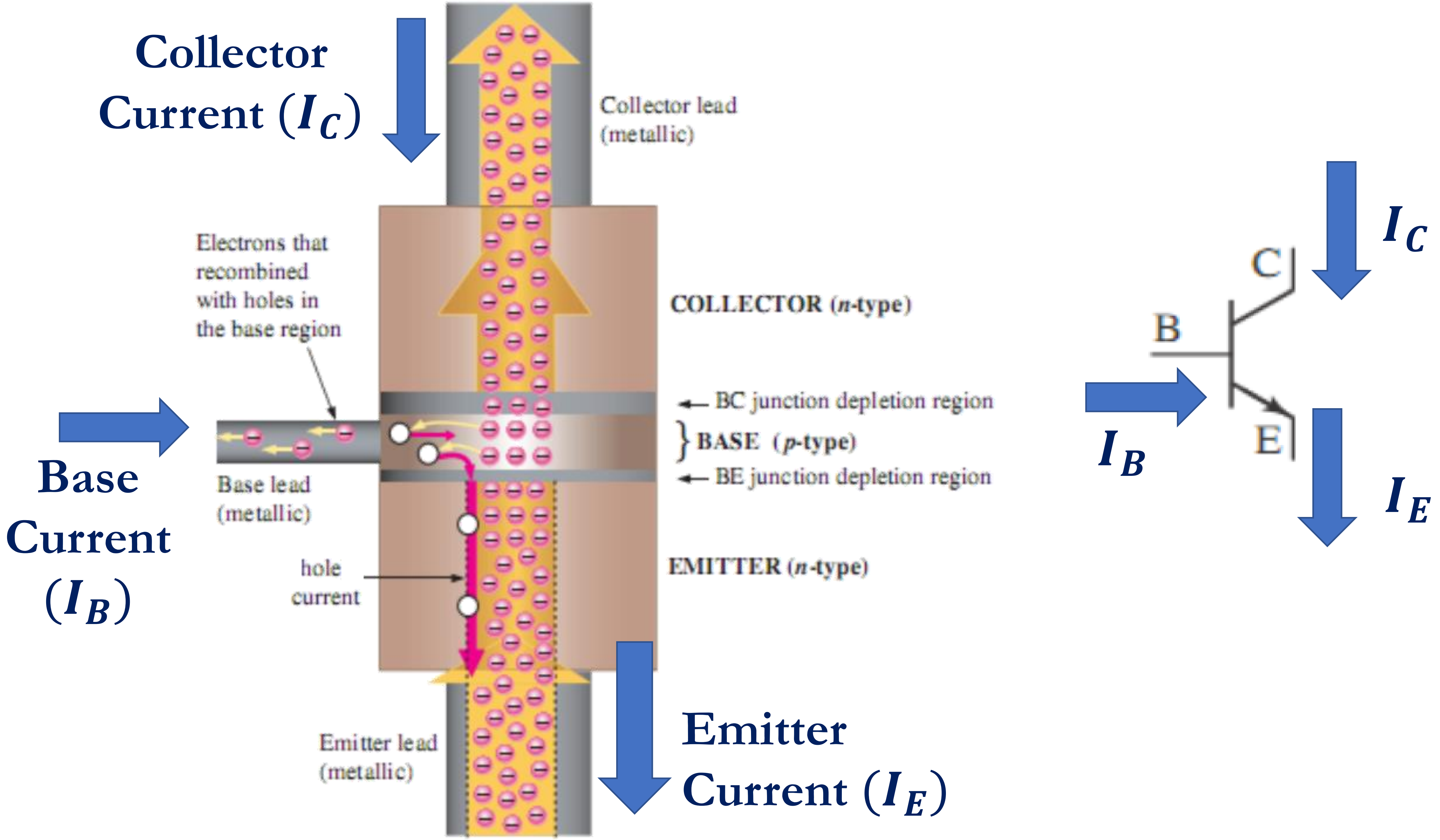
The other part of the collector current (I_{CB}) is due to the flow of the minority electrons from base into collector.

The total **collector current** is the sum of these currents: $I_C = I_{nC} + I_{pC} + I_{CB}$



In base region, a small percentage of emitter electrons recombine with holes.

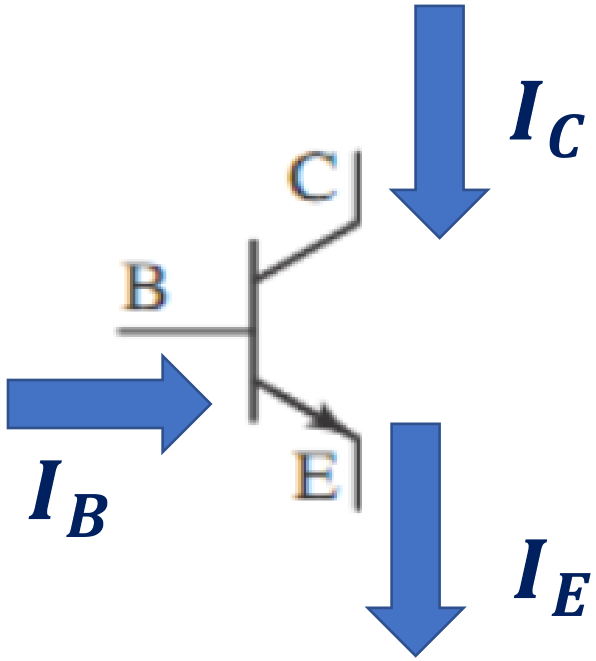
These recombined electrons move from one hole to the next and finally flow out of the base lead toward the positive side of external source forming the base electron current ($\boldsymbol{I_B}$).



Collector
Current (I_C)
Collector lead
(metallic)
Electrons that
recombined
with holes in
the base region
COLLECTOR (n-type)
BC junction depletion region
BASE (p-type)
BE junction depletion region
Base
Current
(I_B)
Base lead
(metallic)
hole
current
EMITTER (n-type)
Emitter lead
(metallic)
Emitter
Current (I_E)
C
B
E
I_C
I_B
I_E

The emitter current ($\boldsymbol{I_E}$) is the sum of the collector current ($\boldsymbol{I_C}$) and the base current ($\boldsymbol{I_B}$).

$$\boldsymbol{I_E = I_C + I_B}$$



The ratio of the collector current ($\boldsymbol{I_C}$) to the base current ($\boldsymbol{I_B}$) is beta ($\boldsymbol{\beta}$).

$$\boldsymbol{\beta = \frac{I_C}{I_B}}$$

The ratio of the collector current ($\boldsymbol{I_C}$) to the emitter current ($\boldsymbol{I_E}$) is alpha ($\boldsymbol{\alpha}$).

$$\boldsymbol{\alpha = \frac{I_C}{I_E}}$$

$$\because I_E = I_C + I_B$$

$$\because \beta = \frac{I_C}{I_B} \Rightarrow I_C = \beta\, I_B$$

$$\therefore I_E = \beta\, I_B + I_B$$

$$I_E = (\beta + 1)\, I_B$$

$$\because\ \alpha = \frac{I_C}{I_E}$$

$$\therefore\ I_C = \alpha\, I_E \qquad \text{and} \ \because\ I_E = I_C + I_B$$

$$I_C = \alpha\,(I_C + I_B) = \alpha\, I_C + \alpha\, I_B$$

$$I_C - \alpha\, I_C = \alpha\, I_B$$

$$I_C\,(1 - \alpha) = \alpha\, I_B$$

$$I_C = \frac{\alpha}{(1-\alpha)}\, I_B \quad \text{and} \ \because\ I_C = \beta\, I_B \;\Rightarrow\; \beta = \frac{\alpha}{(1-\alpha)}$$

$$\because \boldsymbol{\beta} = \frac{\boldsymbol{\alpha}}{(\mathbf{1} - \boldsymbol{\alpha})}$$

$$\therefore \boldsymbol{\beta}(\mathbf{1} - \boldsymbol{\alpha}) = \boldsymbol{\alpha}$$

$$\boldsymbol{\beta} - \boldsymbol{\beta}\,\boldsymbol{\alpha} = \boldsymbol{\alpha}$$

$$\boldsymbol{\beta} = \boldsymbol{\alpha} + \boldsymbol{\beta}\,\boldsymbol{\alpha}$$

$$\boldsymbol{\beta} = \boldsymbol{\alpha}\,(\mathbf{1} + \boldsymbol{\beta})$$

$$\frac{\boldsymbol{\beta}}{(\mathbf{1} + \boldsymbol{\beta})} = \boldsymbol{\alpha}$$

Summary of Active-Mode Currents

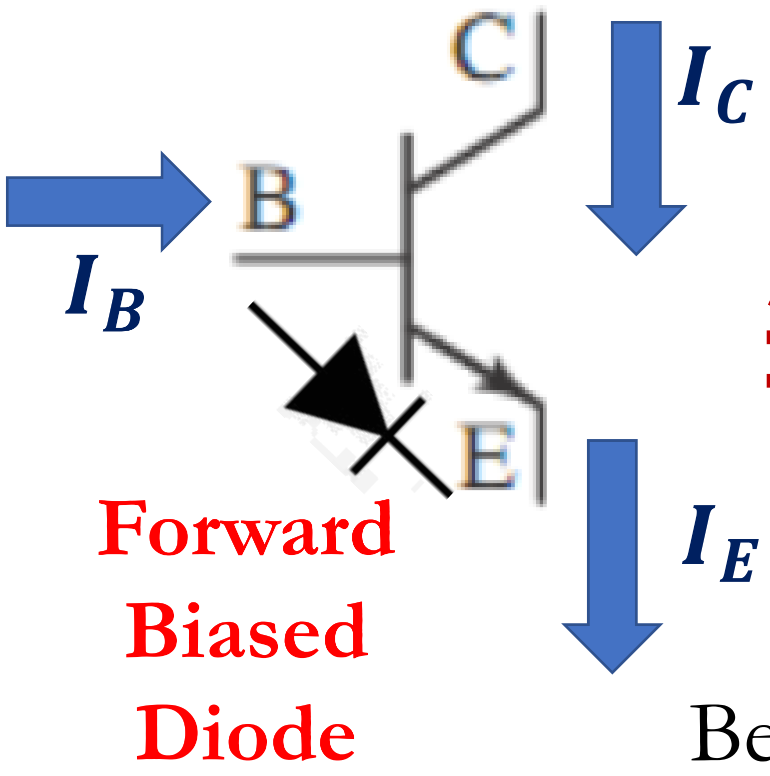
$$I_E = I_C + I_B \Rightarrow I_E = (1+\beta)\, I_B$$

$$\beta = \frac{I_C}{I_B} \Rightarrow I_C = \beta\, I_B$$

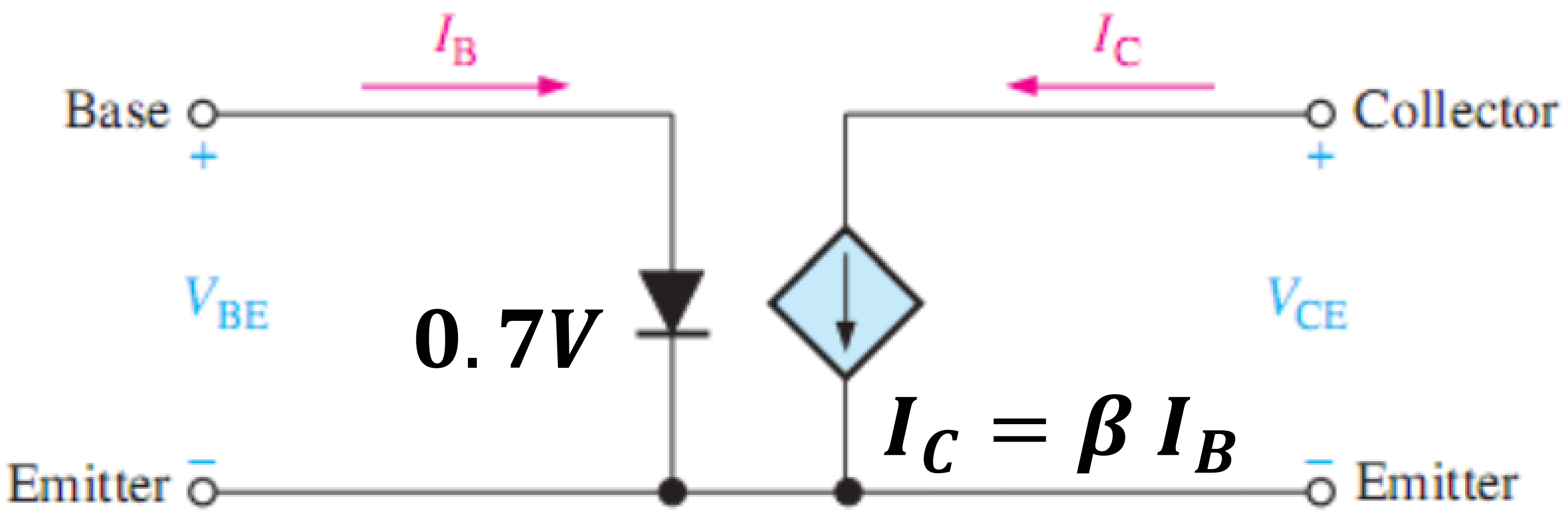
$$\alpha = \frac{I_C}{I_E} \Rightarrow I_C = \alpha\, I_E$$

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

DC Model (Equivalent Circuit) of Active Mode NPN BJT



$\cong$



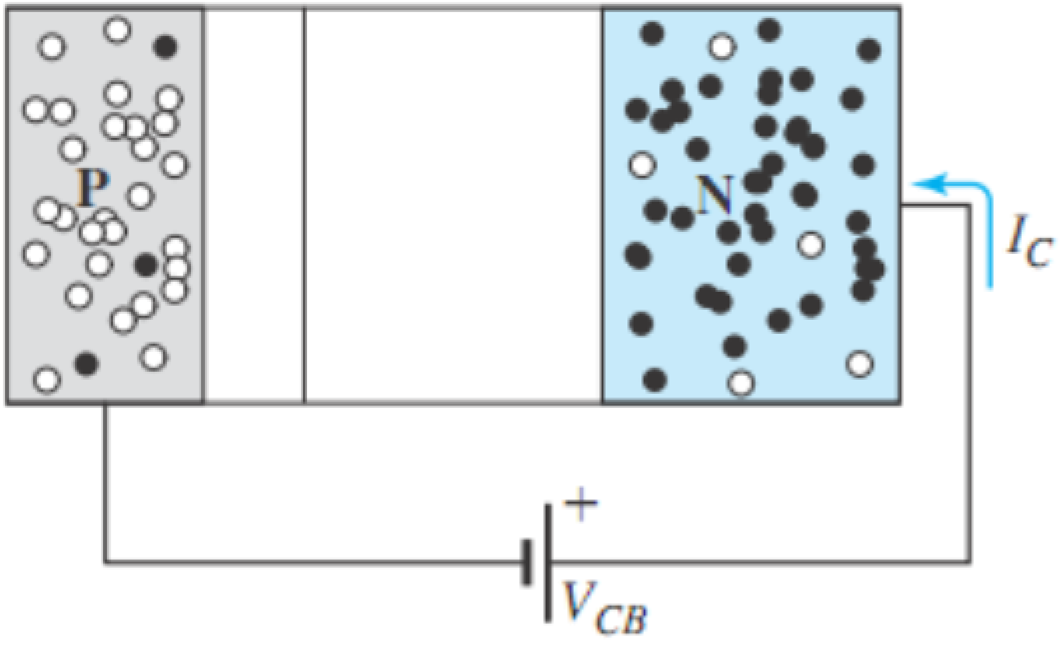
Between base and emitter is a <u>forward-biased diode</u> through which there is the base current.

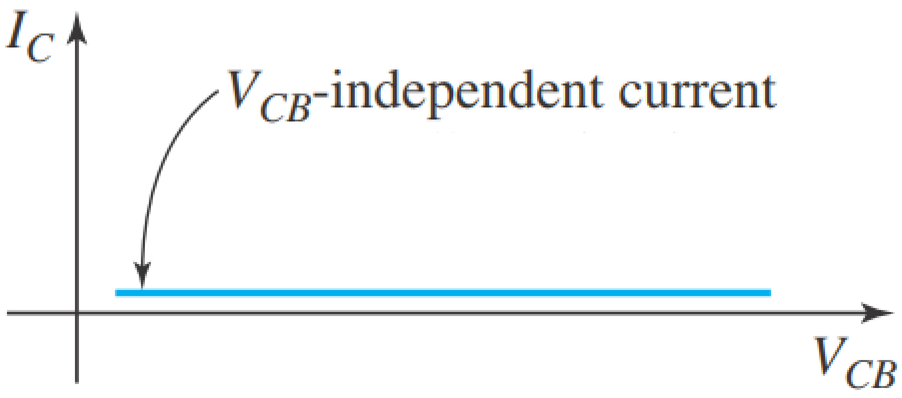
Between collector and emitter is a <u>dependent current source</u> with a value that is dependent on the base current.

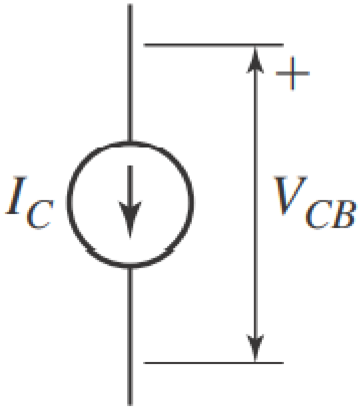
Why Current Source

The reverse-biased base-collector junction is an implementation of a current source.

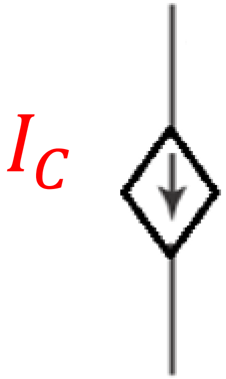
This because the current passing through the reverse-biased junction (***I_C***) is independent on the reverse-bias voltage (***V_{CB}***).



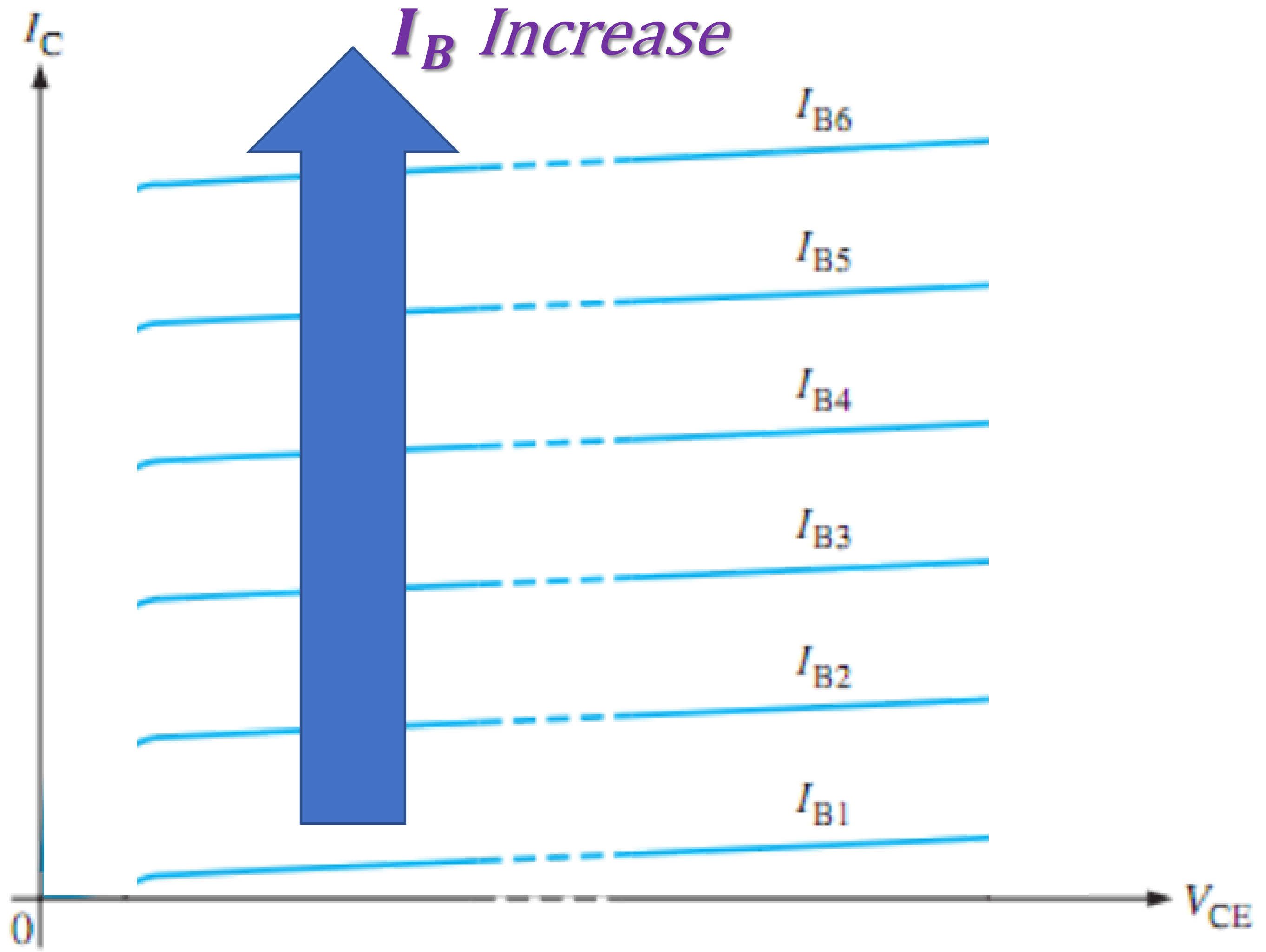




It is possible to change the value of collector current (I_C) by the base current (I_B).



$I_C = \beta I_B$

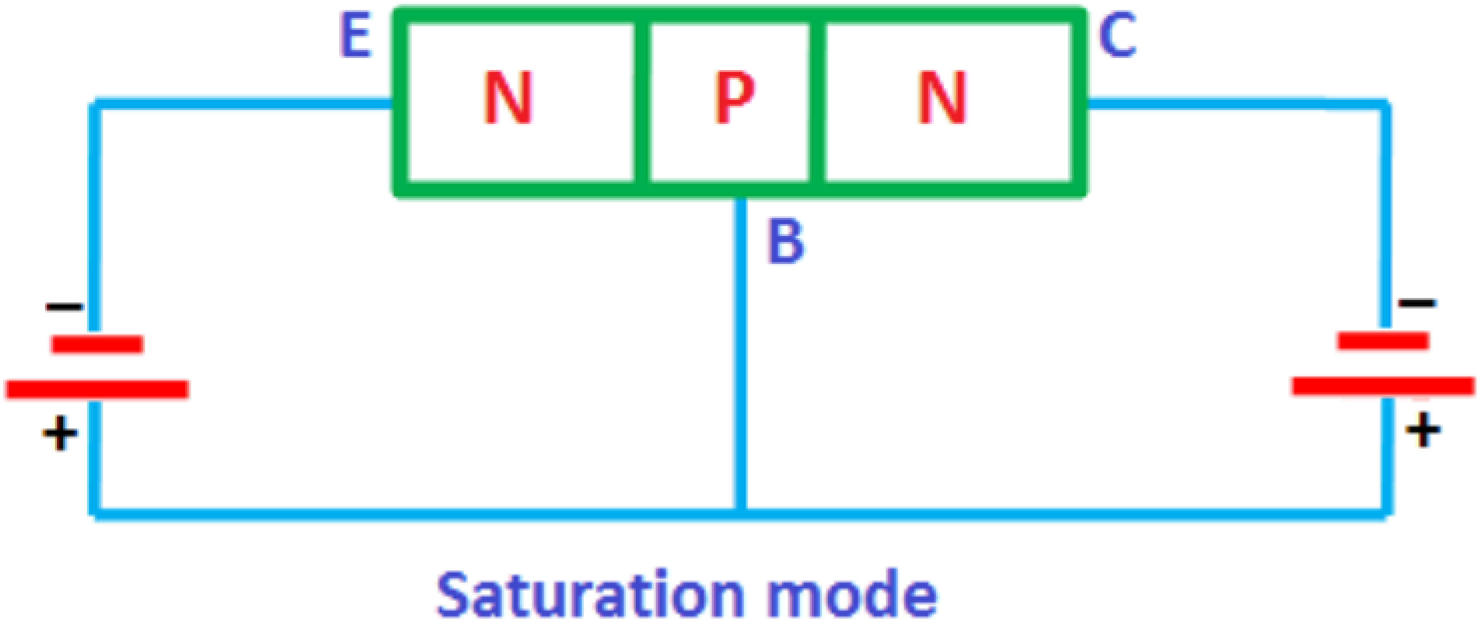


Therefore, in active mode, BJT acts as a current-controlled current-source.

$V_{CE} = V_{CB} + V_{BE}$

Saturation Mode of NPN BJT

In saturation mode, external dc voltages are applied to set BEJ and BCJ are forward-biased.



In saturation mode, BJT acts as a <u>closed switch.</u>

In saturation, the collector current (I_C) consists of two components:

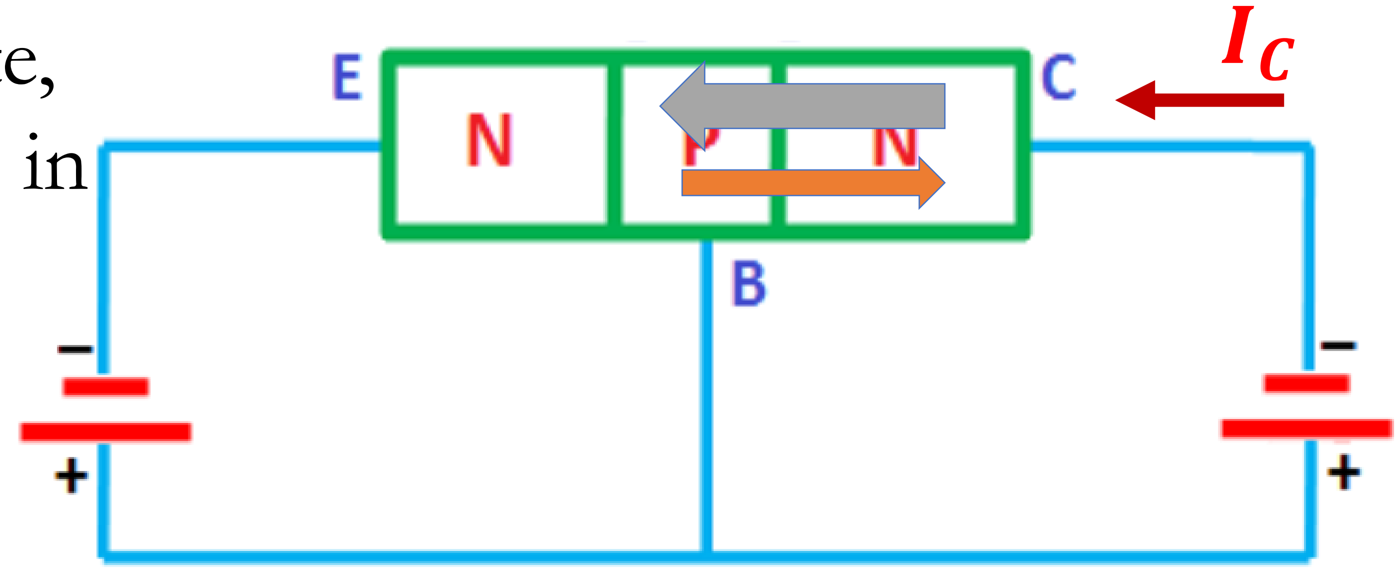
The first component is due to the diffusion of electrons from emitter into collector.

The other is due to the forward current across the base-collector junction.

The two components are opposite, so the collector current decreases in saturation than in active mode.

$$I_C(in\ saturation) < I_C(in\ active)$$

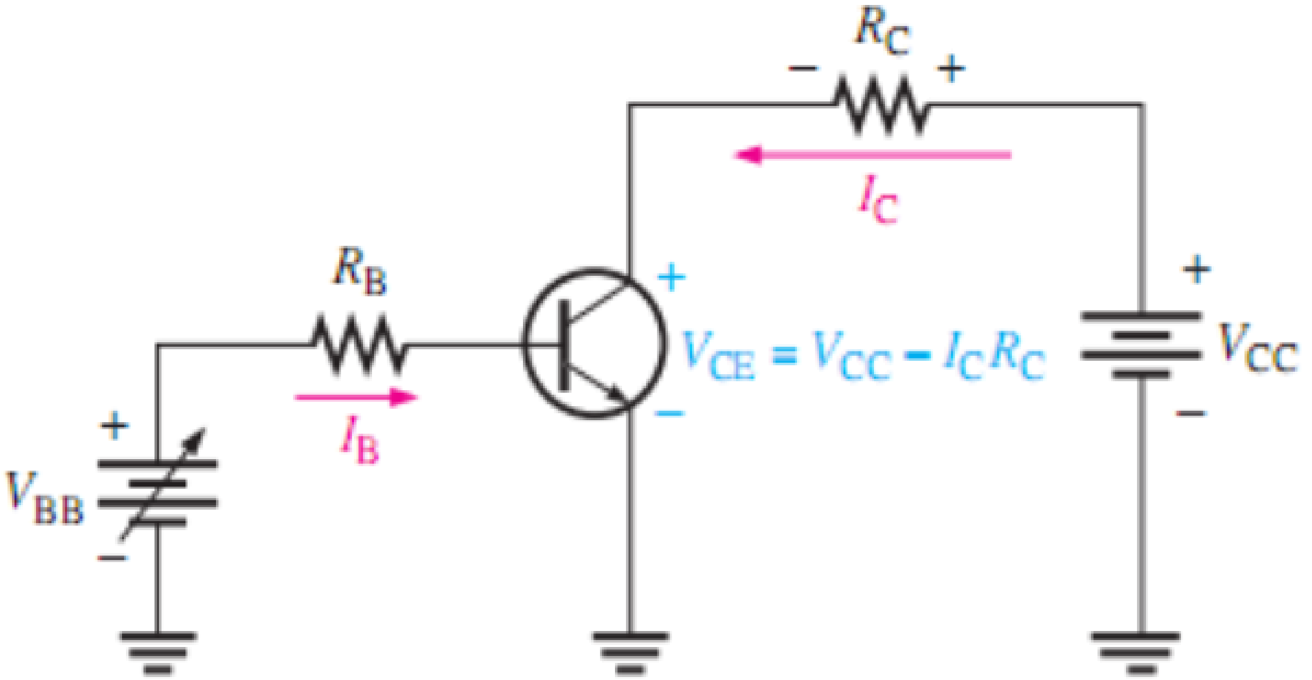
$$\frac{I_C}{I_B}\ (in\ saturation) < \frac{I_C}{I_B}\ (in\ active)$$



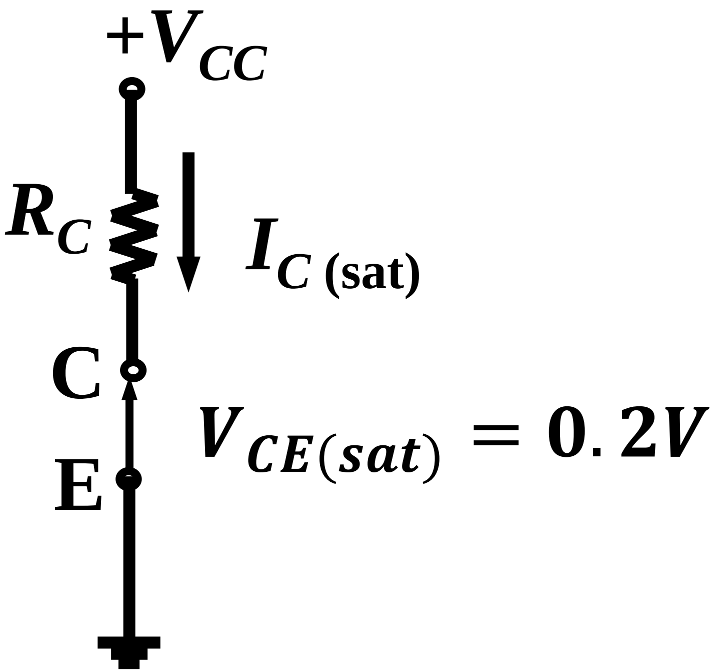
Saturation mode

When the base-emitter junction becomes forward-biased, the base current is increased (I_B), the collector current also increases ($I_C = \beta\, I_B$), and V_{CE} decreases as a result of more voltage drop across the collector resistor ($V_{CE} = V_{CC} - I_C R_C$).

When V_{CE} reaches its saturation value, $\boldsymbol{V_{CE(sat)} = 0.2V}$, the base-collector junction becomes forward-biased.

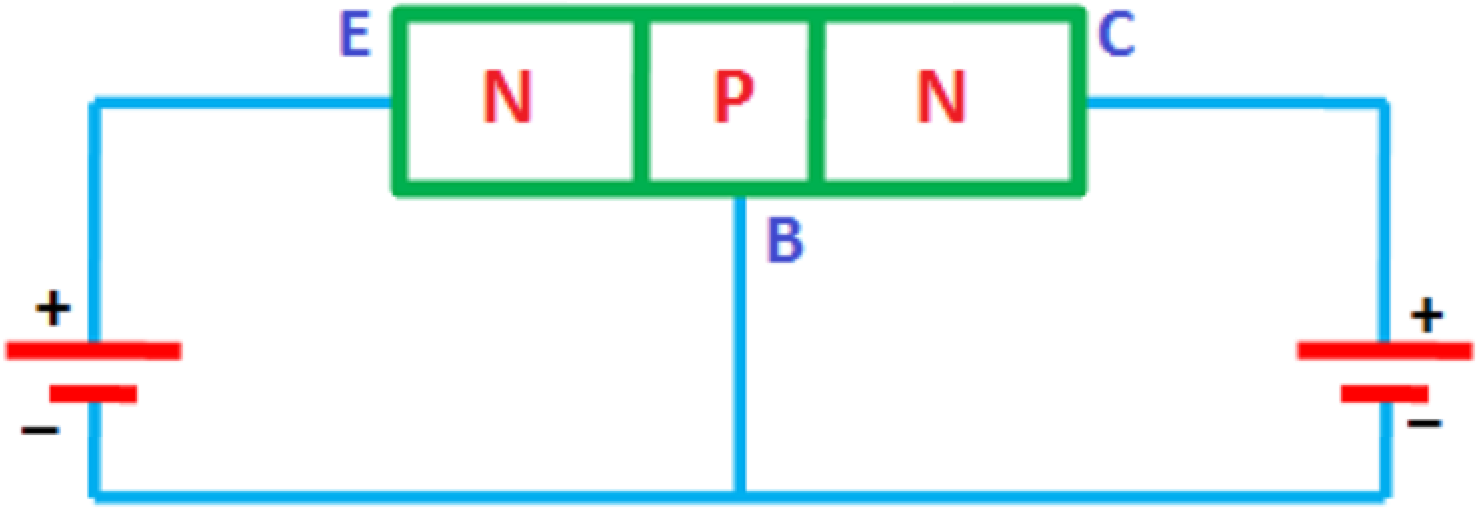


$\cong$



Cutoff Mode of NPN BJT

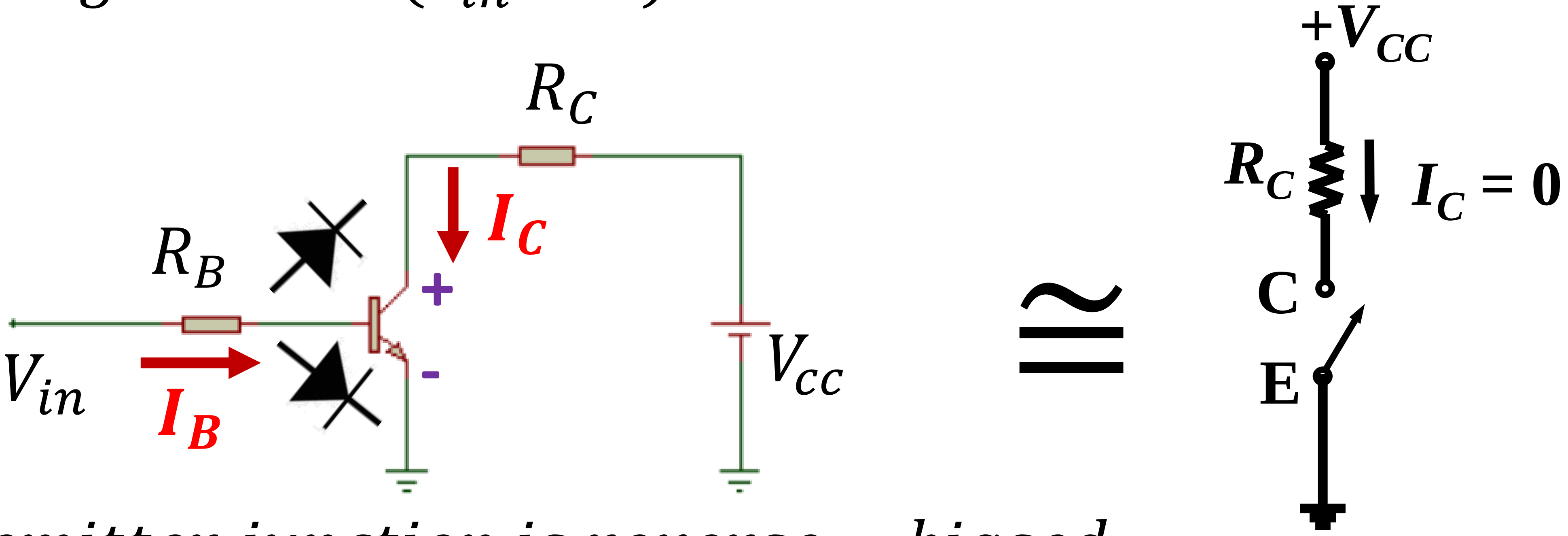
In cutoff mode, external dc voltages are applied to set BEJ and BCJ are reverse-biased.



Cutoff mode

<u>All the terminal currents are zero </u>(when neglecting the reverse saturation current across the junctions) and the <u>BJT</u> acts as an <u>open switch.</u>

$If\ input\ voltage\ is\ zero\ (V_{in} = 0)$



$The\ base - emitter\ junction\ is\ reverse - biased$

$The\ base - collector\ junction\ is\ reverse - biased$

$\therefore \boldsymbol{I_B = I_C = I_E = 0}$

Current and Voltage Analysis

DC currents and dc voltages should be identified.

I_B : Base Current

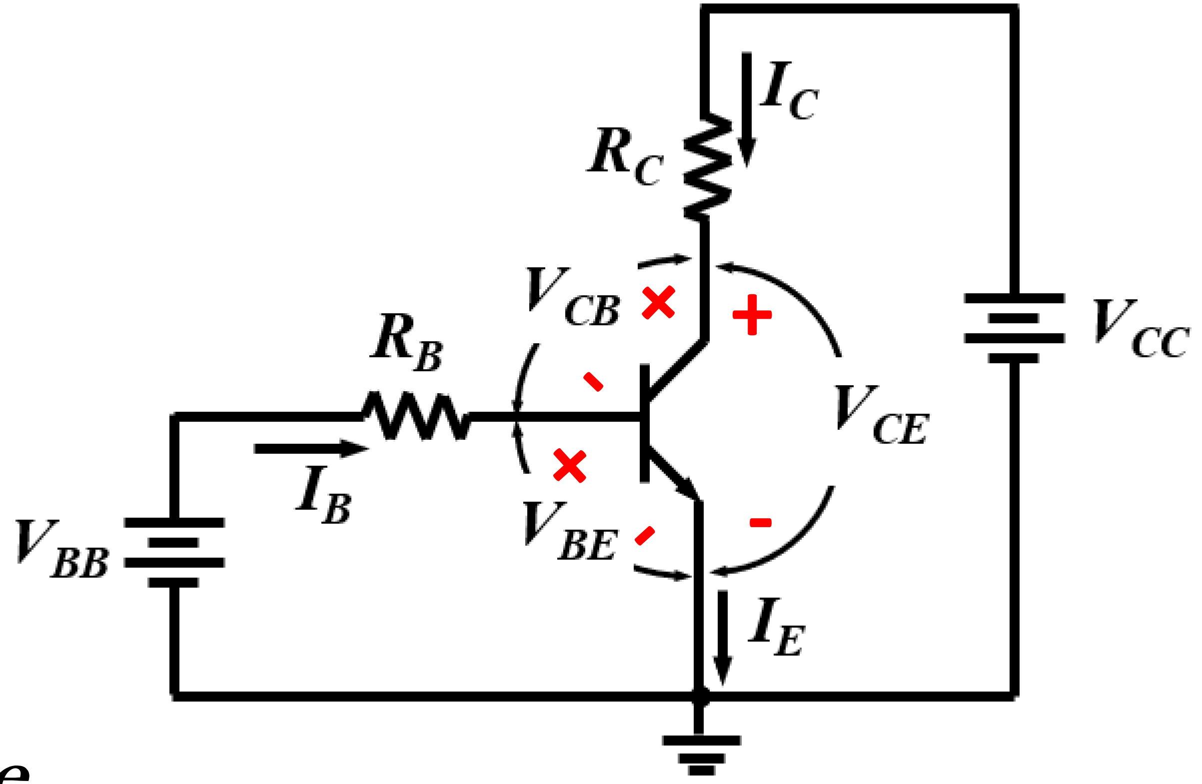
I_C : Collector Current

I_E : Emitter Current

V_{BE} : Base-to-Emitter Voltage

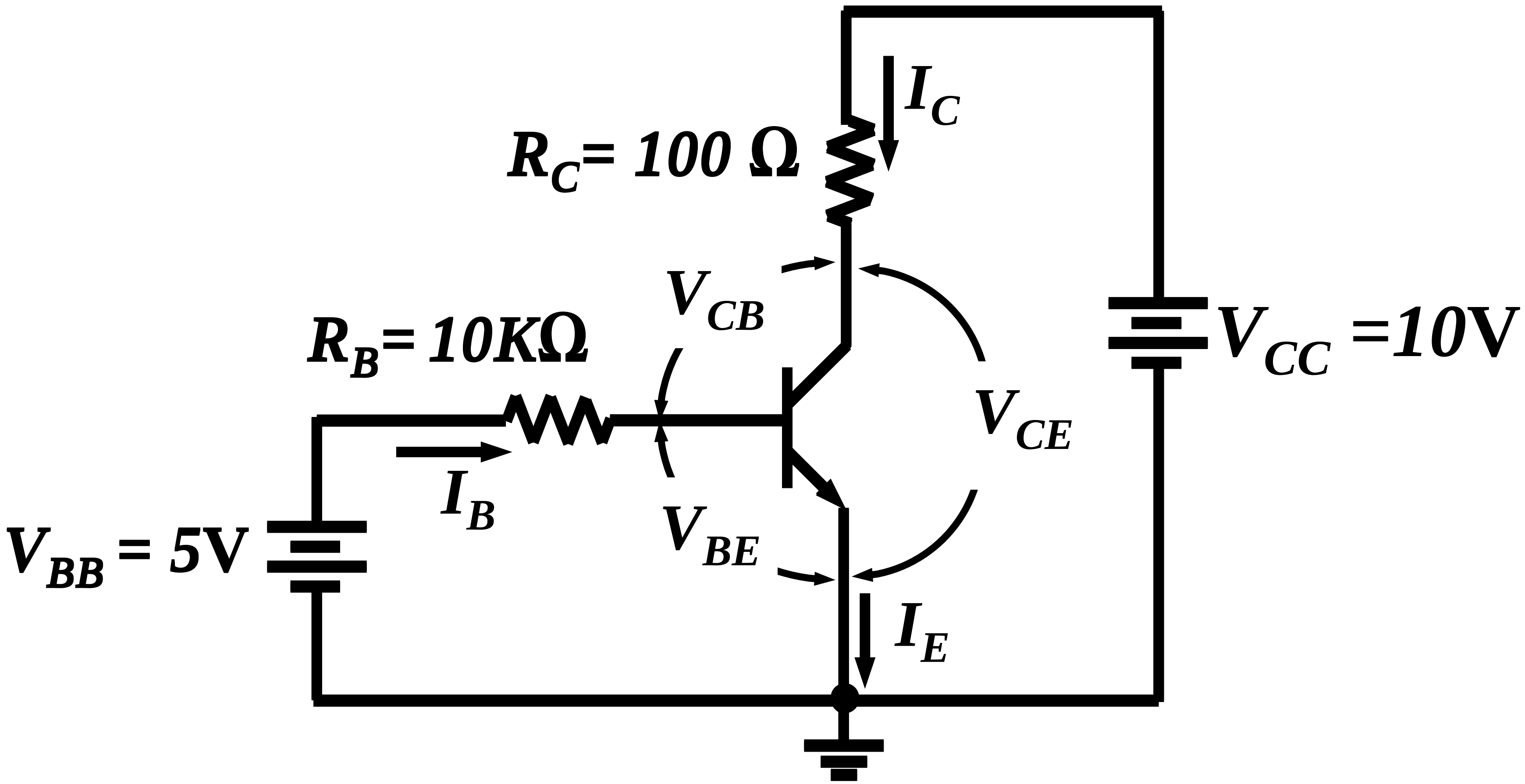
V_{CE} : Collector-to-Emitter Voltage

V_{CB} : Collector-to-Base Voltage



Example 1:

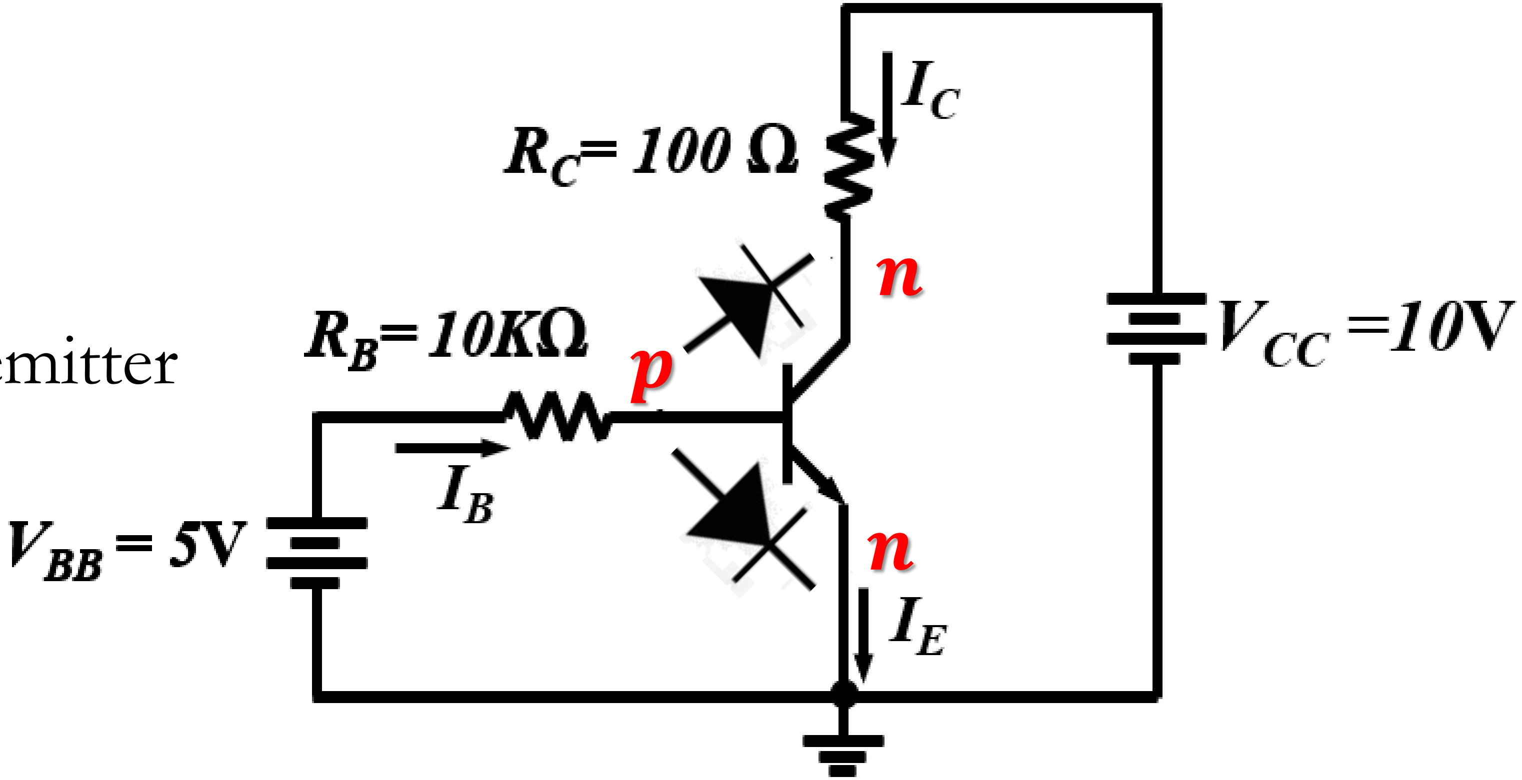
Determine I_B , I_C , I_E , V_{BE} , V_{CE} , V_{CB} in the circuit if β is 150.



Solution:

For the npn BJT :

- Base is connected to V_{BB} (5V) through a resistor 10KΩ and emitter is connected to ground (0V).
  If VB > VE , base–emitter junction will be forward biased.

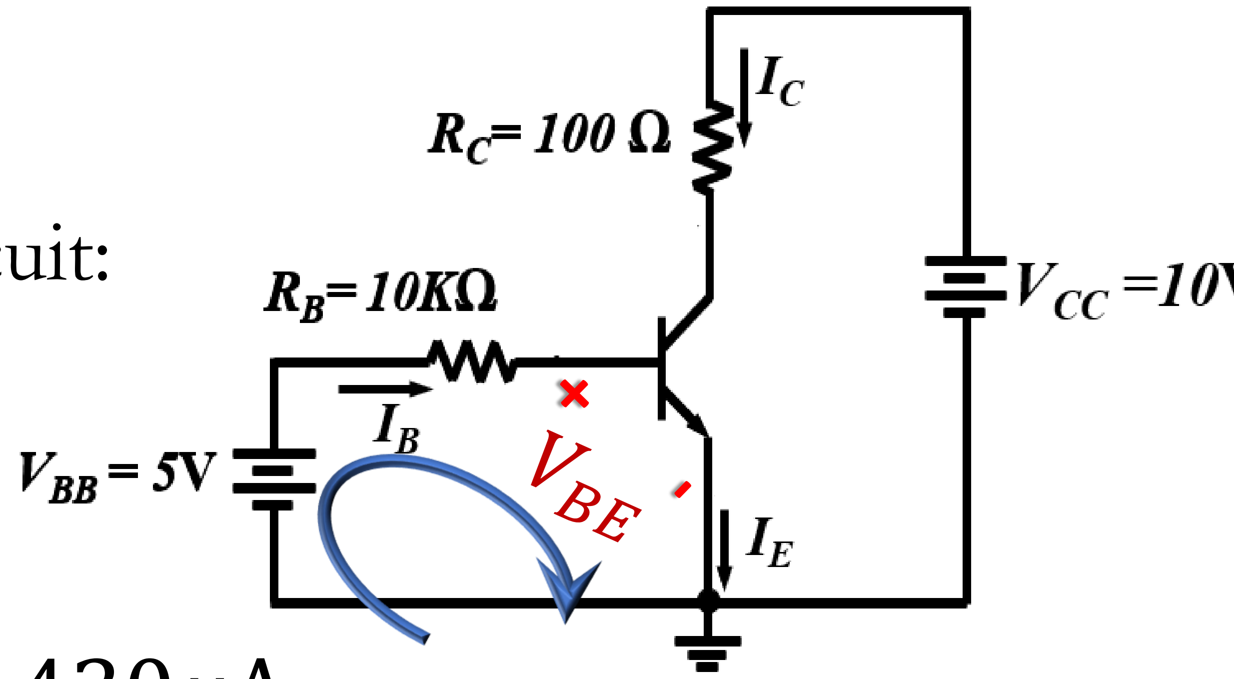


- Base is connected to V_{BB} (5V) through a resistor 10KΩ and collector is connected to V_{CC} (10V) through a resistor 100Ω.
  If VB ≤ VC , base–collector junction is reverse biased.

- Assume transistor is in active mode and VBE=0.7V

In active mode: $V_{BE} = 0.7V$

Applying KVL in the base-emitter circuit:



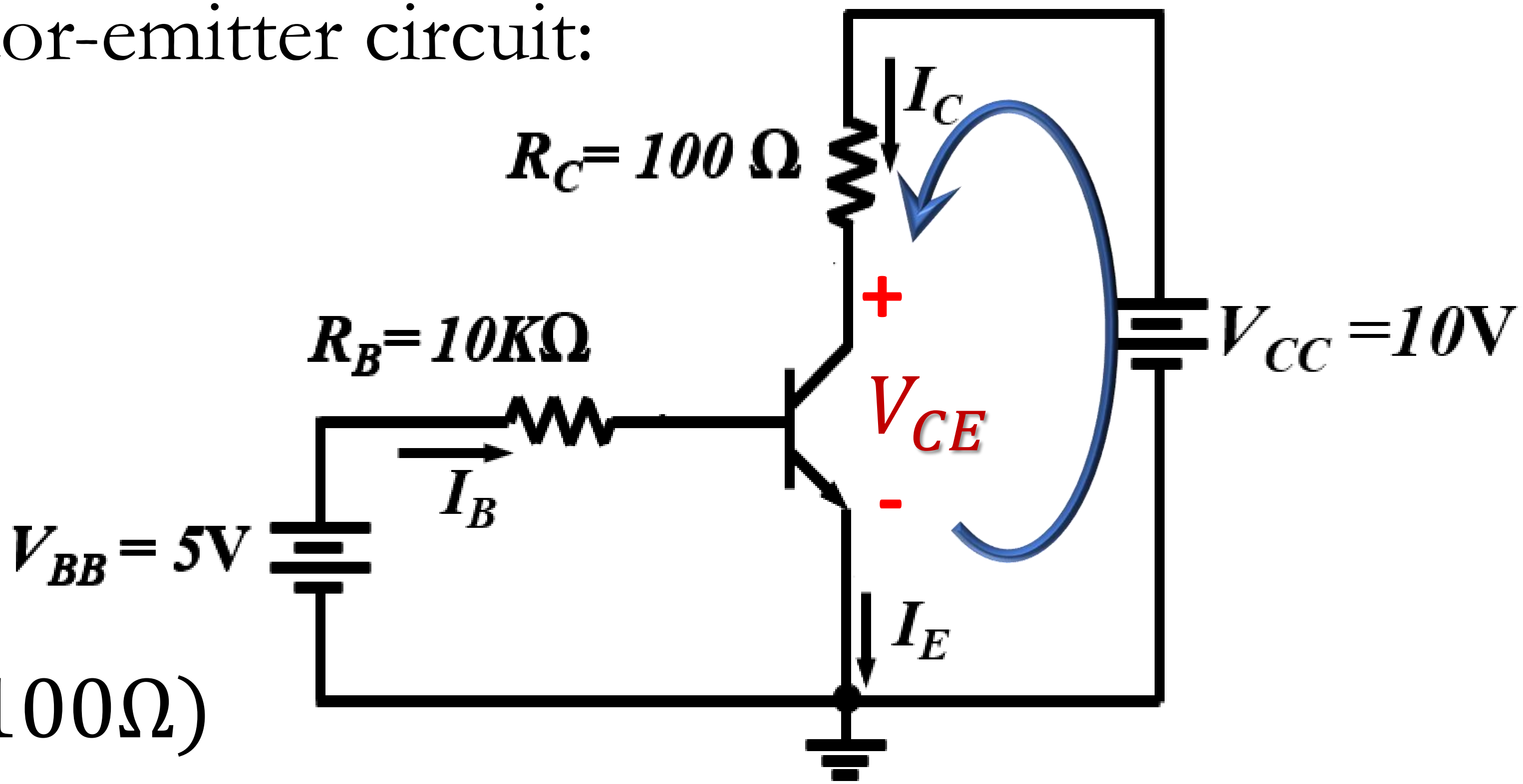
$$V_{BB} - I_B R_B - V_{BE} = 0$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5V - 0.7V}{10K\Omega} = 430\mu A$$

$$I_C = \beta\, I_B = (150)(430\mu A) = 64.5\text{mA}$$

$$I_E = I_C + I_B = 64.5\text{mA} + 430\mu A = 64.9\text{mA}$$

Applying KVL in the collector-emitter circuit:



$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$V_{CE} = V_{CC} - I_C V_C$$

$$V_{CE} = 10\text{V} - (64.5\text{mA})(100\Omega)$$

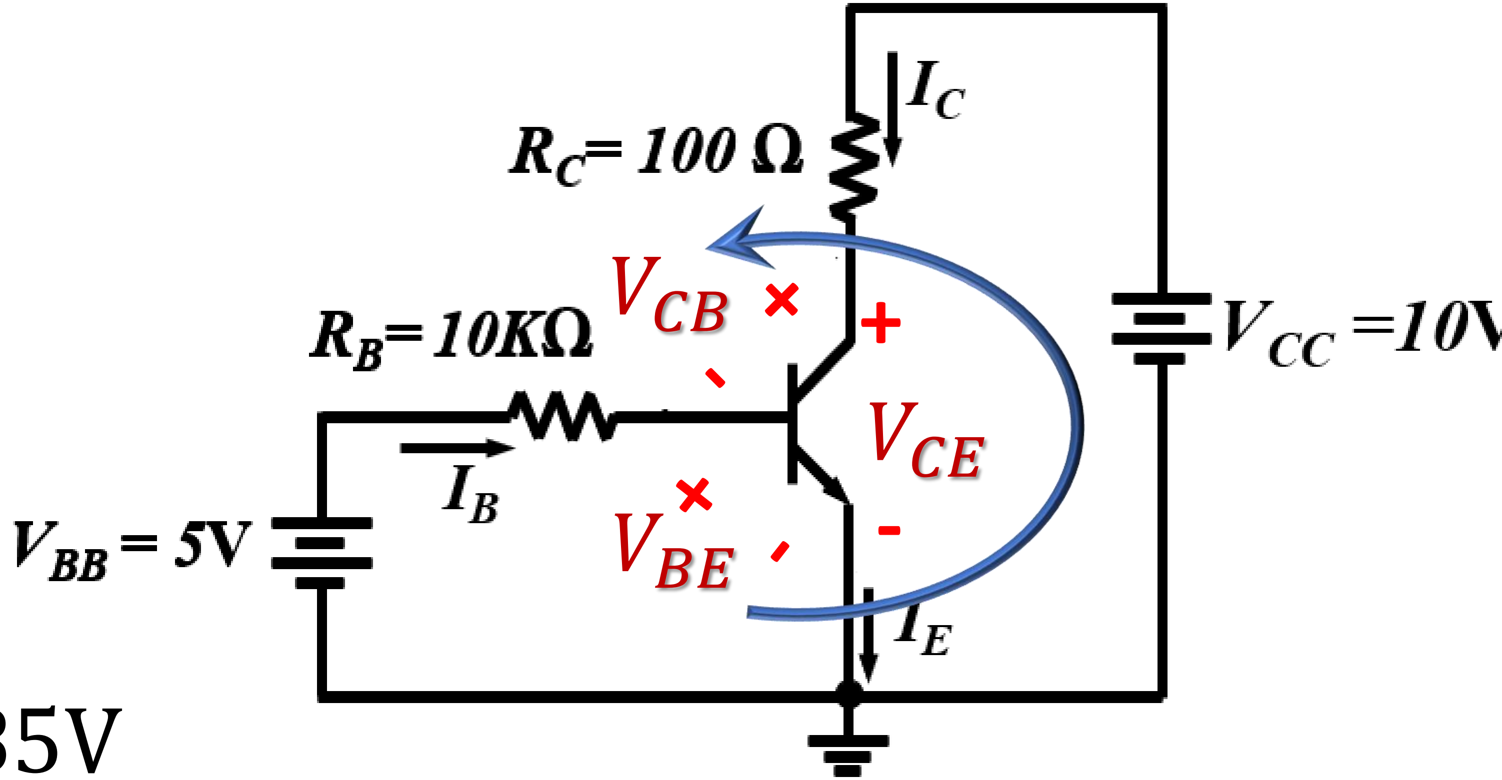
$$V_{CE} = 10\text{V} - 6.45\text{V} = 3.55\text{V}$$

$$\because V_{CE} \gg 0.2V$$

$$\therefore Transistor\ is\ in\ active\ mode$$

The voltage across the base-collector junction (V_{CB}) is given by a KVL around transistor terminals:

$$V_{CE} - V_{CB} - V_{BE} = 0$$



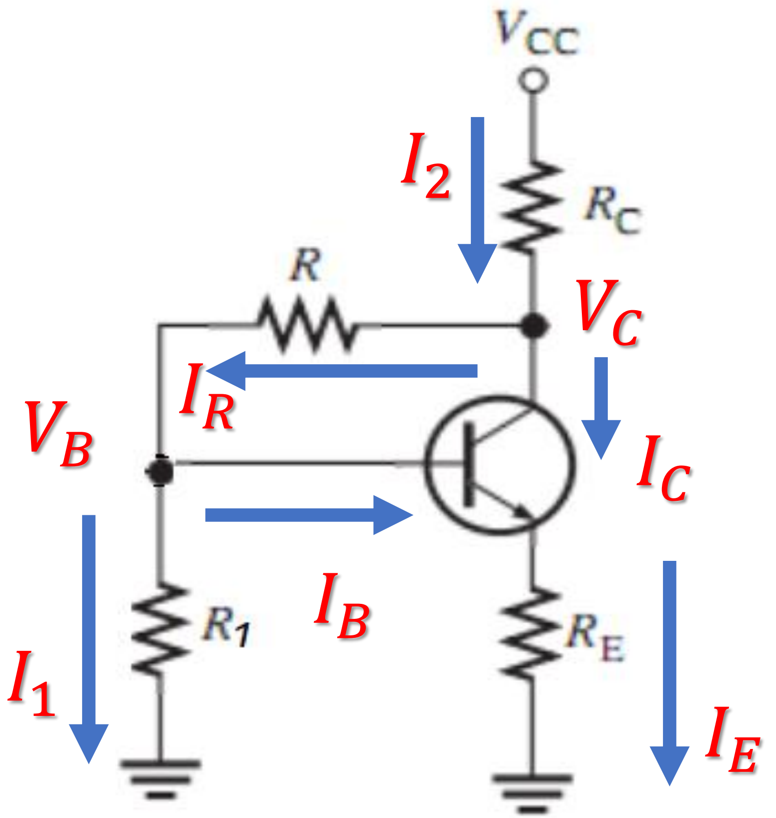
$$V_{CB} = V_{CE} - V_{BE}$$

$$V_{CB} = 3.55\text{V} - 0.7\text{V} = 2.85\text{V}$$

$\because$ V_{CB} *is positive value* → Transistor is in <u>active mode</u>

Example 2:

Assume transistor in active mode with α=0.97 and V_{BE}=0.7V, find R in the circuit shown to yield I_E=2mA.
R_C=2KΩ, R_E=100Ω, R_1=25KΩ, V_{CC}=10V.



Solution:

$$I_C = \alpha\, I_E$$

$$I_B = I_E - I_C$$

$$R = \frac{V_C - V_B}{I_R}$$

$$V_B - V_{BE} - R_E I_E = 0 \Rightarrow V_B = V_{BE} + R_E I_E$$

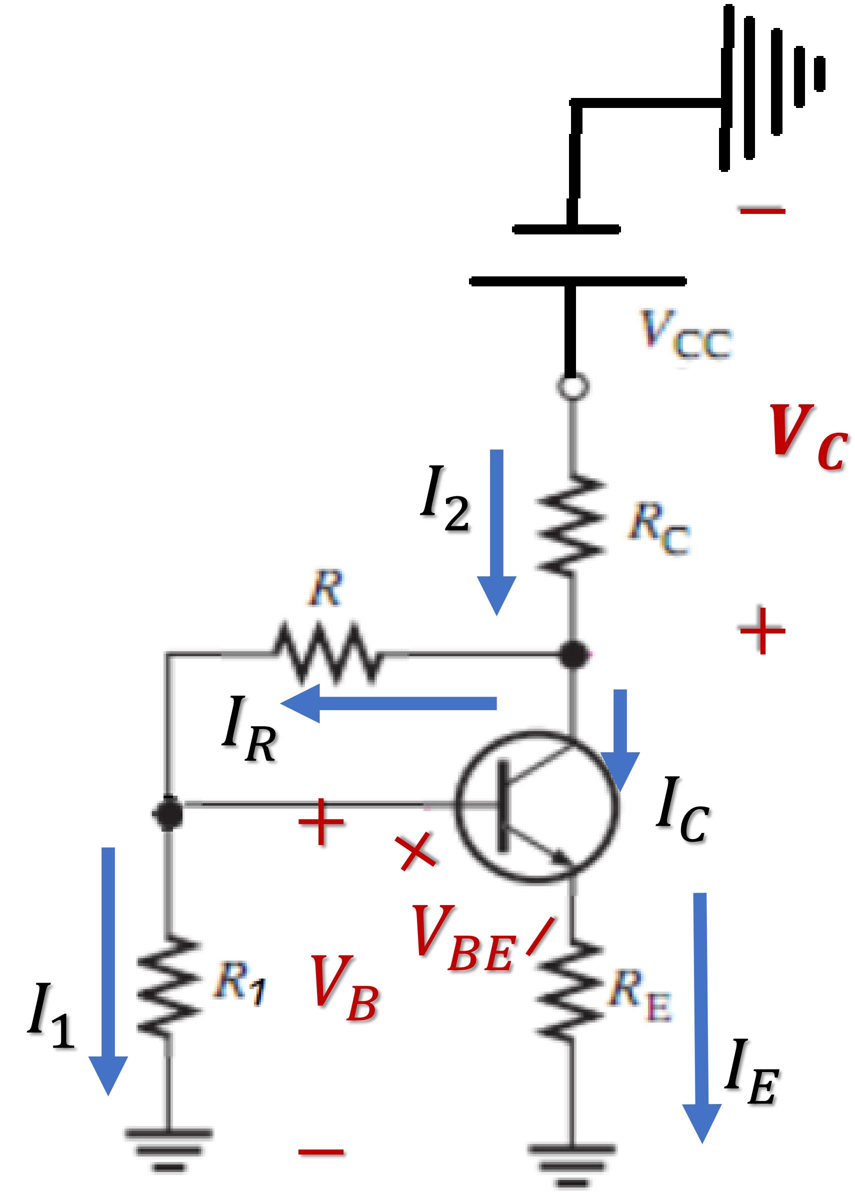
$$I_1 = \frac{V_B}{R_1}$$

$$I_R = I_1 + I_B$$

$$I_2 = I_R + I_C$$

$$-V_C + V_{CC} - I_2 R_C = 0$$

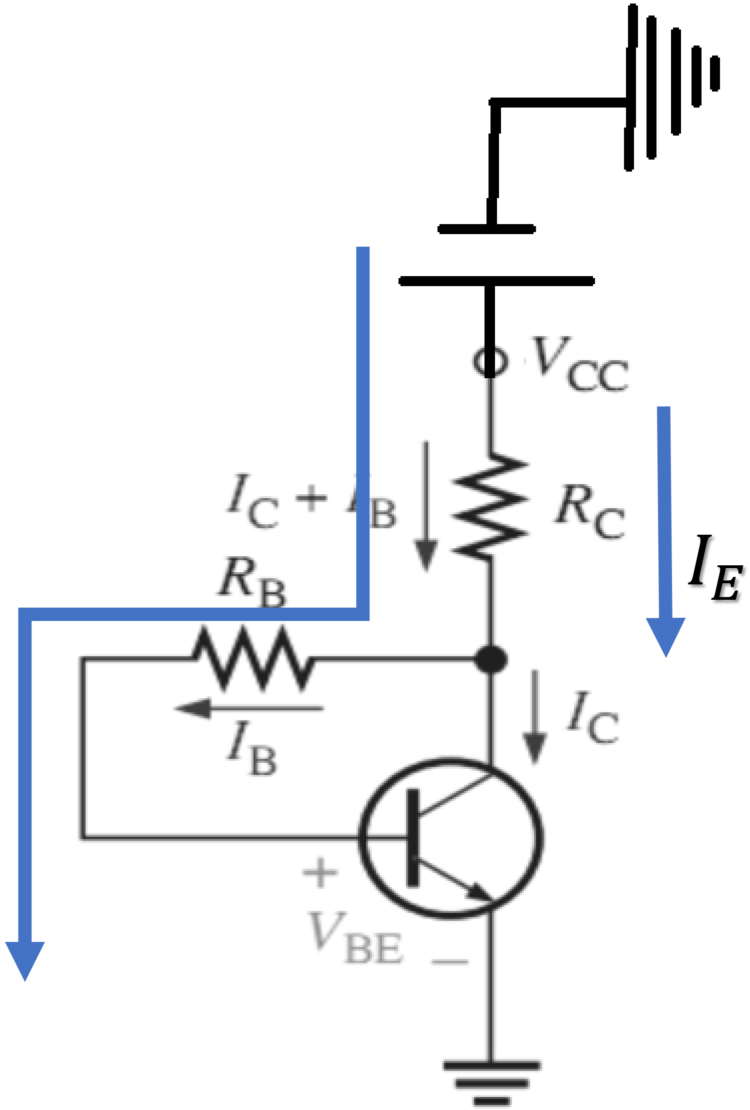
$$V_C = V_{CC} - I_2 R_C$$



Example 3:

A transistor given in the figure has $\boldsymbol{\beta = 100}$.
If $\boldsymbol{V_{CC} = 10V,\ R_C = 2.7K\Omega,\ R_B = 180K\Omega}$.
Determine the value of $\boldsymbol{V_{CE}}$ and $\boldsymbol{I_C}$.

Solution: Assume transistor in active mode



Applying KVL in the base-emitter circuit:

$$VCC - (2.7K)IE \ - (180k)IB - VBE = 0$$

$$VCC - (2.7K)(1+\beta)IB \ - (180k)IB - 0.7 = 0$$

$$IB = positive$$

$$IE = (1 + \beta)IB$$

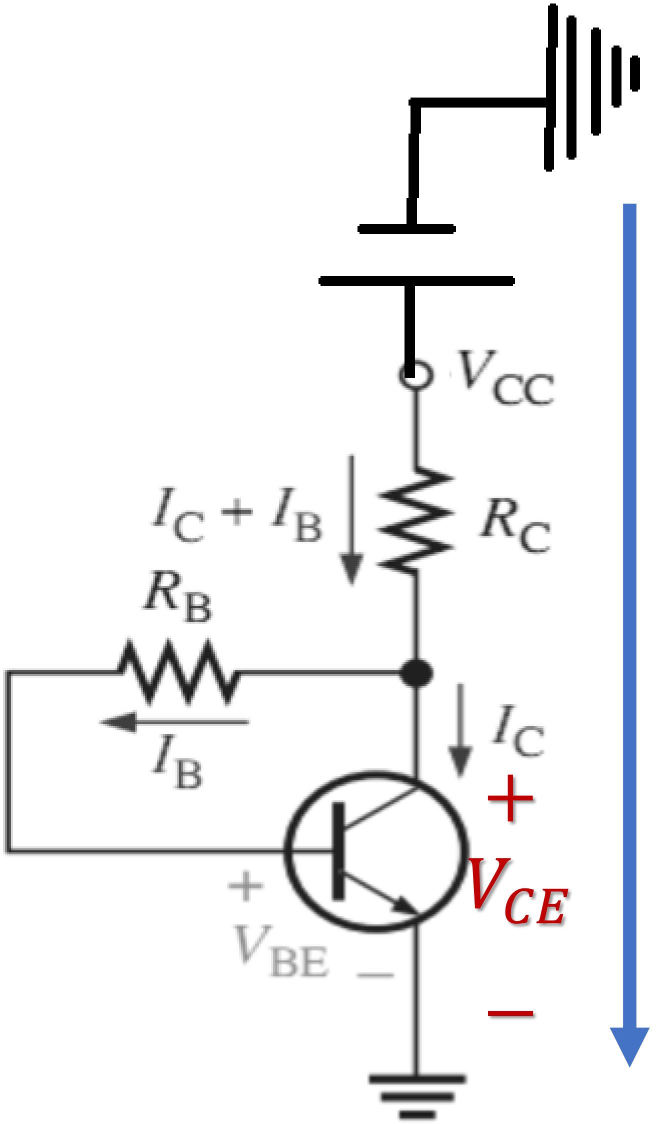
$$IC = IE - IB$$

Applying KVL in the collector-emitter circuit:

$$VCC - (2.7K)IE - VCE = 0$$

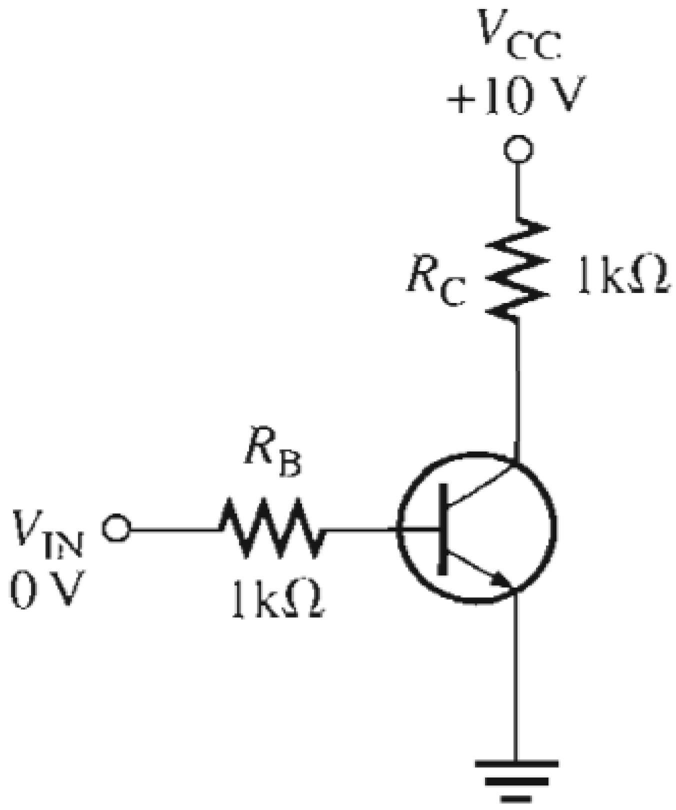
$$V_{CE} \gg 0.2\text{V}$$

∴Transistor in active mode



Example 4:

Determine the node voltages V_B , V_E , V_C and the currents I_B , I_C , I_E .



Solution:

For the npn BJT :

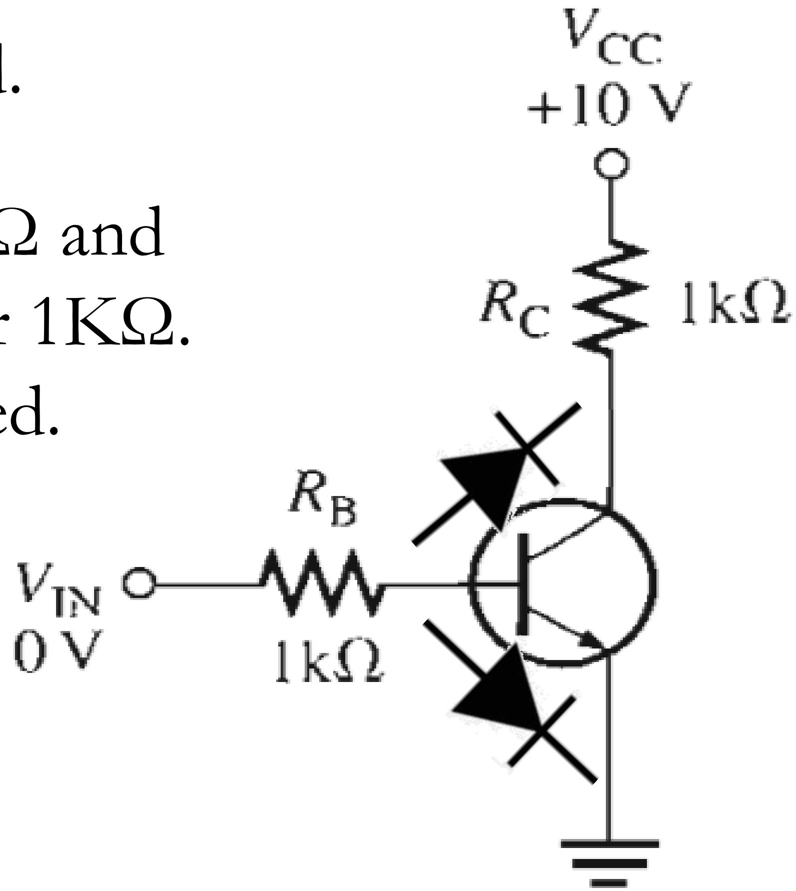
- ❑ Base is connected to V_{IN} (0V) through a resistor 1KΩ and emitter is connected to ground (0V).

$If\ V_B \leq V_E$, base-emitter junction will be reverse biased.

- ❑ Base is connected to V_{IN} (0V) through a resistor 1KΩ and collector is connected to V_{CC} (10V) through a resistor 1KΩ.

$If\ V_B \leq V_C$, base-collector junction will be reverse biased.

- ❑ Assume transistor is in cutoff mode.

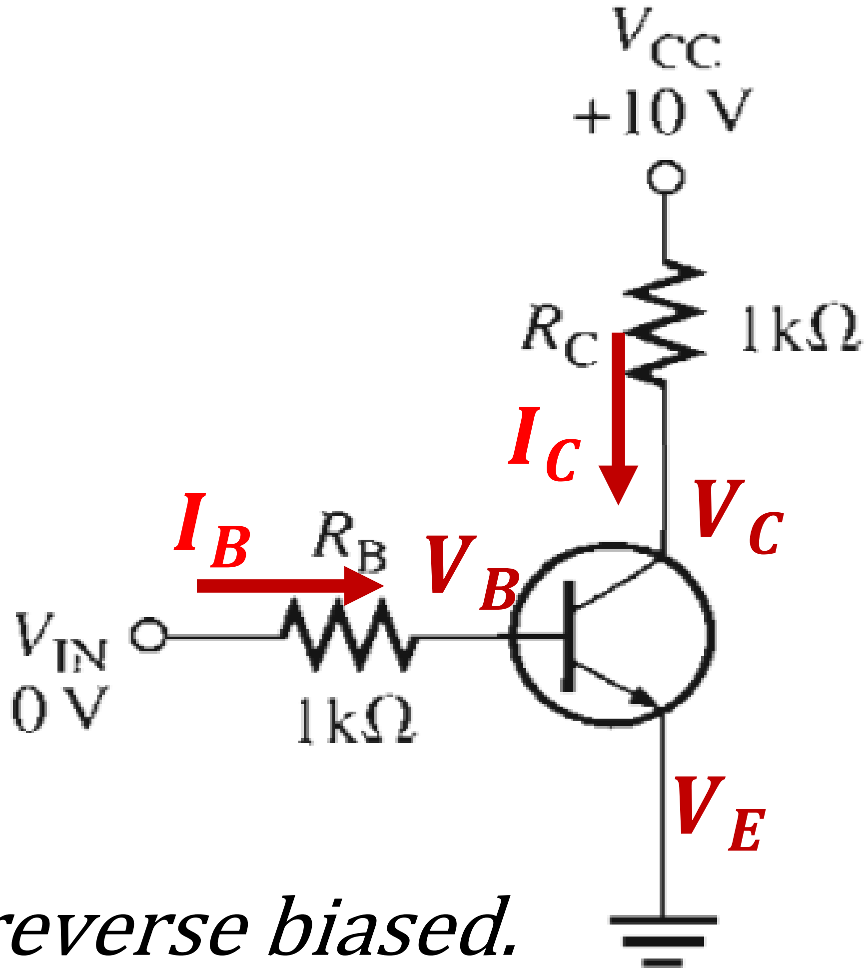


In cutoff mode: $I_B = I_C = I_E = 0$

$$V_B = V_{IN} - R_B I_B = 0V$$

$$V_E = 0V$$

$$V_C = V_{CC} - R_C I_C = 10V$$



$If\ V_B \leq V_E\ \rightarrow \therefore\ base{-}emitter\ junction\ is\ reverse\ biased.$

$If\ V_B \leq V_C\ \rightarrow \therefore\ base{-}collector\ junction\ is\ reverse\ biased.$

$\therefore\ Transistor\ is\ in\ cutoff\ mode.$

Example 5:

If β=100, determine whether or not a transistor is in saturation and find I_B, and I_C. Repeat with the 2KΩ emitter resistance is added.

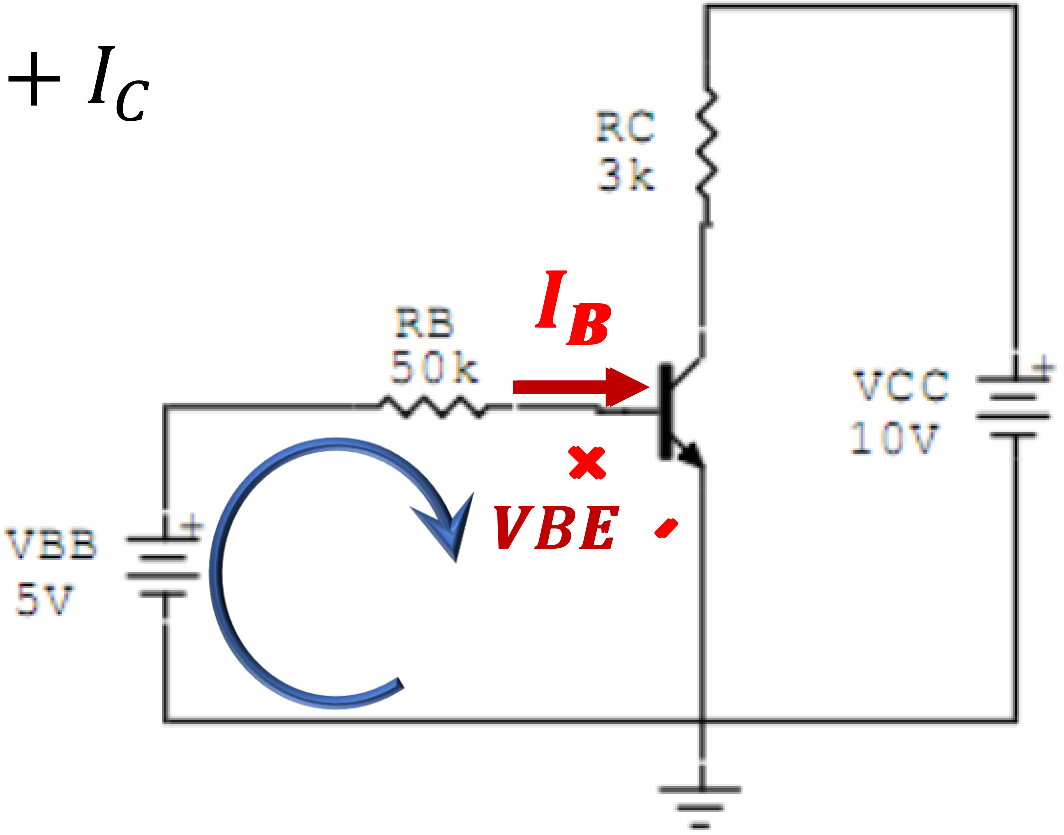
Solution: Assume transistor is in saturation mode:

$$V_{BE} = 0.7V, \quad V_{CE} = 0.2V, \quad I_E = I_B + I_C$$

Apply KVL in the base-emitter circuit:

$$V_{BB} - I_B R_B - V_{BE} = 0$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = 86\mu A$$

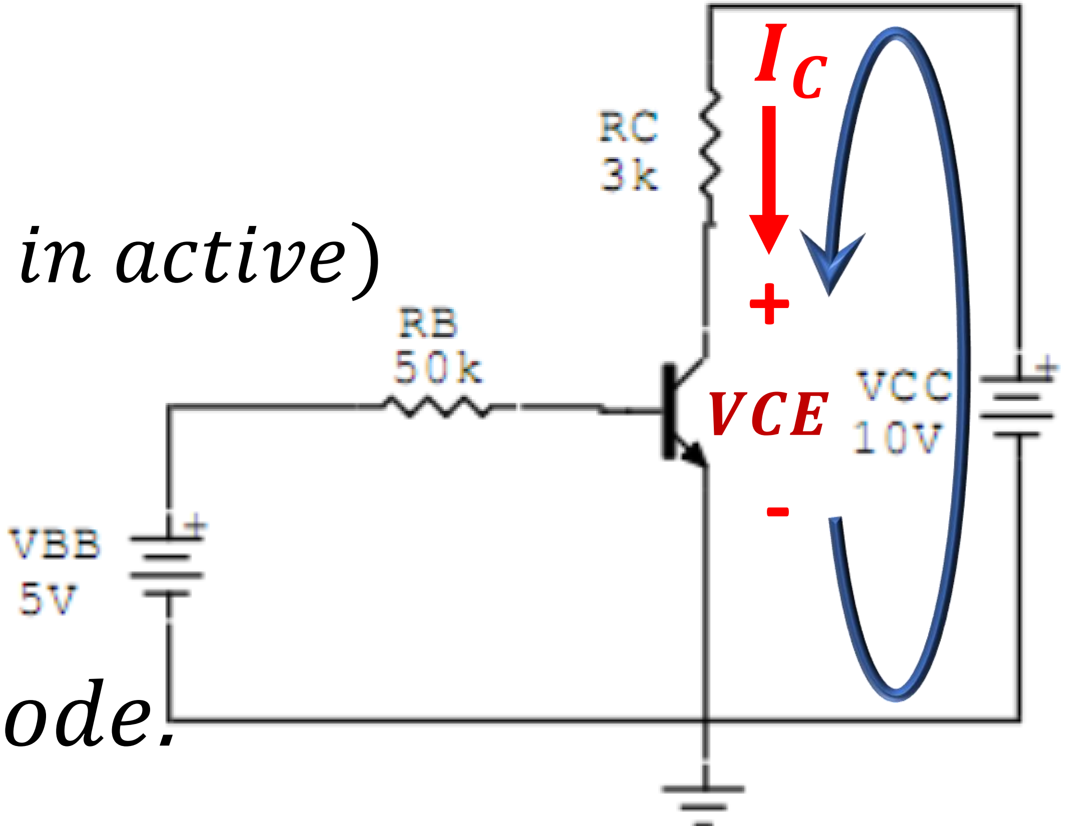


Apply KVL in the collector-emitter circuit:

$$V_{CC} - I_C R_C - V_{CE} = 0 \quad \Rightarrow \quad I_C = \frac{V_{CC} - V_{CE}}{R_C} = 3.26mA$$

$$\frac{I_C}{I_B}\,(in\ saturation) = \frac{3.26x10^{-3}}{8.6x10^{-5}} = 38$$

$$\frac{I_C}{I_B}\,(in\ saturation) < \left(\beta = \frac{I_C}{I_B} = 100\ in\ active\right)$$



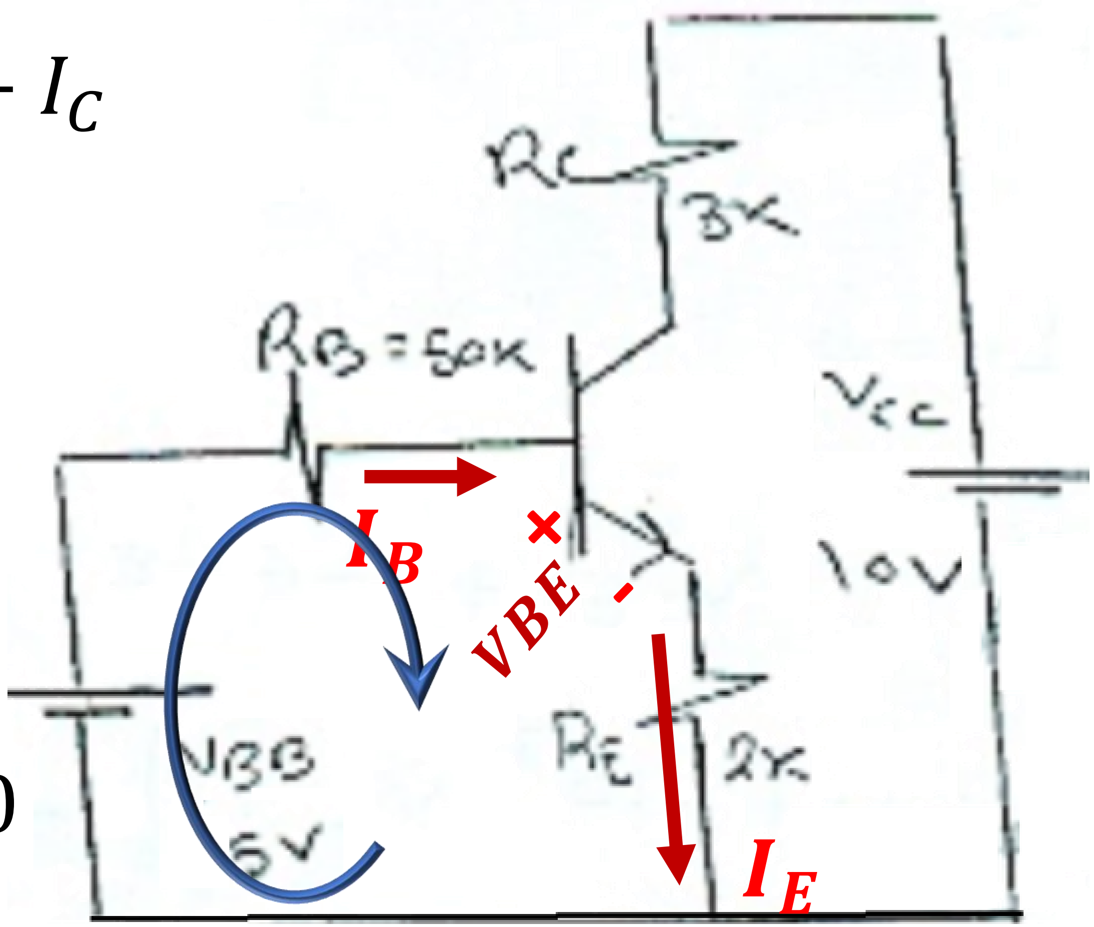
$\therefore$ *Transistor is in saturation mode.*

- Repeat with the 2KΩ emitter resistance is added.

Assume transistor is in saturation mode:

$V_{BE} = 0.7V, \quad V_{CE} = 0.2V, \quad I_E = I_B + I_C$

Apply KVL in the base-emitter circuit:



$$V_{BB} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$VBB - IB\ RB - VBE - (I_B + I_C)R_E = 0$$

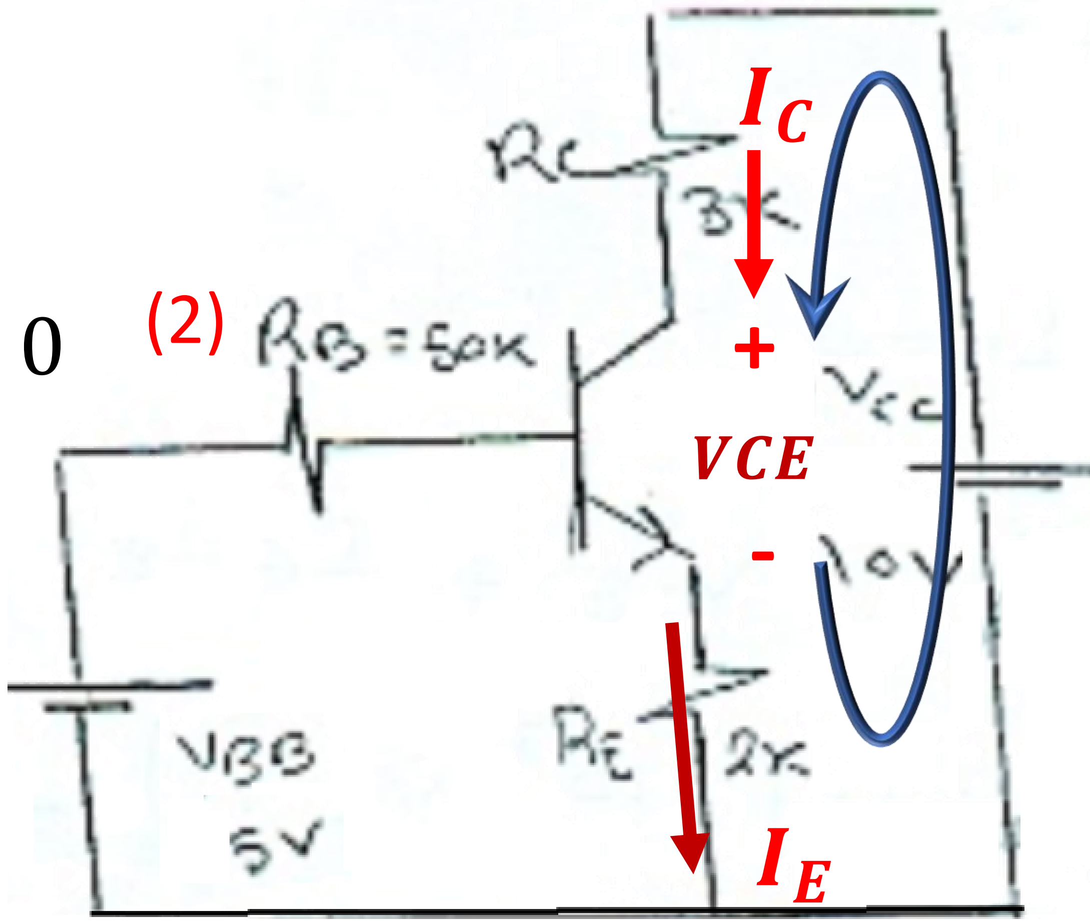
(1)

Apply KVL in the collector-emitter circuit:

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$VCC - IC\ RC - VCE - (IB + IC\ )RE = 0$$

(2)



From (1) and (2):

$$I_B = 6.25\text{x}10^{-6} \text{ A}$$

$$I_C = 1.94\text{x}10^{-3} \text{ A}$$

$$\frac{I_C}{I_B} = \frac{1.94\text{x}10^{-3}}{6.25\text{x}10^{-6}} = 310.4 > (\beta = 100\ in\ active)$$

Transistor is not in saturation

Assume again transistor is in <u>active mode:</u> $V_{BE} = 0.7V$

Apply KVL in the base-emitter circuit:

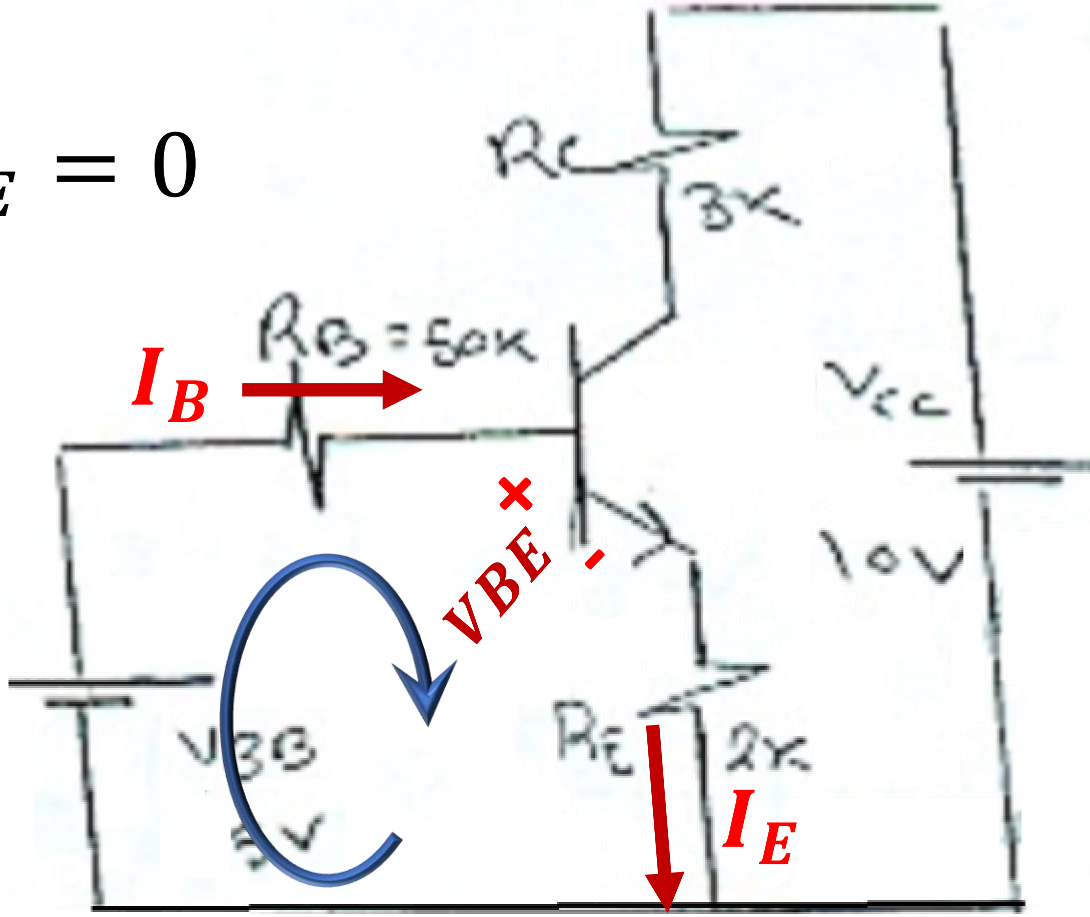
$$V_{BB} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{BB} - I_B R_B - V_{BE} - (1+\beta)\, I_B R_E = 0$$

$$I_B = 0.017mA$$

$$I_E = (1+\beta)\; I_B = 1.72mA$$

$$I_C = \beta\, I_B = 1.70mA$$

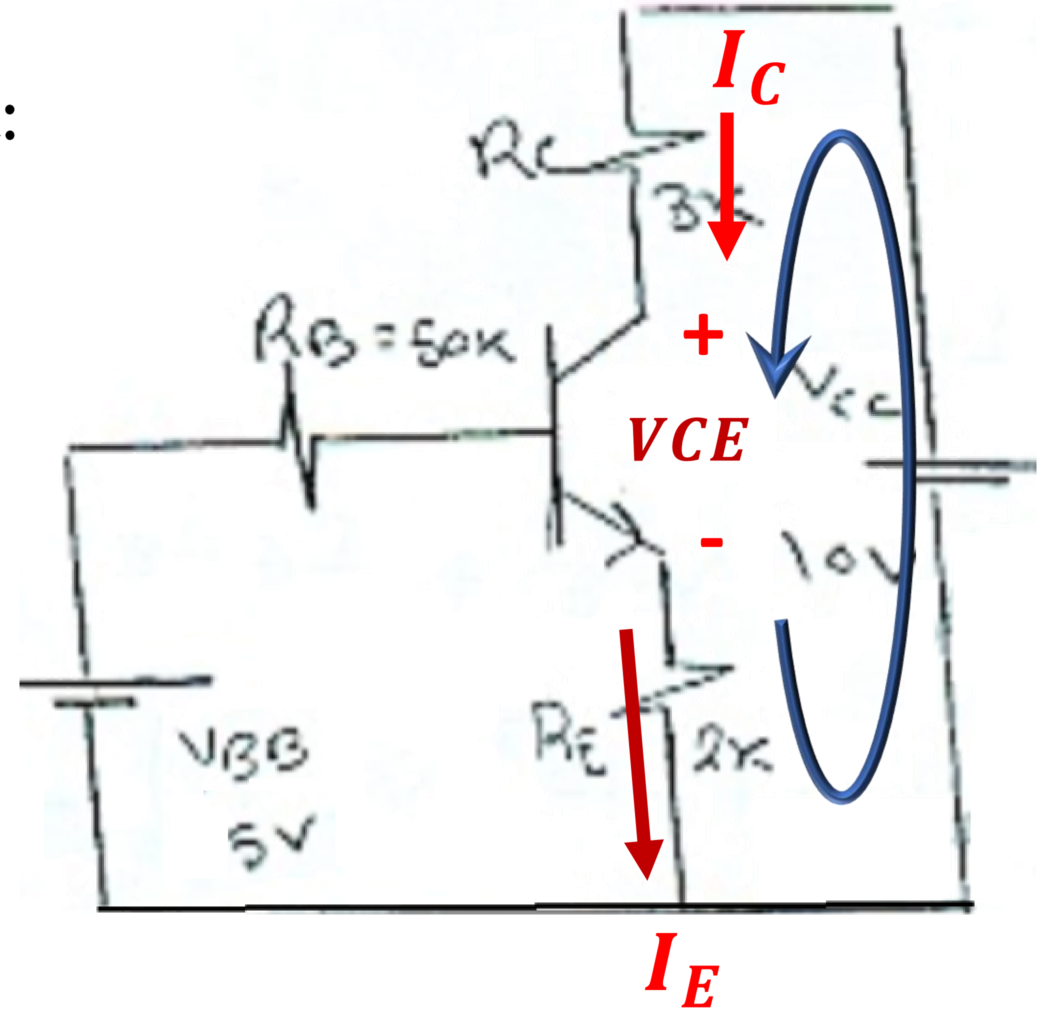


Apply KVL in the collector-emitter circuit:

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$V_{CC} - I_C R_C - I_E R_E = V_{CE}$$

$$V_{CE} = 1.46V$$



$\because VCE > 0.2V$ ➡ $\therefore$ Transistor is in active mode

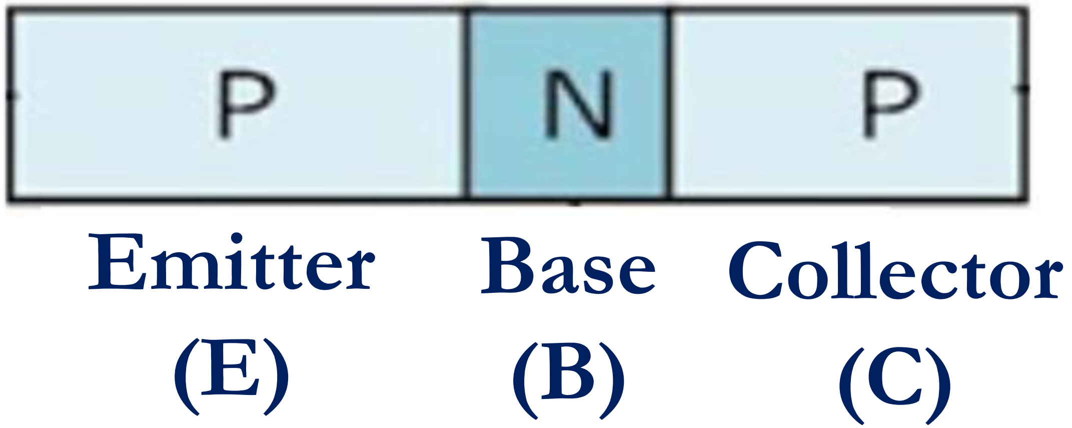
$\therefore The\ correct\ values\ of\ currents\ are$

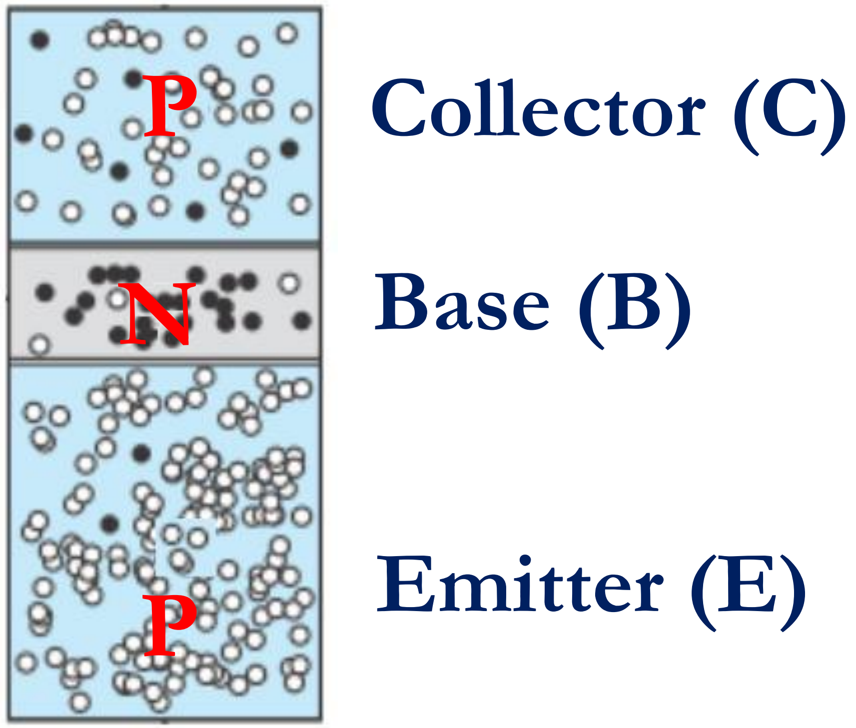
$$I_B = 0.017mA$$

$$I_C = 1.70mA$$

$$I_E = 1.72mA$$

PNP BJT consists of two p regions separated by n region.





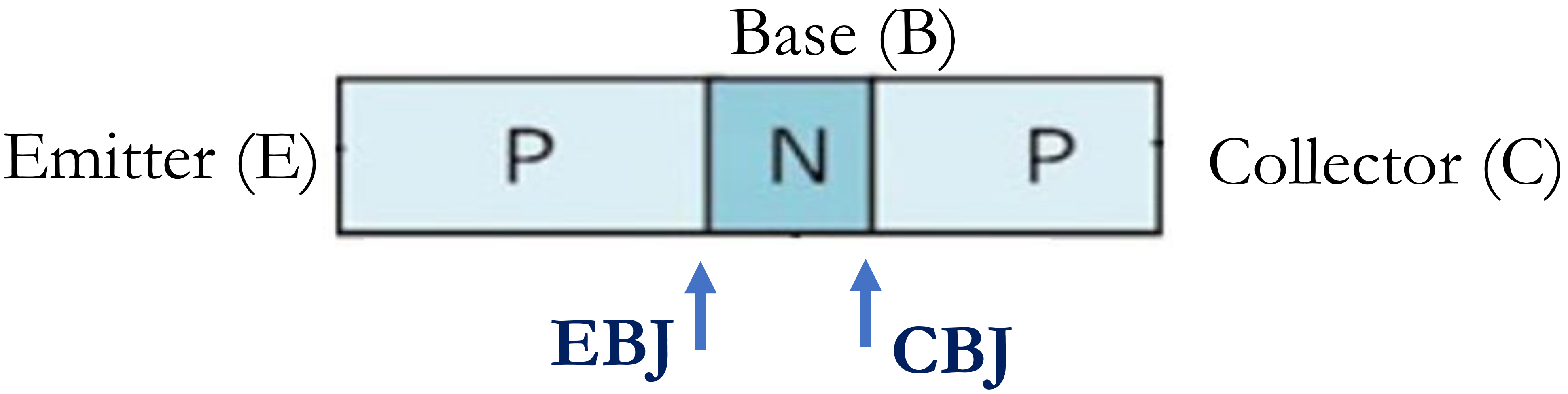
The emitter region is <u>heavily</u> doped.

The collector region is <u>moderately</u> doped.

The base region is <u>lightly</u> doped and very thin.

Junctions of PNP BJT

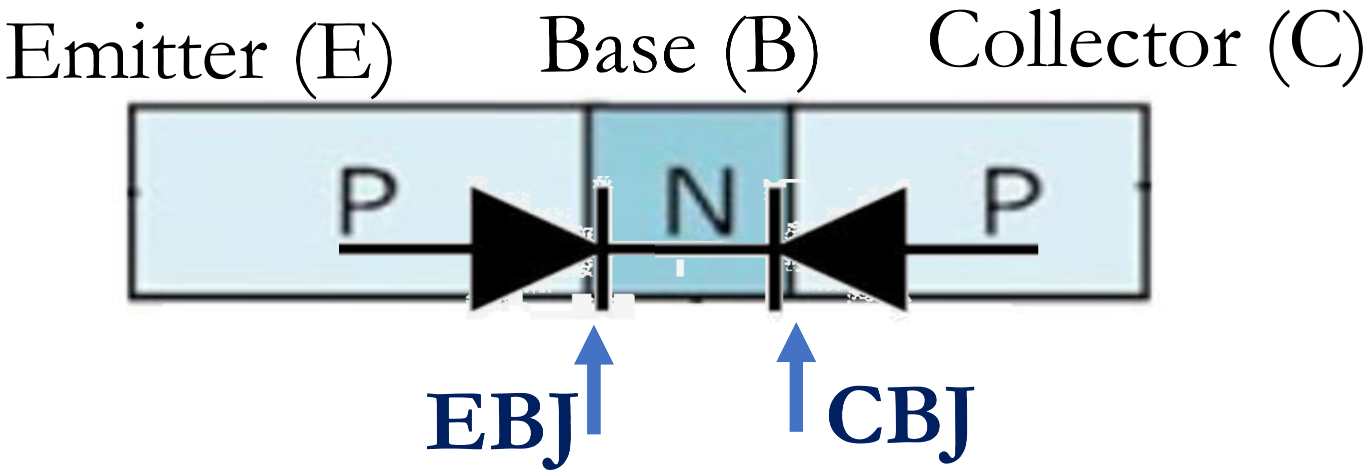
PNP BJT has two pn junctions.



The pn junction joining the emitter region and the base region is called the emitter-base junction (EBJ).

The pn junction joining the collector region and the base region is called the collector-base junction (CBJ).

Modes (Operation Regions) of PNP BJT



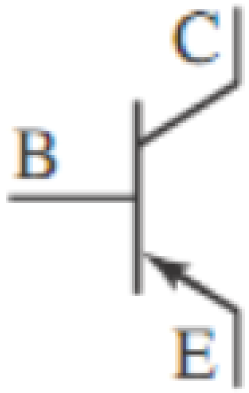
Modes	EBJ	CBJ	Applications
Active	Forward	Reverse	Amplifier
Saturation	Forward	Forward	Closed Switch
Cutoff	Reverse	Reverse	Open Switch

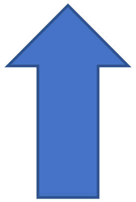
Digital Circuits

Symbol of PNP BJT

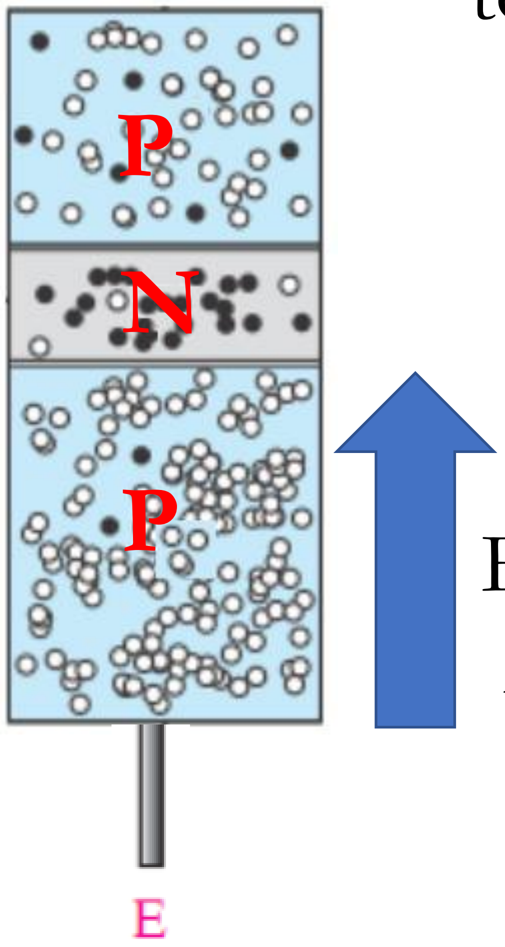
The arrow on the emitter lead refers to the direction of the emitter current when the emitter-base junction is forward-biased.

PNP Symbol

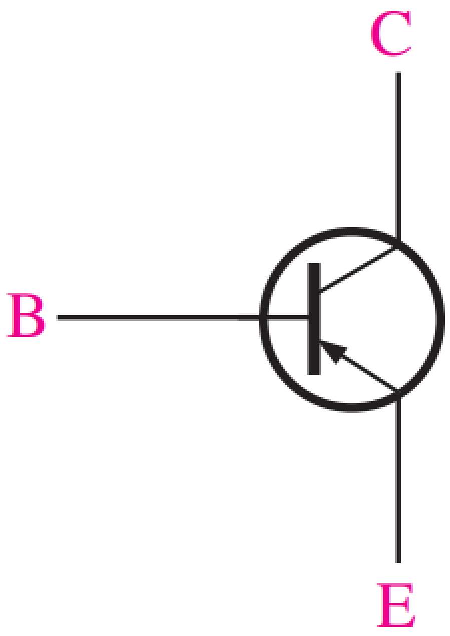




Emitter Current

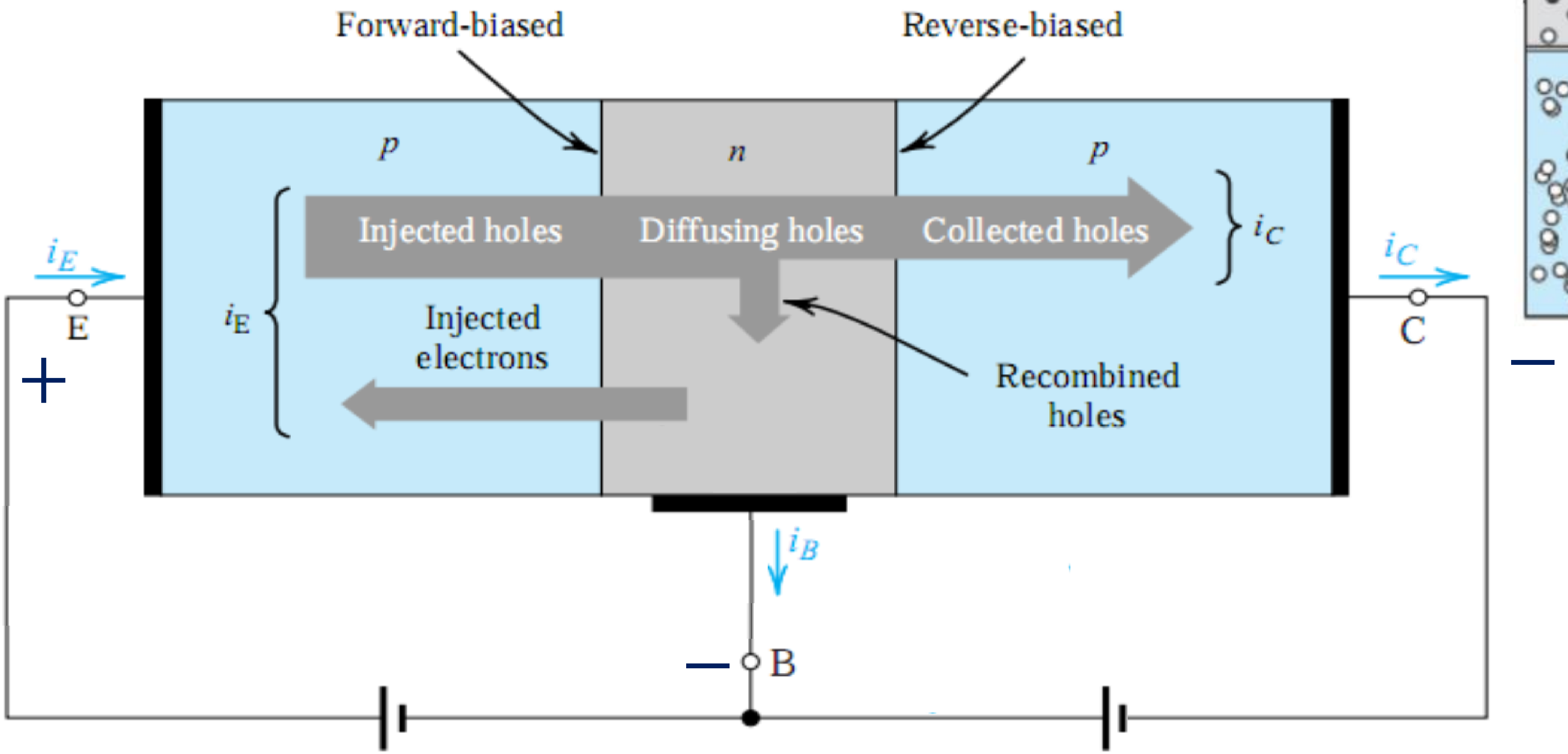


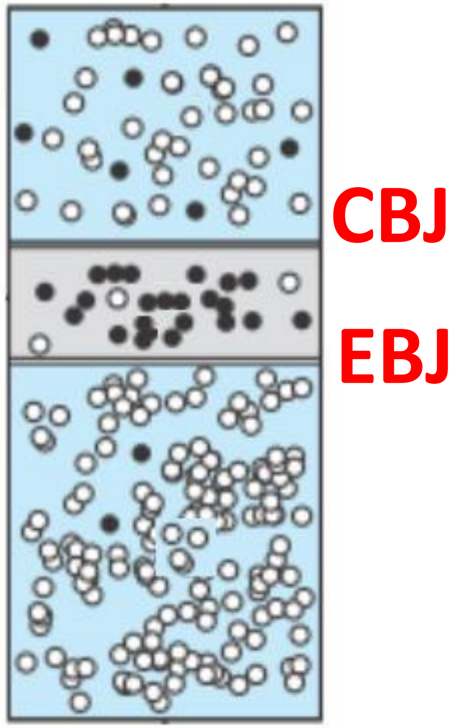
Emitter injects holes



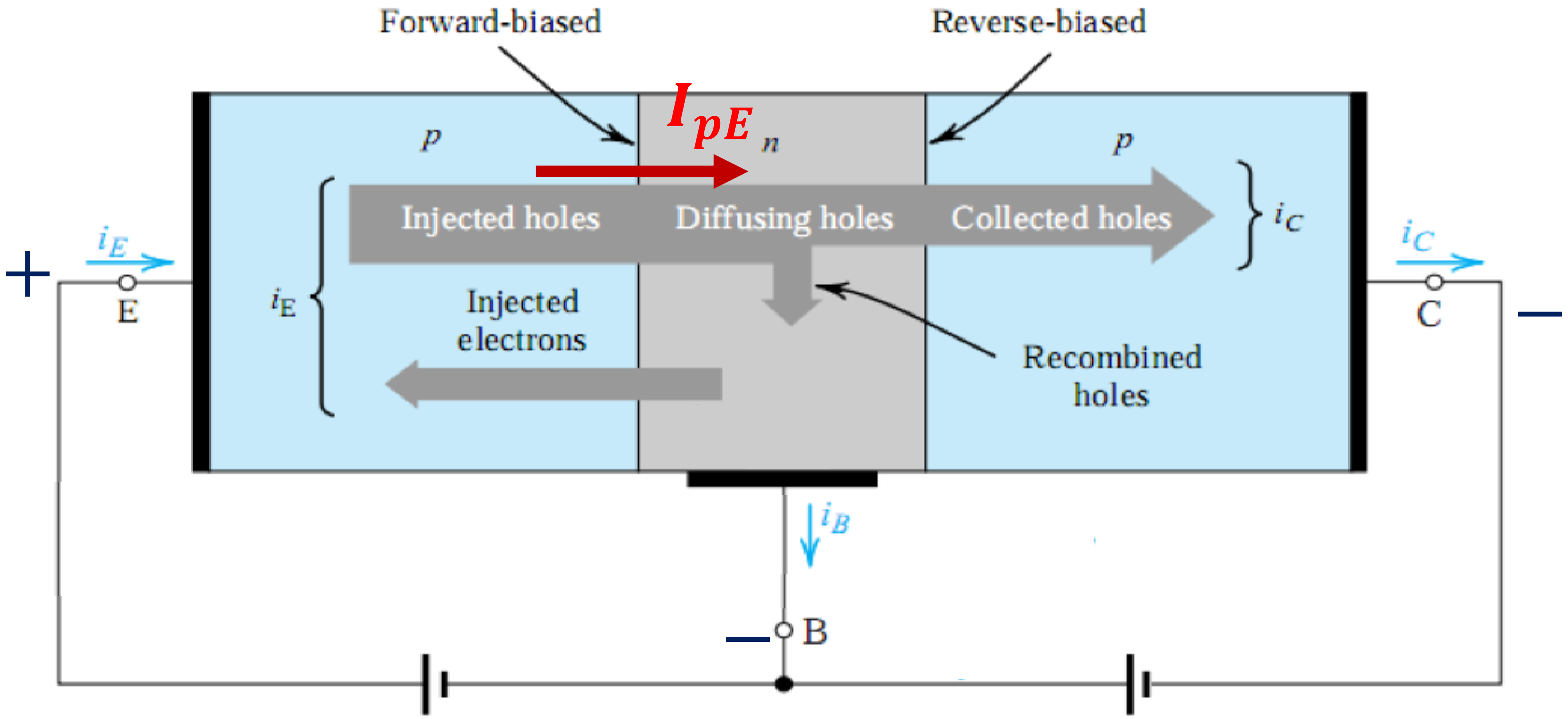
Active Mode of PNP BJT

In active mode, external dc voltages are applied to set EBJ is forward-biased and CBJ is reverse-biased.



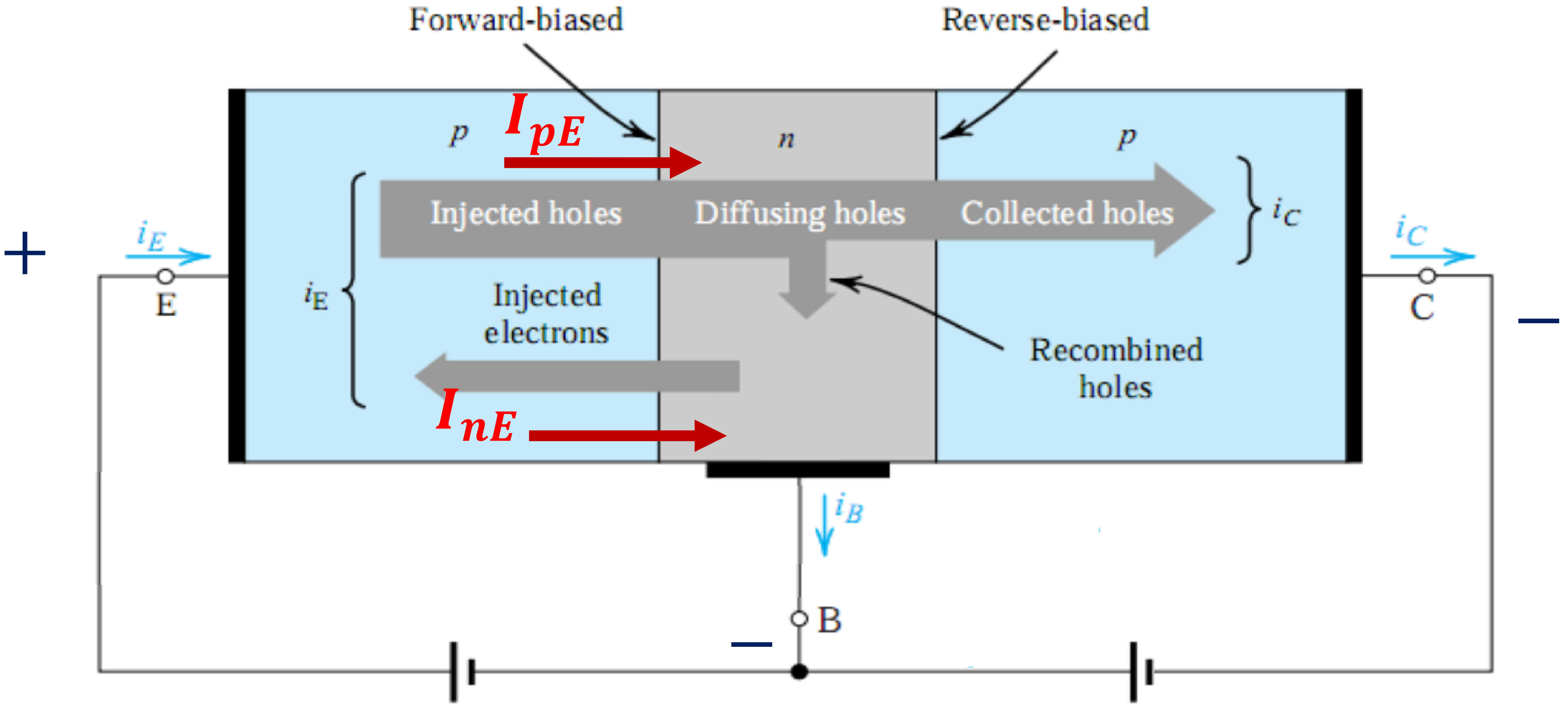


As a result of the forward-bias voltage between emitter and base, holes are injected from the emitter into the base.



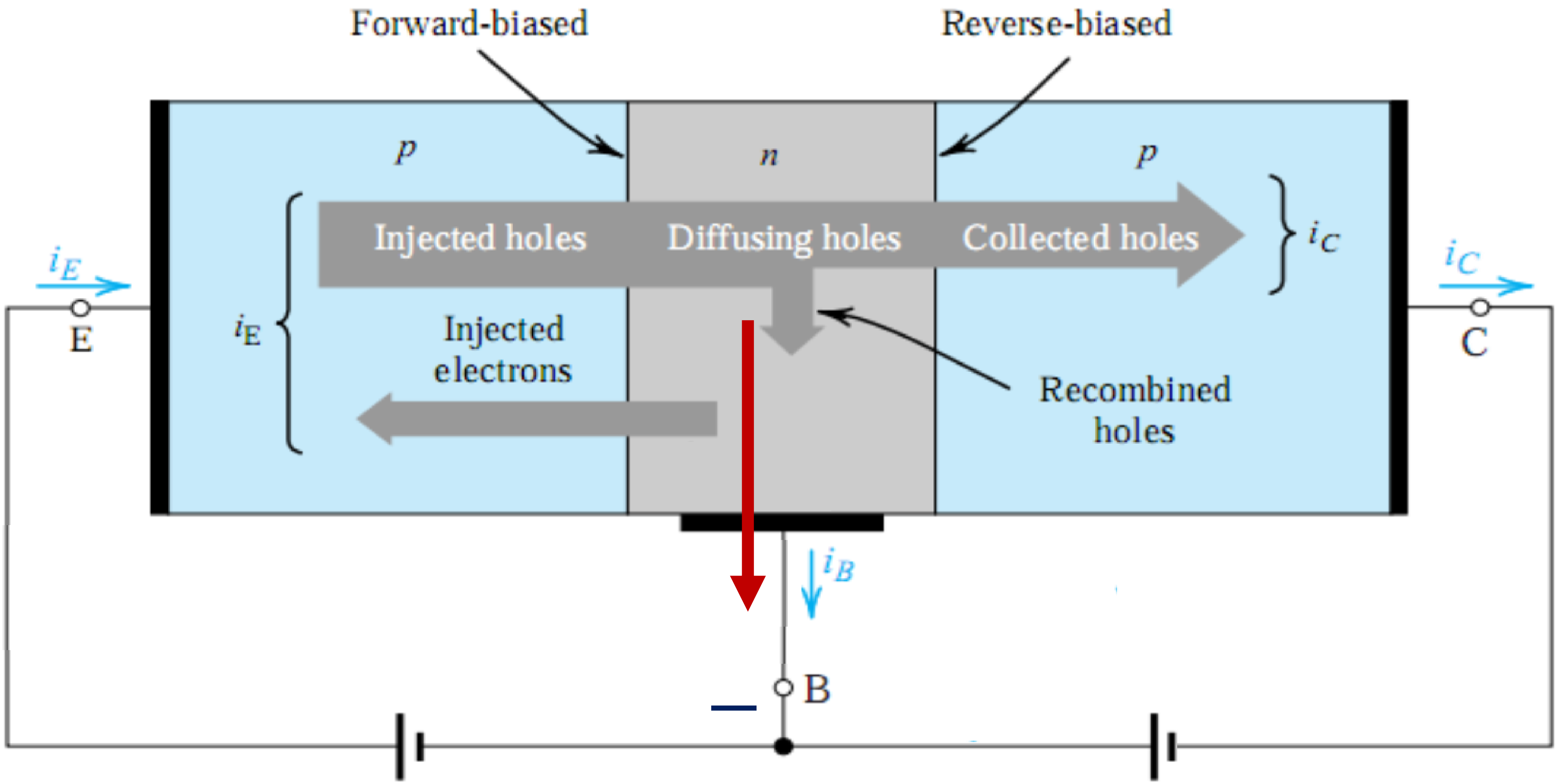
This results in the component of the emitter current I_{pE}

The electrons injected from base to emitter give rise to the second component of emitter current I_{nE}

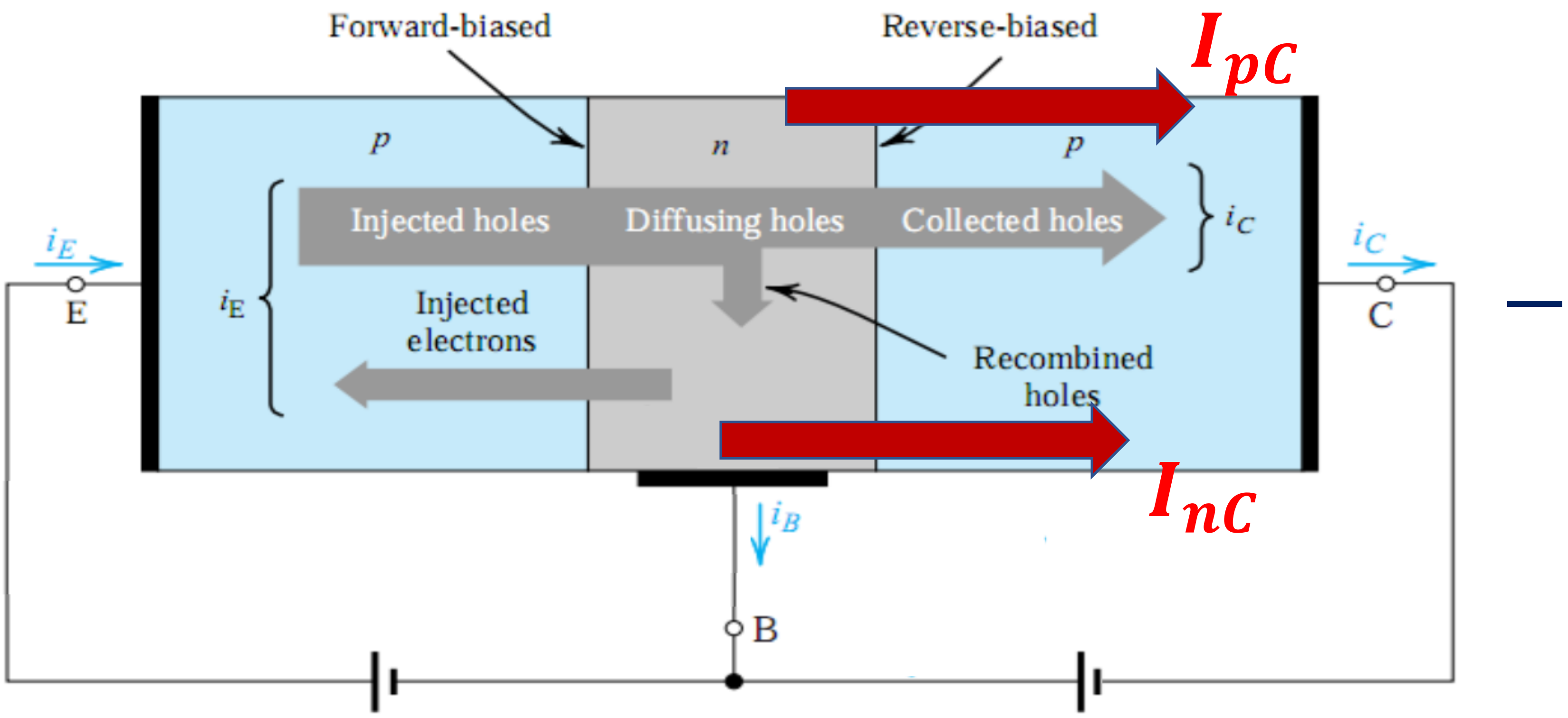


Total **emitter current** is the sum of these two currents: $I_E = I_{nE} + I_{pE}$

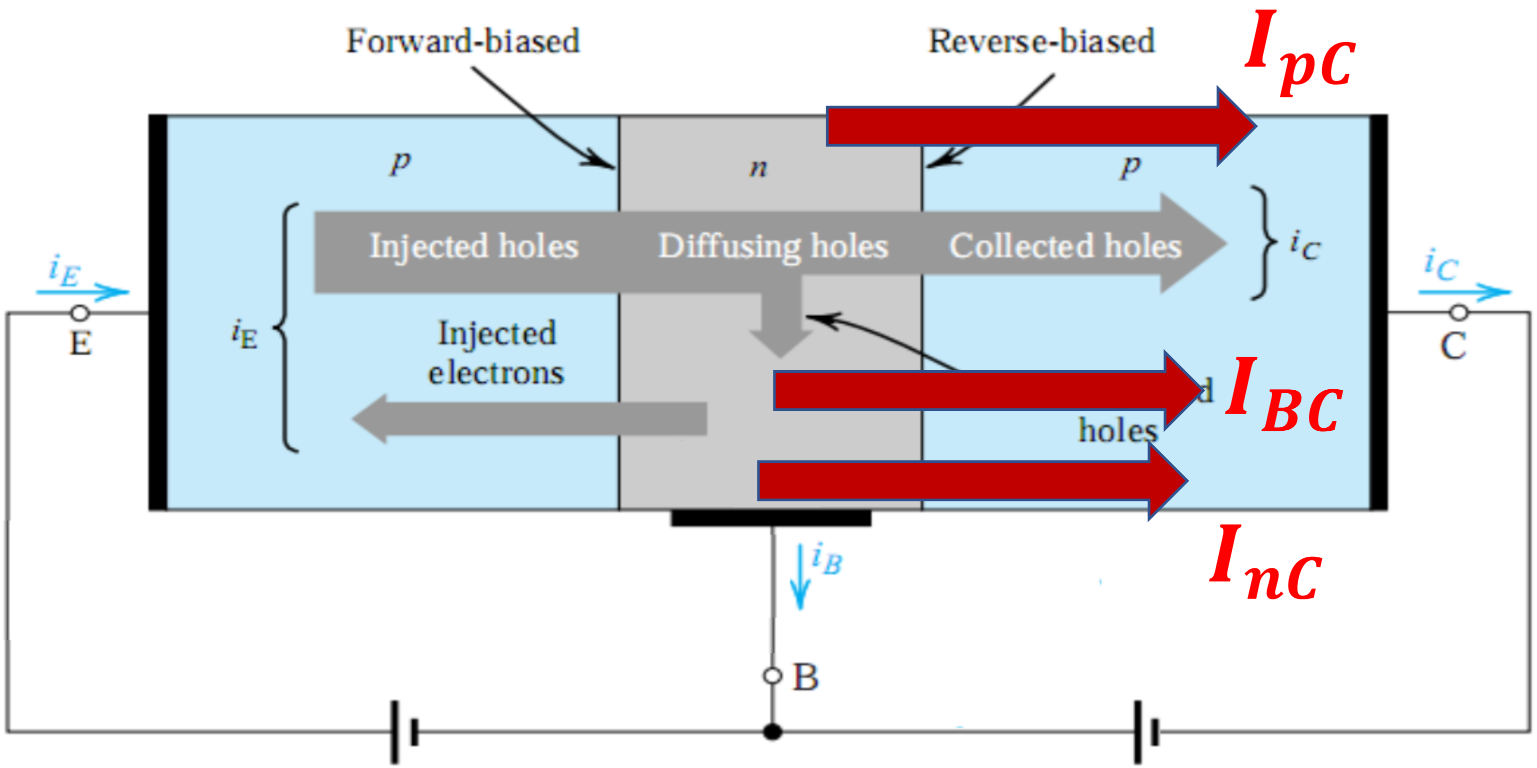
Number of the holes injected into the base will recombine with the majority carriers in the base (electrons), giving rise to the base current $\boldsymbol{I_B}$.



The holes that succeed in reaching the collector will be collected by the negative voltage on the collector and appear as a collector current I_{pC}.



The flow of minority electrons from collector into base results in **electron current** I_{nC}

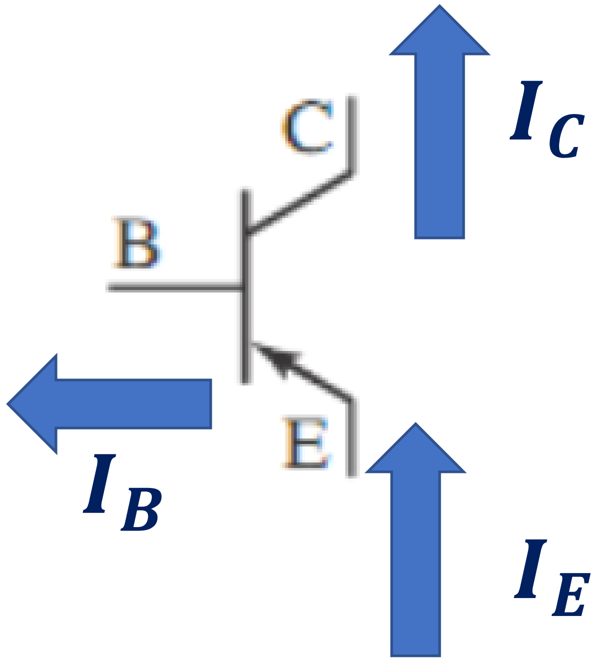


The other part of the collector current ($\boldsymbol{I_{BC}}$) is <u>due to the flow of the minority holes from base into collector</u>.

The total **collector current** is the sum of these currents: $\boldsymbol{I_C = I_{pC} + I_{nC} + I_{BC}}$

The emitter current (I_E) is the sum of the collector current (I_C) and the base current (I_B).

$$I_E = I_C + I_B$$



The ratio of the collector current (I_C) to the base current (I_B) is beta (β).

$$\beta = \frac{I_C}{I_B}$$

The ratio of the collector current (I_C) to the emitter current (I_E) is alpha (α).

$$\alpha = \frac{I_C}{I_E}$$

Summary of PNP BJT Active-Mode Currents

$$I_E = I_C + I_B \Rightarrow I_E = (\beta + 1)\, I_B$$

$$\beta = \frac{I_C}{I_B} \Rightarrow I_C = \beta\, I_B$$

$$\alpha = \frac{I_C}{I_E} \Rightarrow I_C = \alpha\, I_E$$

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

Current and Voltage Analysis

DC currents and dc voltages should be identified.

I_B : Base Current

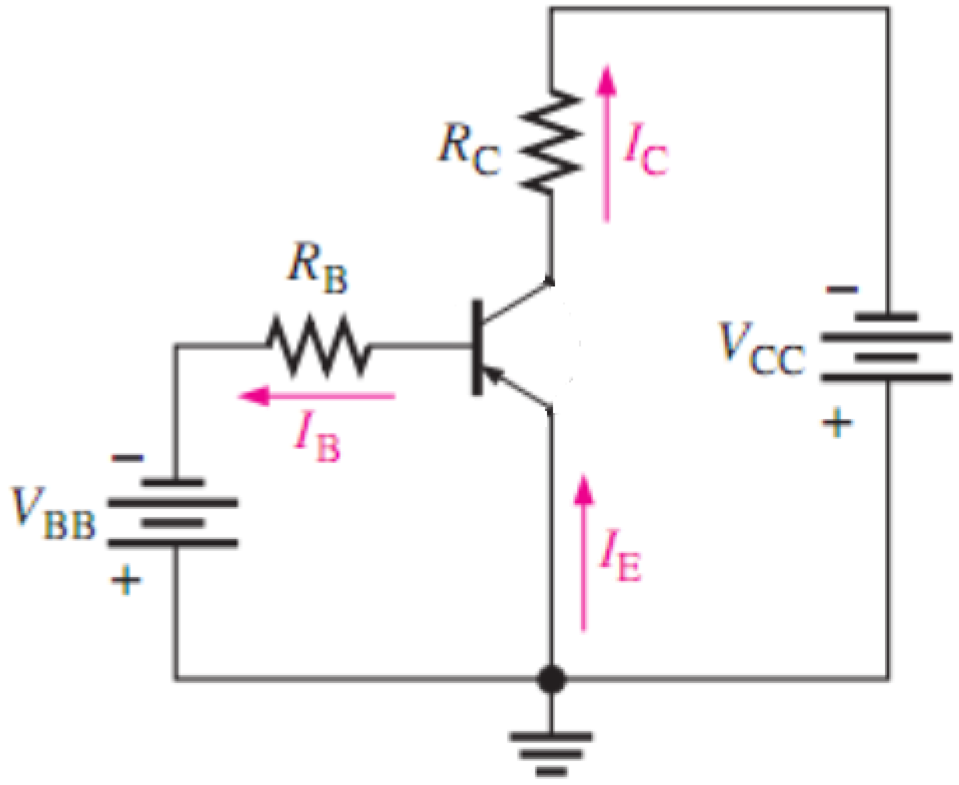
I_C : Collector Current

I_E : Emitter Current

V_{EB} : Emitter-to-Base Voltage

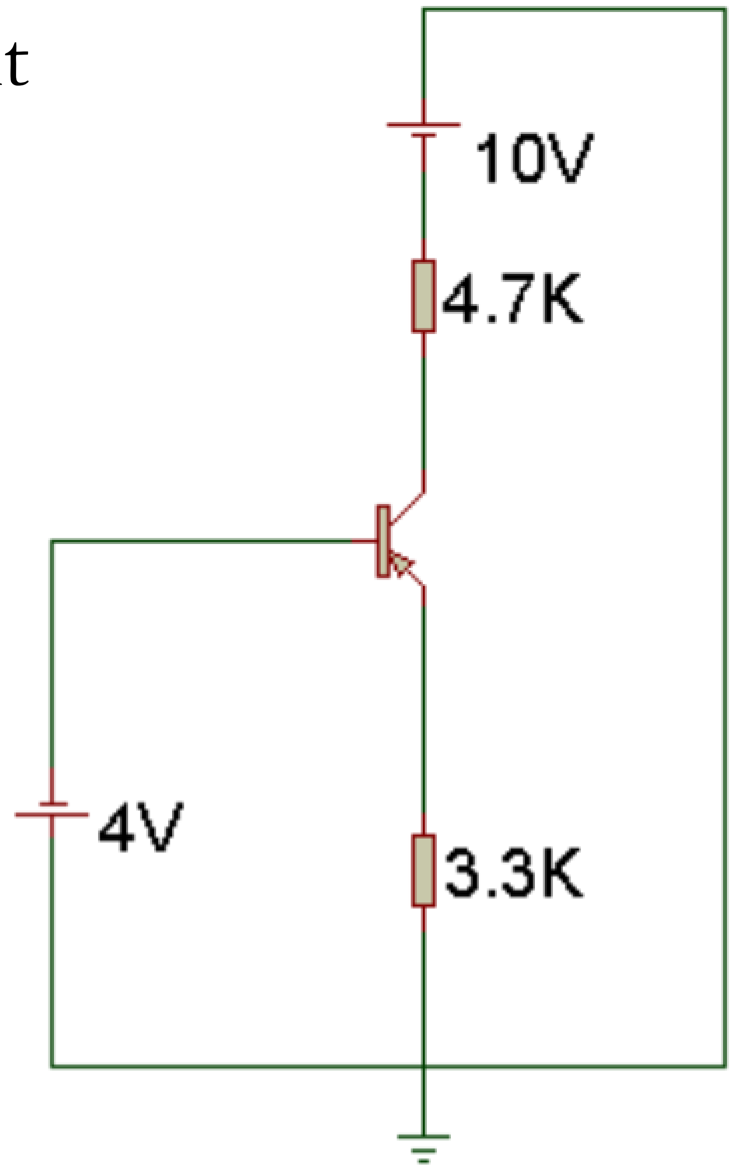
V_{EC} : Emitter-to-Collector Voltage

V_{BC} : Base-to-Collector Voltage



Example 6:

Determine I_B , I_C , I_E , V_{EB} , V_{EC} , V_{BC} in a circuit if β is 50.



Solution:

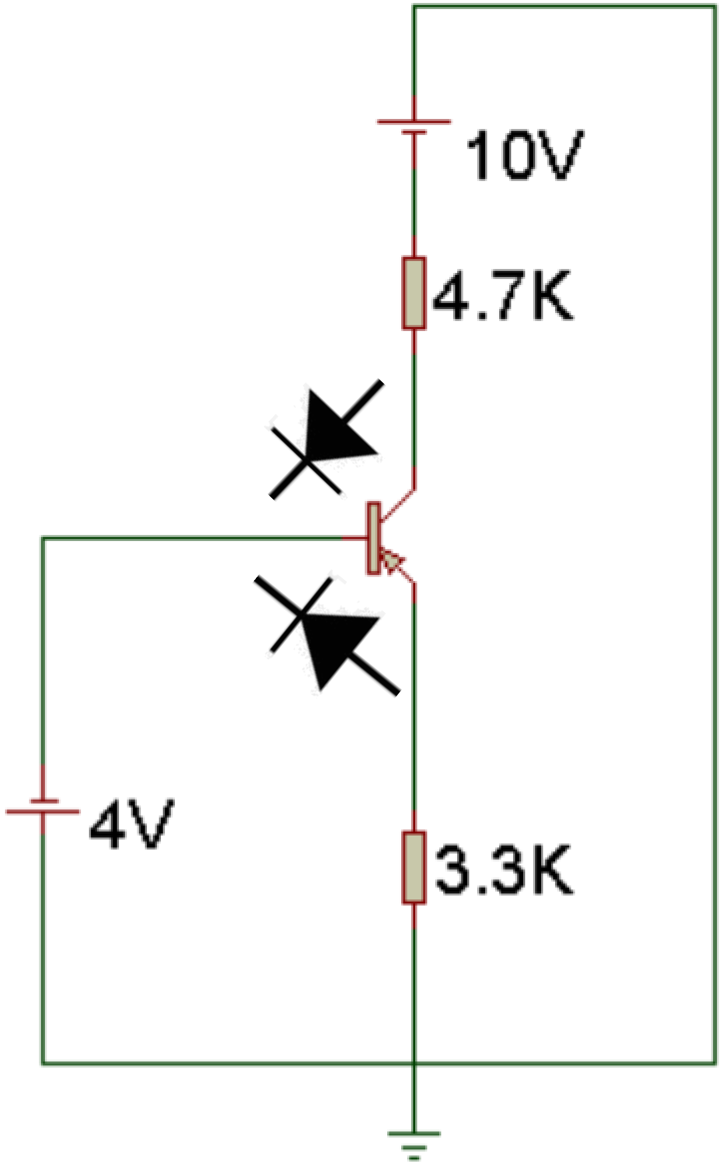
- Base is connected to ~~– 4V~~ and emitter is connected to ground (0V) through a resistor 3.3KΩ.

If VE > VB , emitter-base junction will be forward biased.

- Base is connected to – 4V and collector is connected to – 10V through a resistor 4.7K Ω.

If VC ≤ VB , collector-base junction will be reverse biased.

- Assume transistor is in active mode and VEB=0.7V



In active mode: $VEB = 0.7\text{V}$

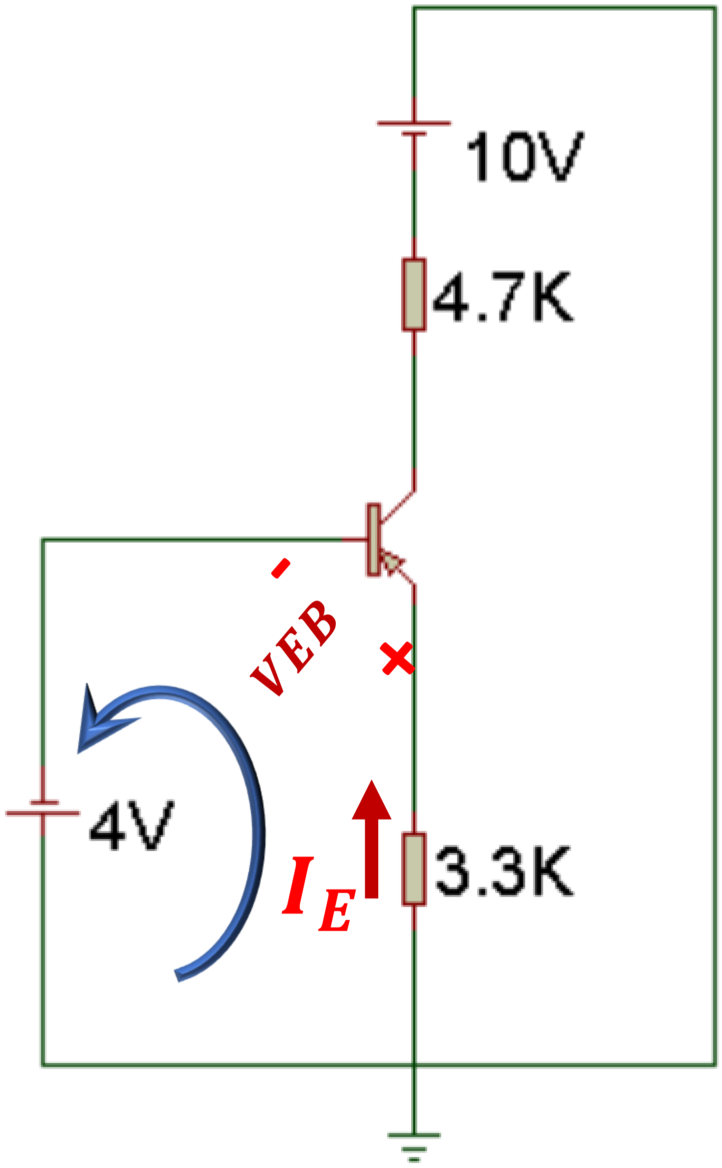
Apply KVL in emitter-base circuit:

$$-(3.3k)IE - VEB + 4 = 0$$

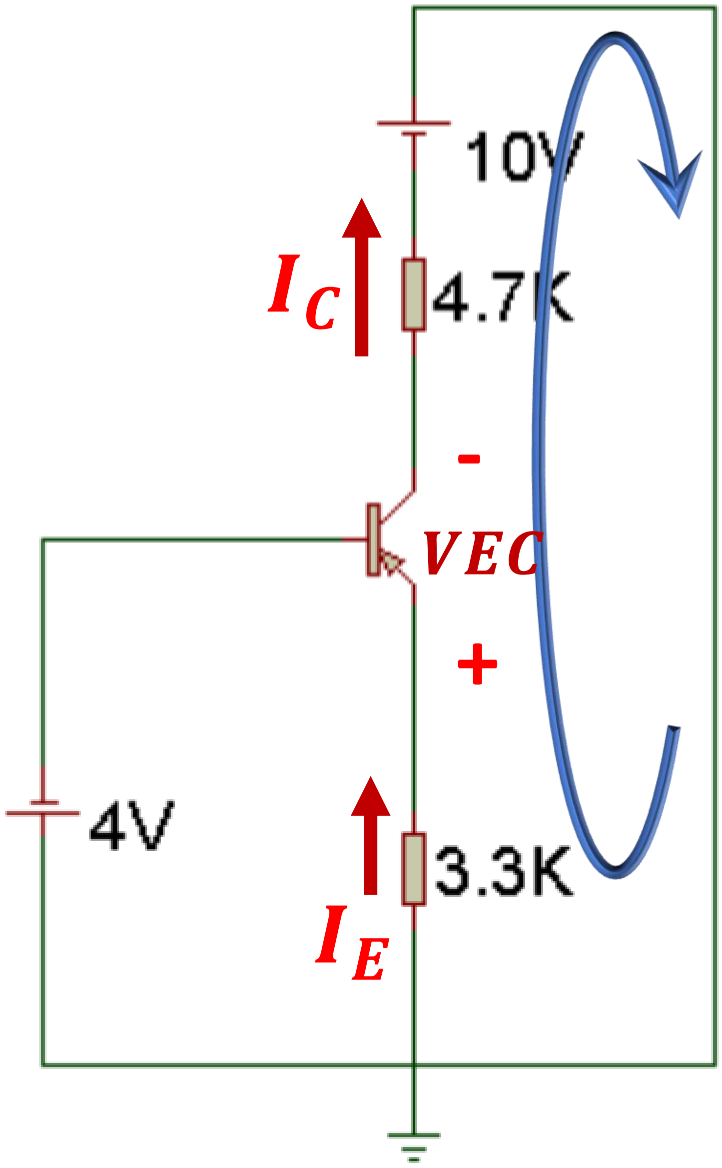
$$IE = 1\text{mA}$$

$$IB = \frac{IE}{1+\beta} = 0.0196\text{mA}$$

$$IC = \text{IE} - \text{IB} = 0.9804\text{mA}$$



Apply KVL in emitter-collector circuit:



$$-(3.3k)IE - V_{EC} - (4.7k)\,IC + 10 = 0$$

$$V_{EC} = 2.092V$$

$$\because\ V_{EC} \gg 0.2V$$

$$\therefore\ Transistor\ is\ in\ active\ mode$$

The voltage across the collector-base junction (V_{BC}) is given by KVL around transistor terminals:

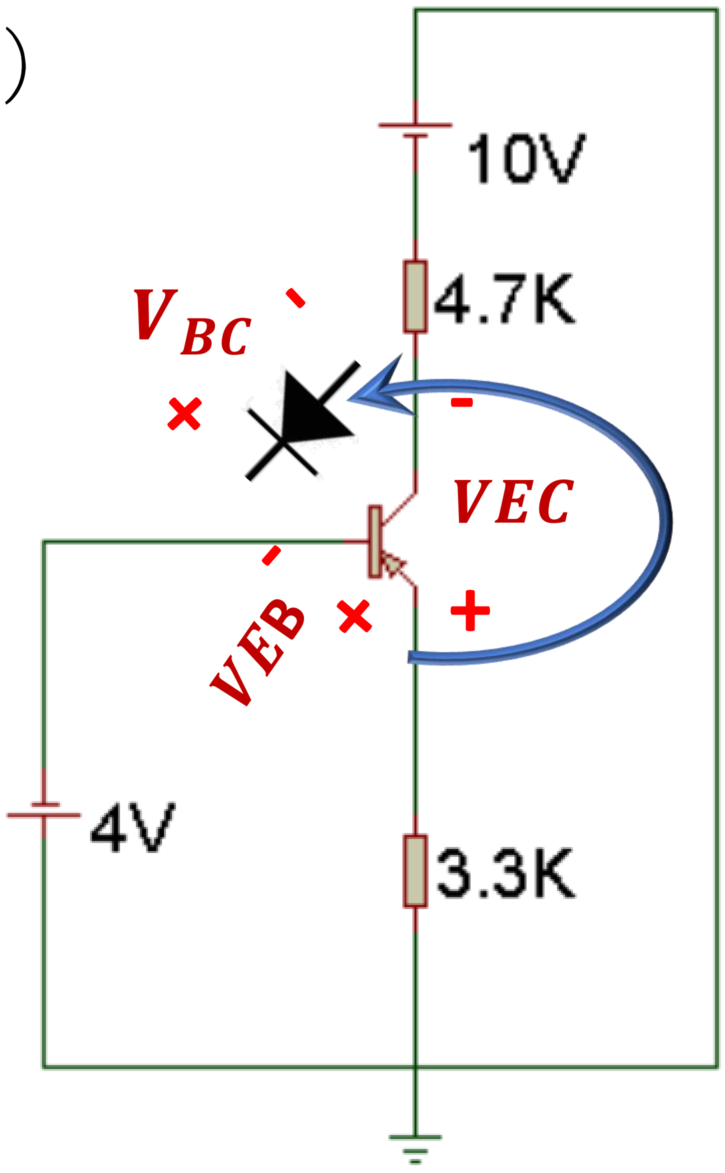
$$-V_{EC} + V_{BC} + V_{EB} = 0$$

$$V_{BC} = V_{EC} - V_{EB}$$

$$V_{BC} = 2.092 - 0.7 = 1.392V$$

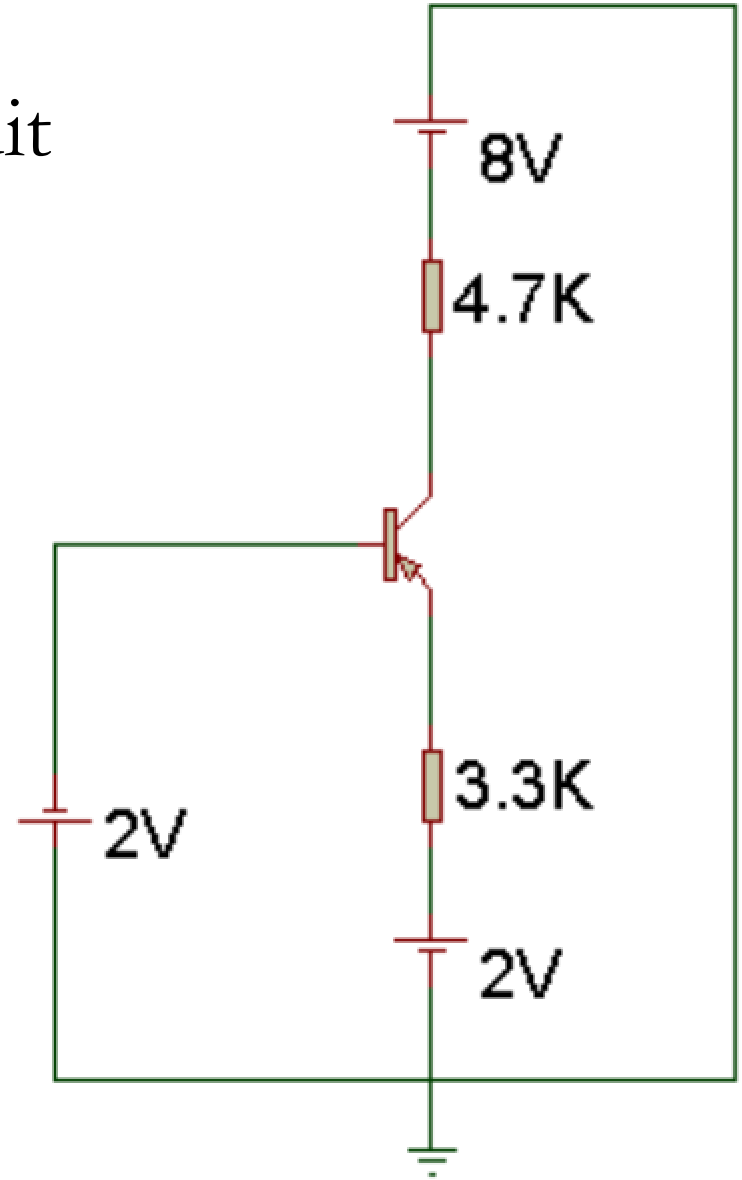
$\because\ V_{BC}$ *is positive value*

$\therefore$ *Transistor is in active mode*



Example 7:

Determine I_B , I_C , I_E , V_{EB} , V_{EC} , V_{BC} in a circuit if β is 50.



Solution:

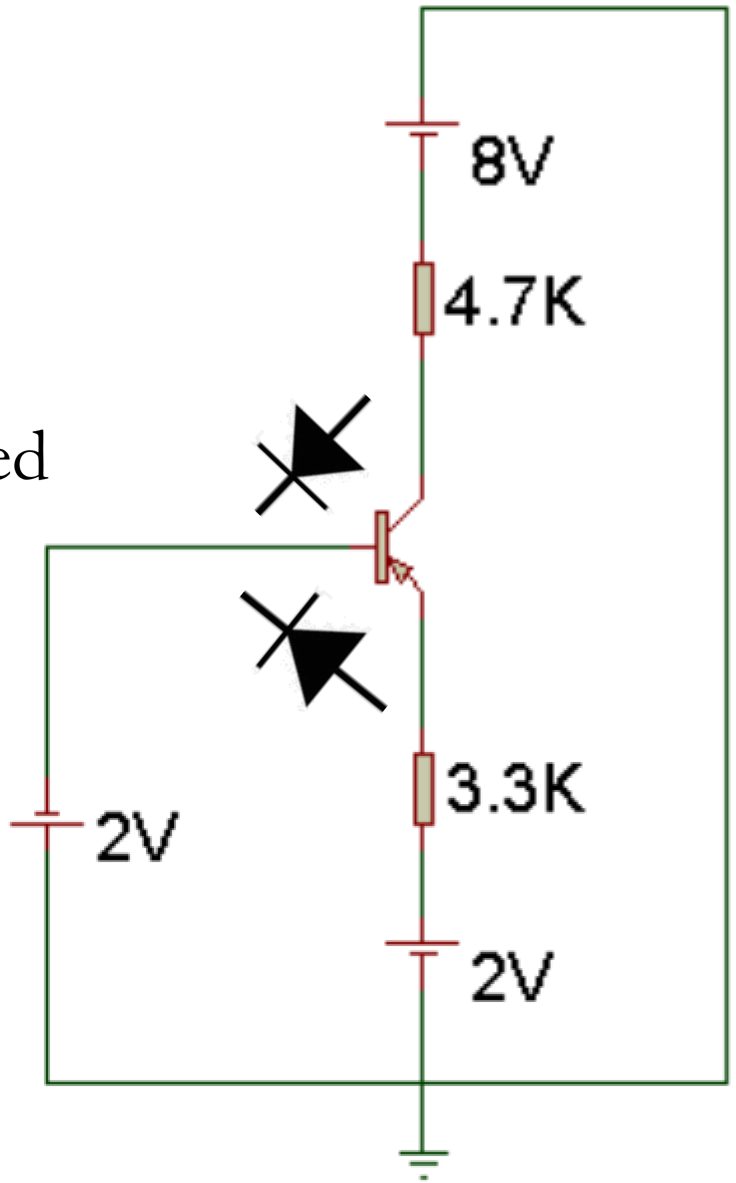
- The base is connected to <u>– 2V</u> and emitter is connected to <u>2V</u> through a resistance 3.3KΩ.

If VE > VB , <u>emitter-base junction</u> will be <u>forward</u> biased.

- The base is connected to <u>– 2V</u> and collector is connected to <u>– 8V</u> through a resistance 4.7K Ω.

If VC ≤ VB , <u>collector-base junction</u> will be <u>reverse</u> biased.

- Assume transistor is in <u>active mode</u> and <u>VEB=0.7V</u>



In active mode: $VEB = 0.7\text{V}$

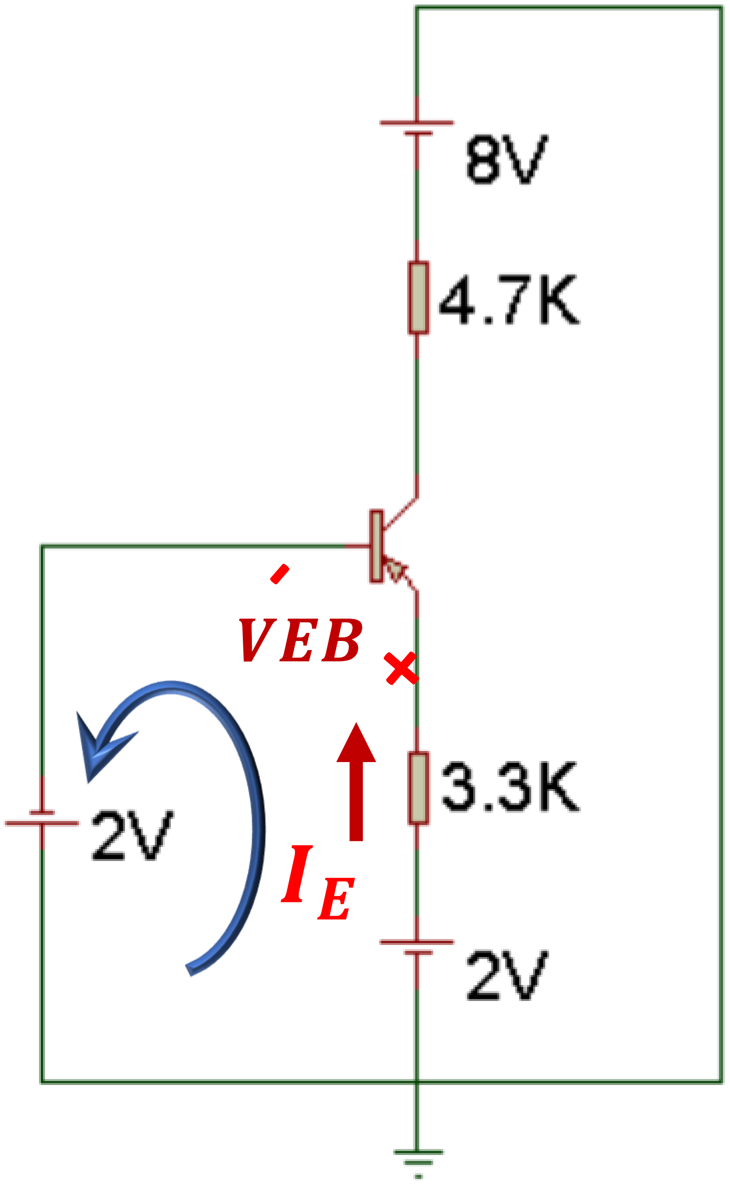
Apply KVL in the emitter-base circuit:

$$2 - (3.3k)IE - VEB + 2 = 0$$

$$IE = 1\text{mA}$$

$$IB = \frac{IE}{1+\beta} = 0.0196\text{mA}$$

$$IC = \text{IE} - \text{IB} = 0.9804\text{mA}$$



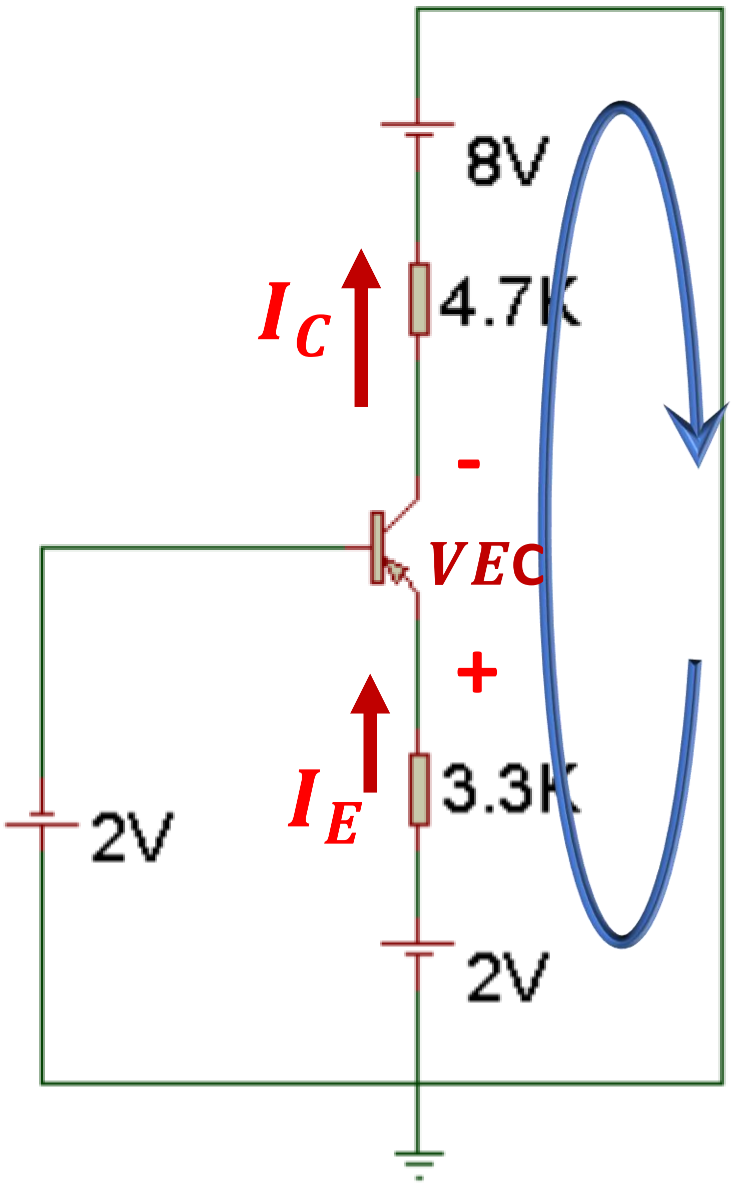
Applying KVL in the emitter-collector circuit:

$$2 - (3.3k)IE - V_{EC} - (4.7k)IC + 8 = 0$$

$$V_{EC} = 2.092V$$

$$\because V_{EC} \gg 0.2V$$

$$\therefore Transistor\ is\ in\ active\ mode$$



The voltage across the collector-base junction (V_{BC}) is given by KVL around transistor terminals:

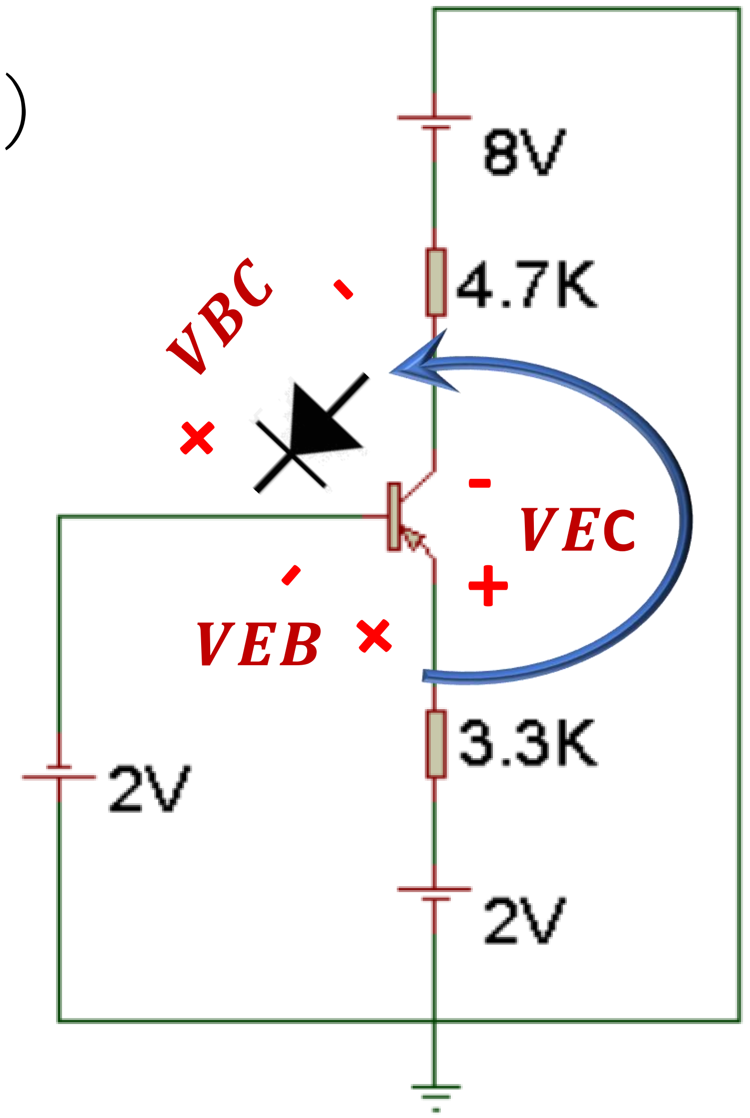
$$-V_{EC} + V_{BC} + V_{EB} = 0$$

$$V_{BC} = V_{EC} - V_{EB}$$

$$V_{BC} = 2.092 - 0.7 = 1.392V$$

$\because$ V_{BC} *is positive value*

$\therefore$ *Transistor is in active mode*



Example 8:

The transistor is in active mode, determine the value of R_B to yield $I_C = 5mA$. Assume $\beta = 60$, $R_C = 0.5K\Omega$, $R_E = 100\Omega$, $V_{CC} = -6V$, $V_{EB} = 0.7V$.

Solution:

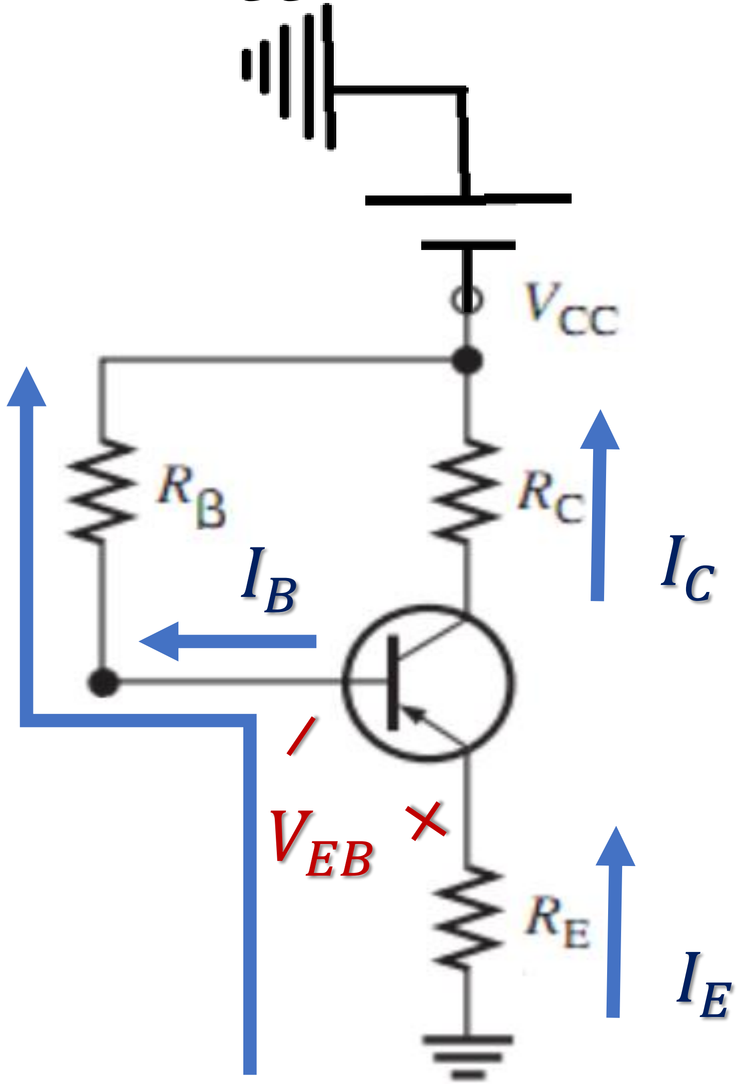
$\because I_C = \beta \, IB \Rightarrow I_B = \dfrac{I_C}{\beta}$

$I_E = (1+\beta) \, IB$

Emitter-base loop equation:

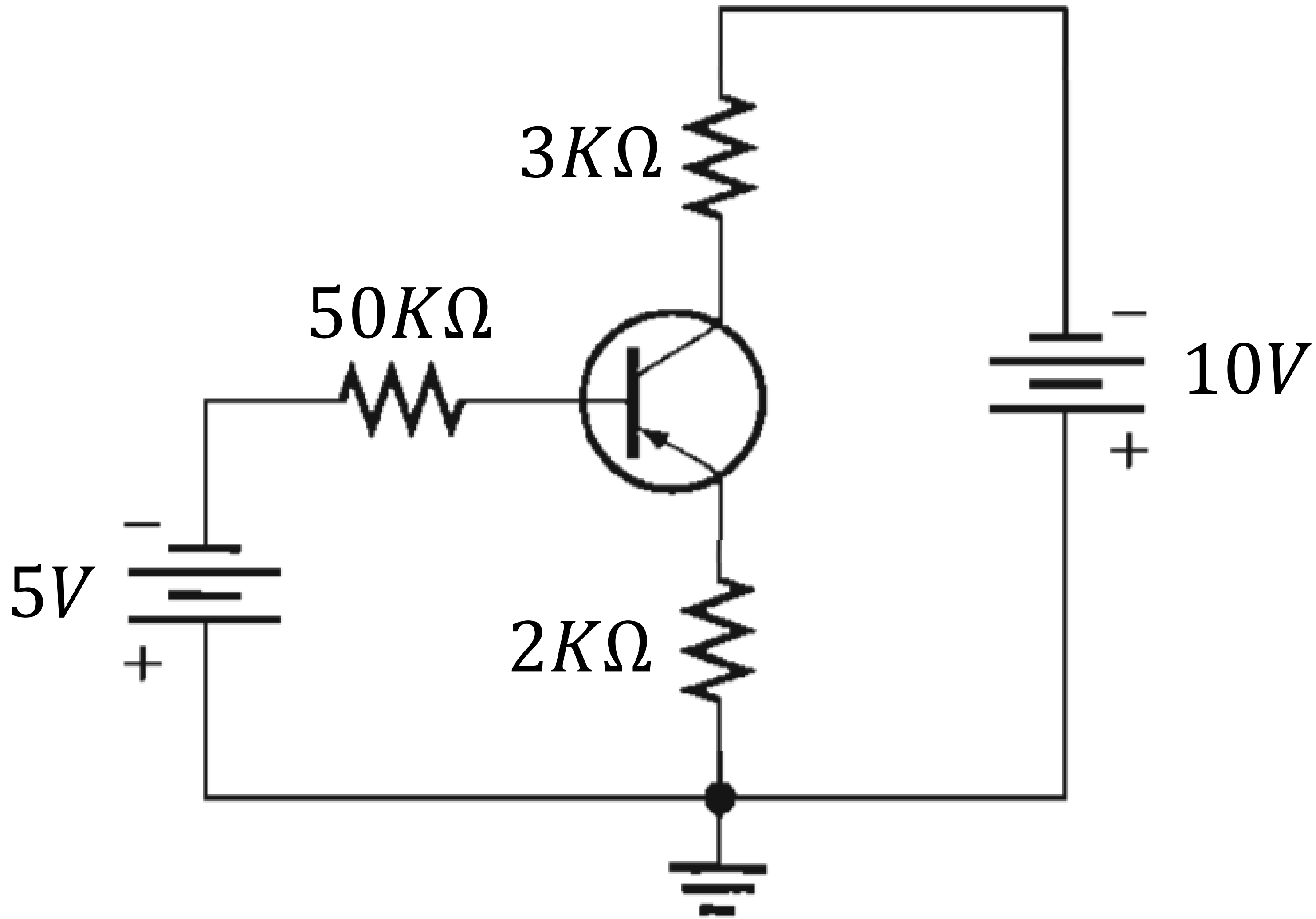
$-R_E IE - V_{EB} - R_B IB + 6 = 0$

$R_B = \cdots$



Example 9:

If β=100, determine whether or not a transistor is in saturation and find I_B, I_C, I_E .

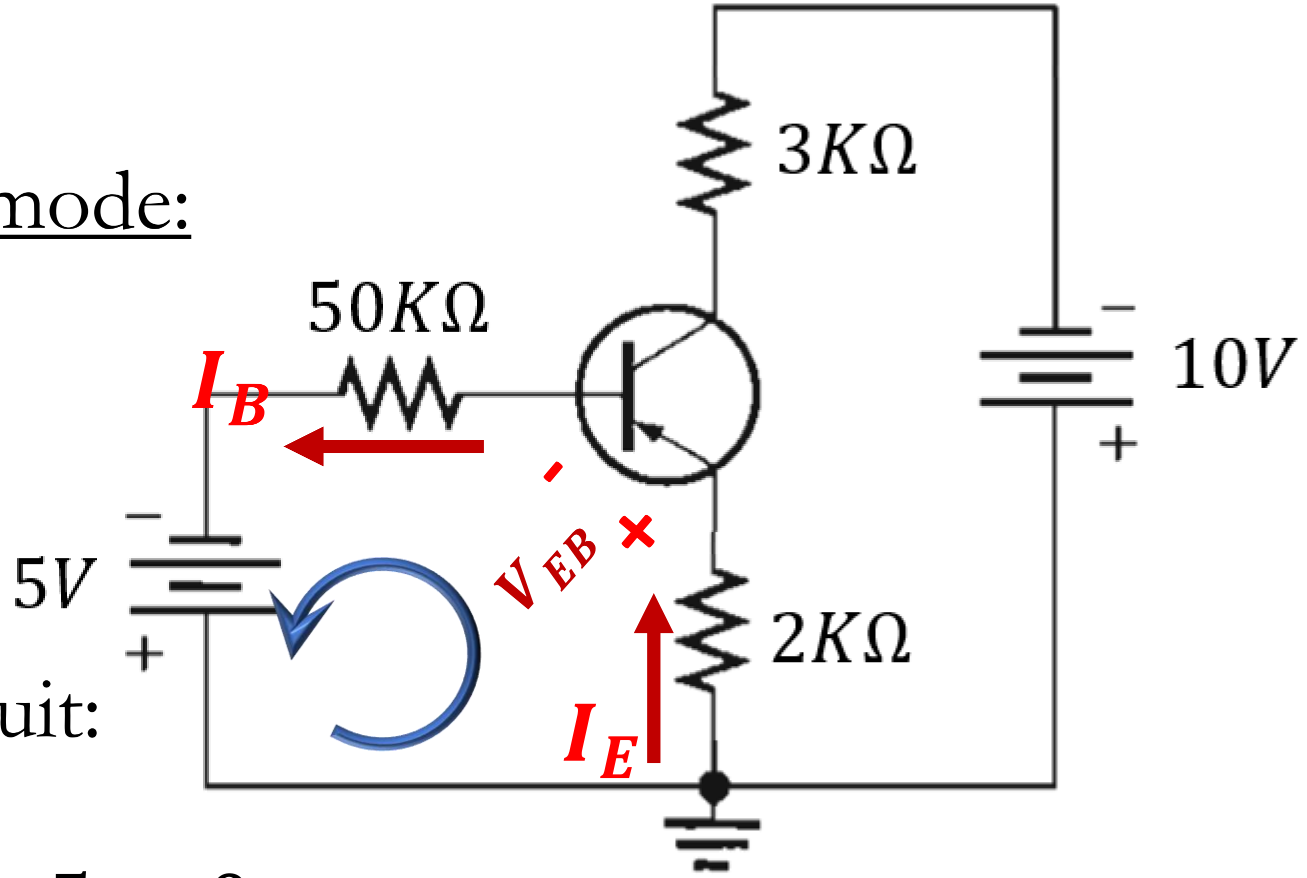


Solution:

Assume transistor is in saturation mode:

$$V_{EB} = 0.7V, \quad V_{EC} = 0.2V,$$

$$I_E = I_B + I_C$$

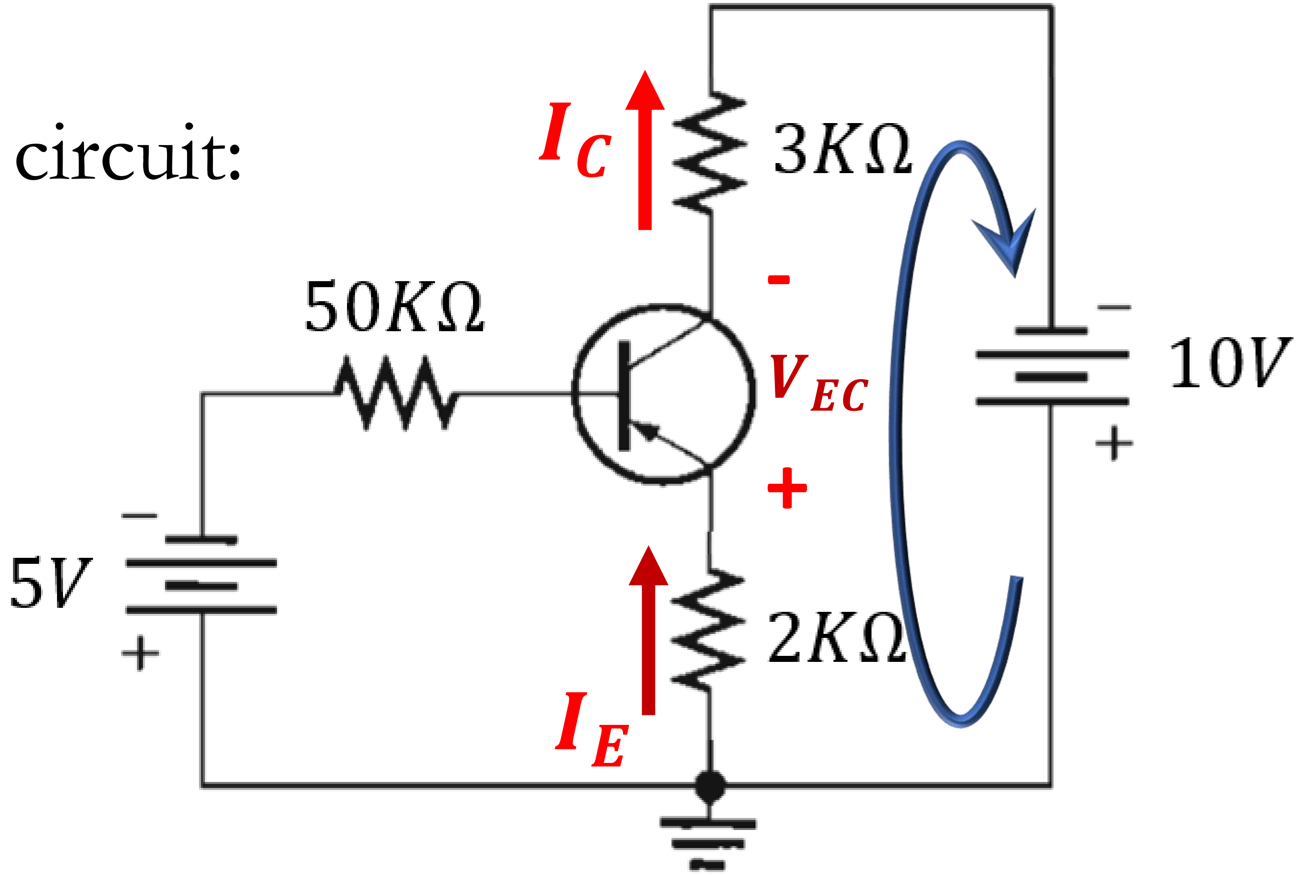


Apply KVL in the base-emitter circuit:

$$-(2K\Omega)\,I_E - V_{EB} - (50K\Omega)\,I_B + 5 = 0$$

$$-(2K\Omega)\,(I_B + I_C) - 0.7 - (50K\Omega)\,I_B + 5 = 0 \qquad (1)$$

Apply KVL in the collector-emitter circuit:



$$-(2K\Omega)\, I_E - V_{EC} - (3K\Omega)\, I_C + 10 = 0$$

$$-(2K\Omega)(I_B + I_C) - 0.2 - (3K\Omega)\, I_C + 10 = 0 \qquad (2)$$

From (1) and (2):

$$I_B = 0.0074 \text{ mA}$$

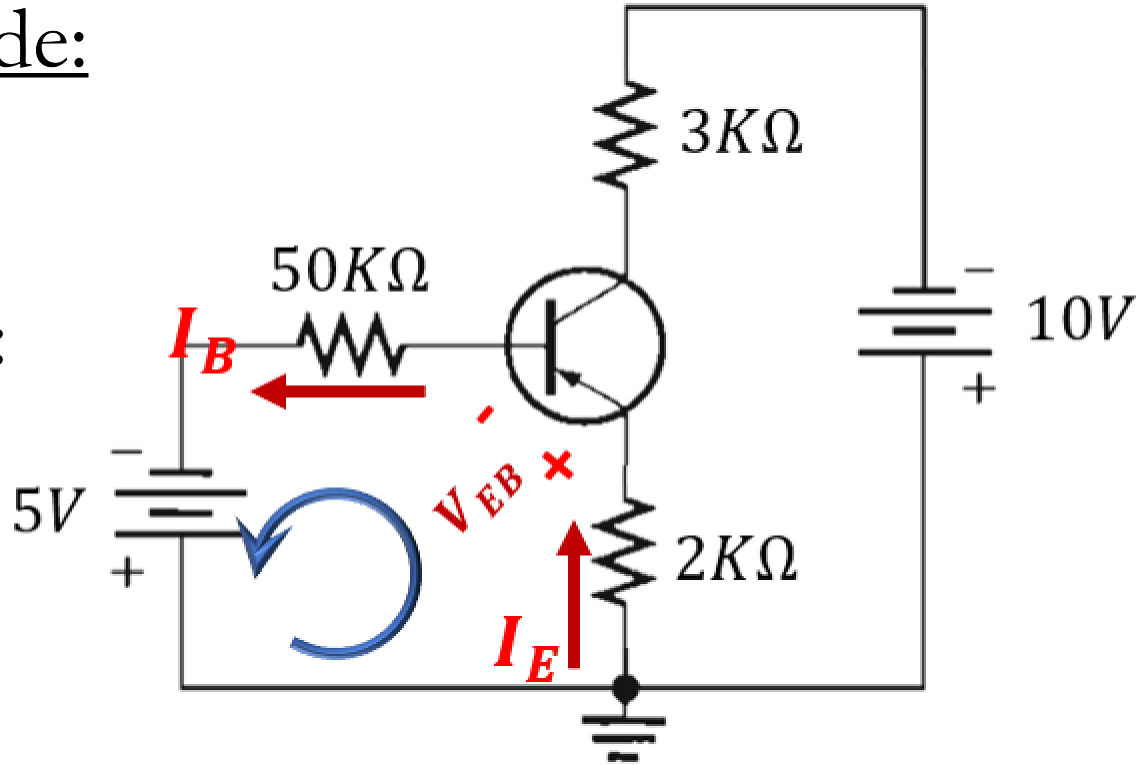
$$I_C = 1.957 \text{ mA}$$

$$\frac{I_C}{I_B} = \frac{1.957}{0.0074} = 264.5 > (\beta = 100\ in\ active)$$

$\therefore$ Transistor is not in saturation mode

Assume again transistor is in <u>active mode:</u>

Apply KVL in the base-emitter circuit:



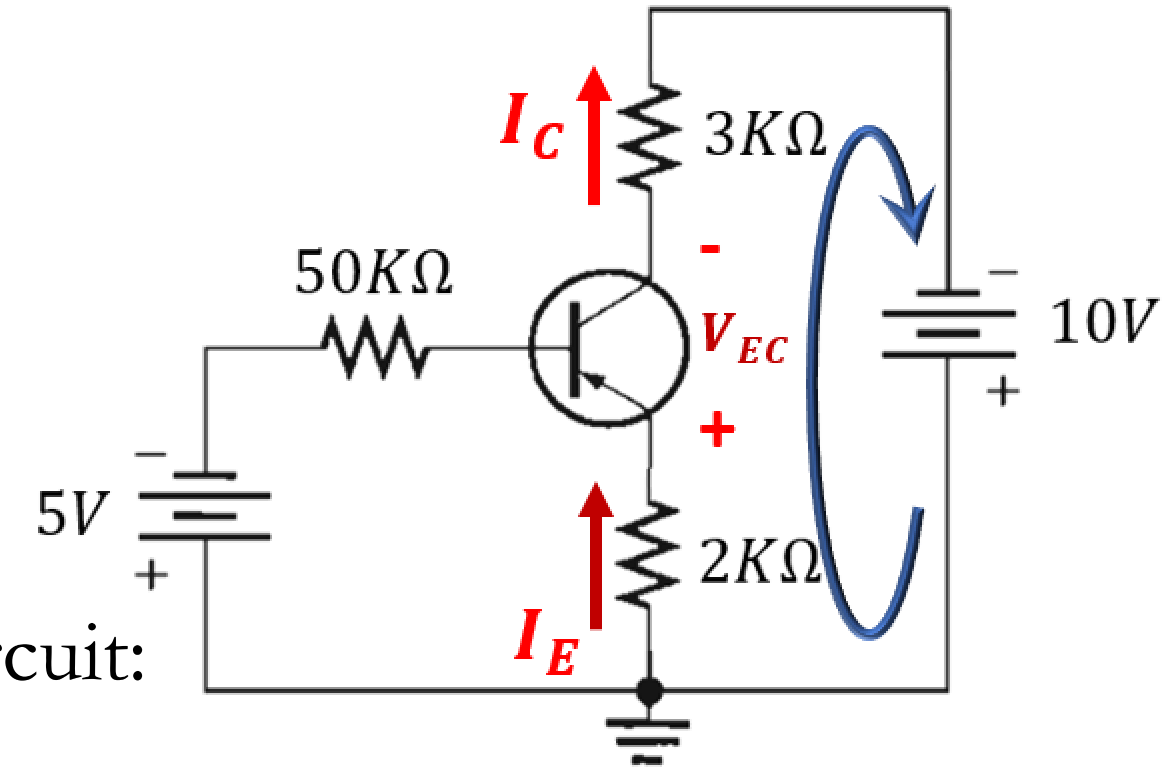
$$-(2K\Omega)\,I_E - V_{EB} - (50K\Omega)\,I_B + 5 = 0$$

$$-(2K\Omega)(1+\beta)\,I_B - 0.7 - (50K\Omega)\,I_B + 5 = 0$$

$$I_B = 0.0171\,mA$$

$$I_E = (1+\beta)\ I_B = 1.723\ mA$$

$$I_C = \beta\ I_B = 1.71\ mA$$



Apply KVL in the collector-emitter circuit:

$$-\ (2K\Omega\ )\ I_E - V_{EC} - (3K\Omega\ )\ I_C + 10 = 0$$

$$V_{EC} = 1.424$$

$$\because V_{EC} > 0.2V$$

$$\therefore Transistor\ is\ in\ active\ mode$$

$\therefore The\ correct\ values\ of\ currents\ are$

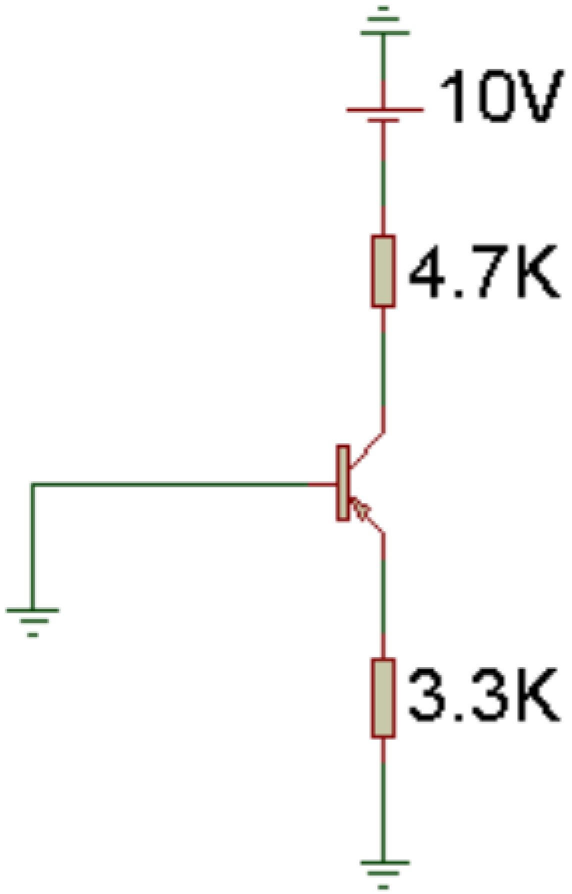
$$I_B = 0.0171\, mA$$

$$I_E = 1.723\, mA$$

$$I_C = 1.71\, mA$$

Example 10:

Determine the node voltages V_B , V_E , V_C and the currents I_B , I_C , I_E .



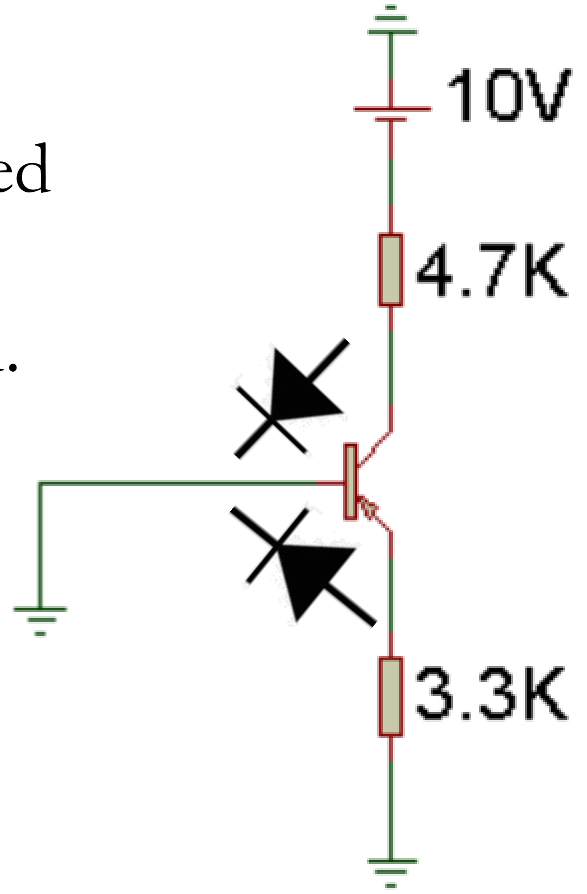
Solution:

For the pnp BJT :

- Base is connected to ground (0V) and emitter is connected to ground (0V) through a resistor 3.3KΩ.
  If VE ≤ VB , emitter-base junction will be reverse biased.

- Base is connected to ground (0V) and collector is connected to – 10V through a resistor 4.7K Ω.
  If VC ≤ VB , collector-base junction will be reverse biased.

- Assume transistor is in cutoff mode.

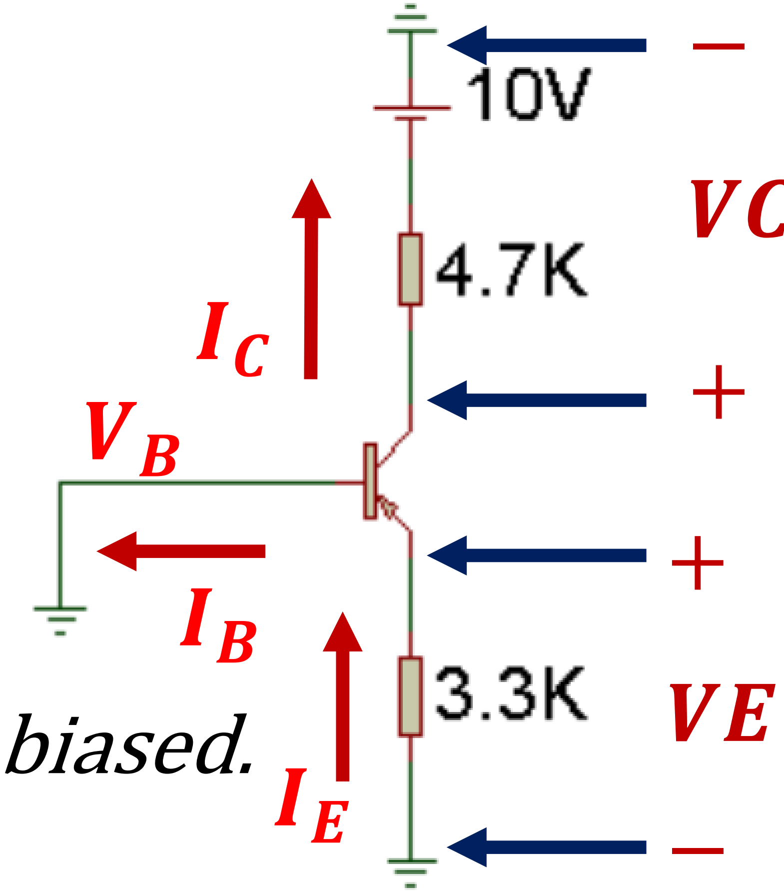


In cutoff mode: $I_B = I_C = I_E = 0$

$$VB = 0$$

$$VE = -(3.3k)IE = 0$$

$$VC = (4.7k)IC - 10 = -10$$



$If\ VE \leq VB\ \therefore\ emitter{-}base\ junction\ is\ reverse\ biased.$

$If\ VC \leq VB\ \therefore\ collector{-}base\ junction\ is\ reverse\ biased.$

$\therefore\ Transistor\ is\ in\ cutoff\ mode.$