Bipolar Junction Transistor (BJT) Basics- GATE Problems

One Mark Questions

1. The break down voltage of a transistor with its base open is BV_{CEO} and that with emitter open is BV_{CBO}, then
   (a) $BV_{CEO} = BV_{CBO}$
   (b) $BV_{CEO} > BV_{CBO}$
   (c) $BV_{CEO} < BV_{CBO}$
   (d) BV_{CEO} is not related to BV_{CBO}

[GATE 1995]

Soln. The given voltage ratings are reverse breakdown voltages.

BV_{CEO} – Voltage between the collector and emitter with base open

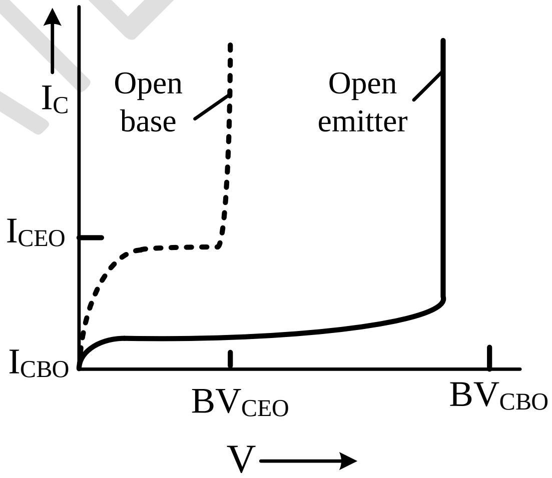
BV_{CBO} – Voltage from collector to base with emitter open

The mechanism involved for such breakdown is due to Avalanche.

The equation relating these breakdown is

$$BV_{CEO} = \frac{BV_{CBO}}{(\beta)^{1/n}}$$

This shows that voltage in open base configuration is smaller by $(\beta)^{1/n}$



Thus, $BV_{CEO} < BV_{CBO}$

Option (c)

2. A BJT is said to be operating in the saturation region if
   (a) Both junctions are reverse biased
   (b) Base – emitter junction is reverse biased and base collector junction is forward biased
   (c) Base – emitter junction is forward biased and base – collector junction reverse biased
   (d) Both the junctions are forward biased

[GATE 1995]

Soln. A BJT has four modes for operation depending on polarities of emitter base junction and collector base junction

	B – E Junction	**B – C junction**
Active mode	**F. B.**	**R. B.**
Saturation	**F. B.**	**F. B.**
Cut – off	**R. B.**	**R. B.**
Inverted	**F. B.**	**R. B.**

Thus for saturation both junctions are forward biased.

Option (d)

3. The Ebers – Moll model is applicable to
   (a) Bipolar junction transistors
   (b) NMOS transistors
   (c) Unipolar junction transistors
   (d) Junction field – effect transistors

[GATE 1995]

Soln. Ebers Moll model is one of classical models of BJT for small signals.

This model is based on interacting diode junctions and is applicable to any transistor operating modes

Option (a)

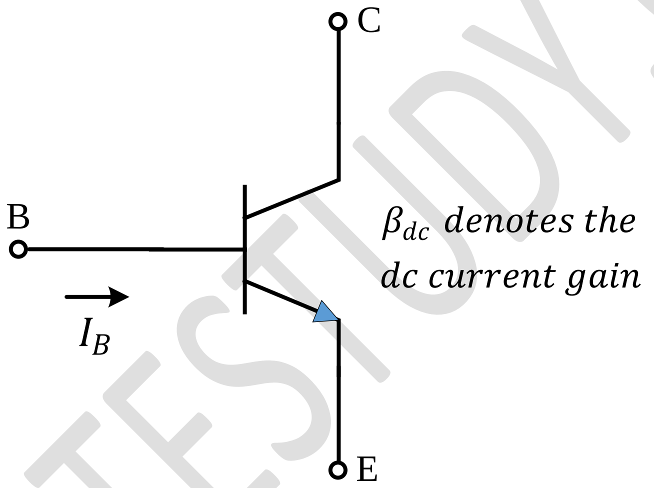
4. The Early – Effect in a bipolar junction transistor is caused by
   (a) Fast – turn – on.
   (b) Fast – turn – off.
   (c) Large collector – base reverse bias.
   (d) Large emitter – base forward bias.

[GATE 1995]

Soln. **When the effective base width of the transistor is changed by varying the collector junction voltage is called base width modulation or Early effect. This happens for transistor of p^+ - n – p^+**

Option (c)

5. If the transistor in the figure is in saturation then,



   (a) I_C *is always equal to* $\beta_{dc} I_B$.
   (b) I_C *is always equal to* $-\beta_{dc} I_B$.
   (c) I_C *is greater than or equal to* $\beta_{dc} I_{dc}$.
   (d) I_C *is less than* $\beta_{dc} I_B$.

[GATE 2001]

Soln. **For transistor in common emitter mode the relation between collector current and collector emitter voltage is given by**

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

Cut off

It occurs when $I_C = 0$

Saturation

It occurs when there is no longer a change in collector current for a change in base current

Active Mode

In this mode the following relation is valid

$$I_C = \beta\, I_B$$

Thus in saturation the collector current does not increase with base current.

Option (d)

6. If for S_i n – p – n transistor, the base to emitter voltage (V_{BE}) is 0.7V and collector to base voltage (V_{CB}) is 0.2V then the transistor is operaty in the
(a) Normal active mode
(b) Saturation mode
(c) Inverse active mode
(d) Cut – off mode

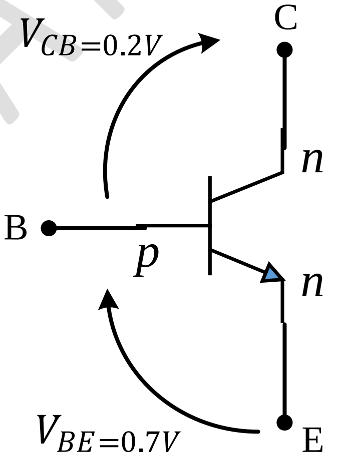
[GATE 2004]

Soln. Given,

S_i n – p – n transistor

V_{BE} = 0.7

V_{CB} = 0.2



Emitter base junction forward biased

Collector base junction Reverse biased

Input junction F.B and output junction R.B

Option (a)

7. Consider the following statements S_1 and S_2

   S_1: The β of a bipolar transistor reduces if the base width is increased.

   S_2: The β of a bipolar transistor increases if the doping concentration in the base is increased.

   Which one of the following is correct?

   (a) S_1 is FLASE and S_2 is TRUE
   (b) Both S_1 and S_2 are TRUE
   (c) Both S_1 and S_2 are FLASE
   (d) S_1 TRUE and S_2 is FALSE

[GATE 2004]

Soln. Note the relation between α and β current gains

$$\boldsymbol{\beta = \frac{I_C}{I_B} = \frac{\alpha}{1-\alpha}}$$

If base width of transistor increases, recombination in base region increases, and thus α decreases and hence β decreases.

Thus S_1 is true

If doping of base region increases, then recombination is base increases and α decreases thereby decreasing β

Thus S2 is true false Option (d)

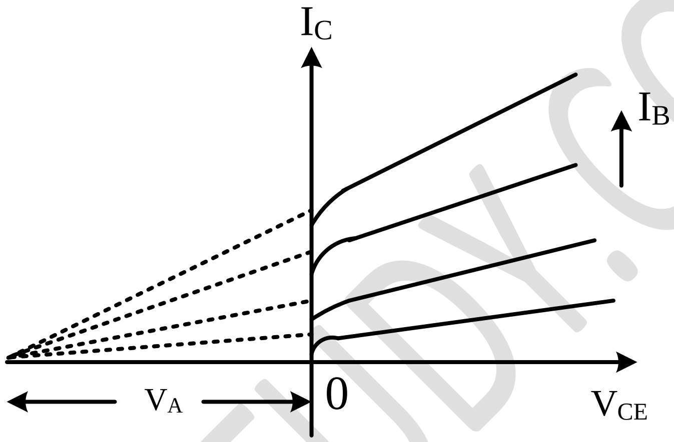
8. The phenomenon known as "Early Effect" in a bipolar transistor refers to a reduction of the effective base – width caused by
   (a) Electron – hole recombination at the base
   (b) The reverse biasing of the base – collector junction
   (c) The forward biasing of emitter – base junction
   (d) The early removal of stored base charge during saturation – to – cutoff switching

[GATE 2006]

Soln. **For the transistor in common – emitter configuration the collector current for a given I_B is expected to be independent of V_{CE}. This is true when base width is constant, but when the base collector voltage (reverse bias) is increased the base width will be reduced.**

This reduced base width causes the minority carries to increase, which causes increase in diffusion current. As a result β will be increased i.e. I_C increases with V_{CE}. This deviation is known as Early effect or base width modulation.

An extrapolation of collector currents gives interaction with V_{CE} axis, which is called Early voltage (V_A)



9. For a BJT, the common – base current gain $\alpha = 0.98$ and the collector base junction reverse bias saturation current $I_{C0} = 0.6\mu A$. This BJT is connected in the common emitter mode and operated in the active region with a base drive current $I_B = 20\mu A$. The collector current I_C for this mode of operation is

(a) 0.98 mA
(b) 0.99 mA
(c) 1.0 mA
(d) 1.01 mA

[GATE 2011]

Soln. **Given,**

$$\boldsymbol{\alpha = 0.98}$$

$$\boldsymbol{I_{CO} = 0.6\ \mu A}$$

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

$$or, \quad 0.98 = \frac{1}{\frac{1}{\beta}+1}$$

$$or, \quad \beta = 49$$

$$I_{CEO} = (1+\beta)I_{CBO}$$

$$= (1+49) \times 0.6\mu A$$

$$I_{CEO} = 30\ \mu A$$

$$I_C = \beta\, I_B + I_{CEO}$$

$$= 49 \times 20\mu A + 30\mu A$$

$$I_C = 1.01\ mA$$

10. An increase in the base recombination of a BJT will increase
    (a) The common emitter dc current gain β
    (b) The breakdown voltage BV_{CEO}
    (c) The unity – gain cut – off frequency f_T
    (d) The transconductance g_m

[GATE 2014]

Soln. The breakdown voltage BV_{CEO} is related to BV_{CBO} through the following

$$BV_{CEO} = \frac{BV_{CBO}}{(\beta)^{1/n}}$$

As recombination increases, the base current (I_B) will increase

Since $I_C = I_E - I_B$

So, I_C decreases

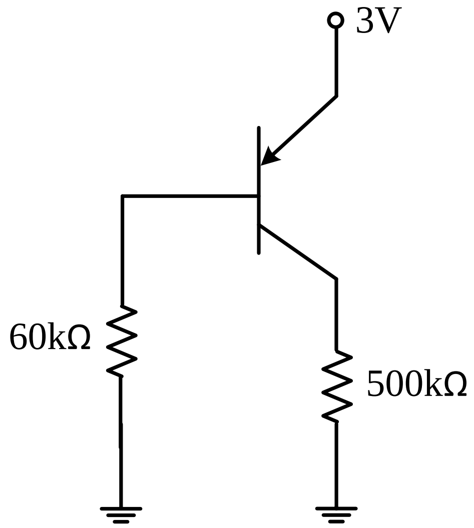
Thus, β decreases

Hence 1 / β increases

Hence, BV_{CEO} increases

Option (b)

11.In the circuit shown in the figure, the BJT has a current gain (β) of 50. For an emitter – base voltage V_{EB} = 600 mV, the emitter – collector voltage V_{EC} (in Voltas) is _____________.

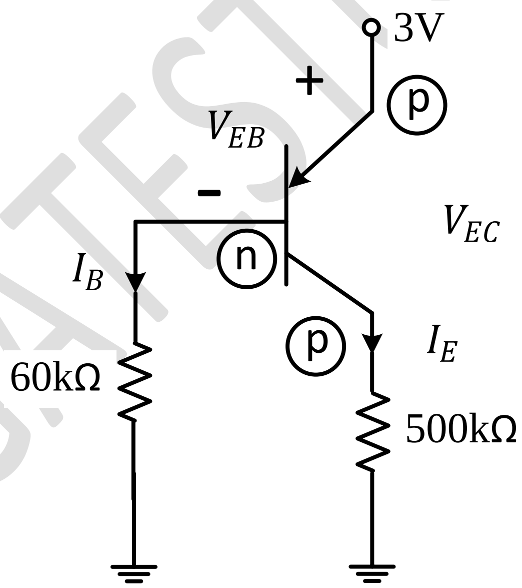


[GATE 2015]

Soln. Given,

$$\boldsymbol{\beta = 50}$$

$$\boldsymbol{V_{EB} = 600\ mV}$$



Note

$$\boldsymbol{V_{EB} - V_E - V_B}$$

$$\boldsymbol{or,\ \ V_B = V_E - V_{EB}}$$

$$or,\ \ V_B = 3 - 0.6 = 2.4\ V$$

$$I_B = \frac{V_B}{60\ K} = \frac{2.4}{60\ K} = 40\ \mu A$$

$$I_C = \ \ \beta\ I_B = 50 \times 40\ \mu A$$

$$= 2\ mA$$

$$V_C = R_E.I_C = 500\ I_C$$

$$= 500 \times 2\ mA = 1V$$

$$So,\ \ V_{EC} = V_E - V_C = 3 - 1 = 2\ V$$

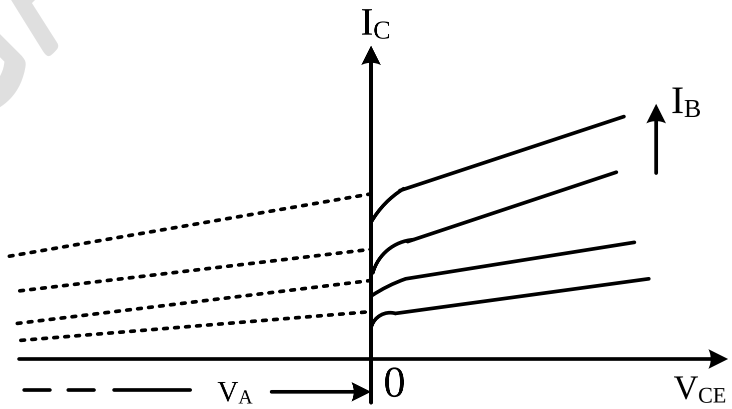
Answer 2 V

12. If the base width in a bipolar junction transistor is doubled, which one of the following statements will be TRUE?

(a) Current gain will increase
(b) Unity gain frequency will increase.
(c) Emitter – base junction capacitance will increase.
(d) Early voltage will increase

[GATE 2015]

Soln. As the base width is increased, the base current will increase thus reducing the collector current. The collector– emitter characteristics will be more flat, thus the extrapolation of collector currents will be farther i.e. Early voltage will increase.



Option (d)

13. The Ebers – Moll model of a BJT is valid
   (a) Only in active mode
   (b) Only in active and saturation modes
   (c) Only in active and Cut – off modes
   (d) In active, saturation and cut – off modes

[GATE 2016]

Soln. Ebers Moll model is the classical model of BJT. This model is based on interacting diode junctions and is applicable to all the transistor operating modes

Option (d)

Two Marks Questions

1. In a transistor having finite β, the forward bias across the base emitter junction is kept constant and the reverse bias across the collector base junction is increased. Neglecting the leakage across the collector base junction and the depletion region generations current, the base current will _________ **(increase / decrease / remains constant)**

[GATE 1992]

Soln. As the reverse bias at the collector base junction is increased, the effective base width decreases, so the recombination in base will decrease. This will reduce base current (I_B)

Answer :- decreases

2. Match the following.

   List – I
   A. The current gain of a BJT will be increased
   B. The current gain of a BJT will be reduced
   C. The break – down voltage of a BJT will be reduced

   List – II

   1. The collector doping concentration is increased
   2. The base width is reduced.

3. The emitter doping concentration to base doping concentration ratio is reduced.
4. The base doping concentration is increased keeping the ratio of the emitter doping concentration to base doping concentration constant.
5. The collector doping concentration is reduced.

(a) A – 2, B – 3, C – 1
(b) A – 2, B – 5, C – 1
(c) A – 2, B – 3, C – 4
(d) A – 4, B – 3, C – 1

[GATE 1994]

Soln. Note that list II gives the actions taken on the device and list I corresponds to the results so, look at list II first.

The second option is that base width is reduced, this will decrease recombination in base, thus I_C will increase, this will increase α

As per option 3 in List II

If emitter doping concentration to base doping concentration is reduced, then emitter injection efficiency is reduced, this decreases α.

3. In a bipolar – transistor at room temperature, if the emitter current is doubled, the voltage across its base – emitter junction

(a) Doubles
(b) Halves
(c) Increases by about 20 mV
(d) Decreases by about 20 mV

[GATE 1997]

Soln. In a BJT emitter current is doubled and one has to find the base emitter voltage, so we consider the p – n junction formed by emitter and base. The junction current is given by

$$I_e = I_0\left(e^{Vb_e/\eta V_T} - 1\right)$$

Given the current is doubled

$$So, \quad \frac{2I_1}{I_1} = \frac{I_0\left[e^{Vb_{e2}/\eta V_T} - 1\right]}{I_0\left[e^{Vb_{e1}/\eta V_T} - 1\right]}$$

$$or \quad \frac{2}{1} = \frac{e^{Vb_{e2}/\eta V_T} - 1}{e^{Vb_{e2}/\eta V_T} - 1}$$

$$since, \qquad e^{Vb_{e2}/\eta V_T} \gg 1$$

$$e^{Vb_{e1}/\eta V_T} \gg 1$$

$$Then \qquad e^{(V_{be2} - V_{be1})/\eta V_T} = 2$$

$$or, \ (V_{be2} - V_{be1}) = \eta V_T \ln 2$$

$$Taking\ \eta = 1$$

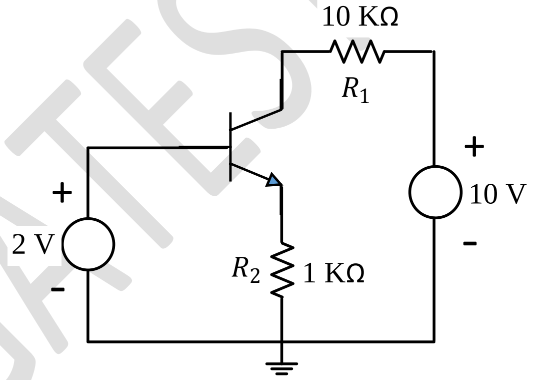
$$V_{be2} - V_{be1} = 1 \times 0.026 \times 0.693$$

$$= 18\ mV$$

$$\cong 20\ mV$$

Option (c)

4. For a BJT circuit shown, assume that the 'β' of the transistor is very large and V_{BE} = 0.7 V. The mode of operation of the BJT is



(a) Cut – off
(b) Saturation
(c) Normal active
(d) Reverse active

[GATE 2006]

Soln. Given,

$$V_{BE} = 0.7\ V$$

Input junction (base emitter) junction is forward biased since $V_{BE} = 0.7\ V$

We should find the condition of output junction i.e. C – B junction

Note,

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

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

To determine V_{CB} we find I_C

$$I_C \cong I_C = \frac{2 - V_{BE}}{R_2} = \frac{2-0.7}{1\ K\Omega}$$

$$or,\ I_C = 1.3\ mA$$

$$V_{CE} = V_{CC} - I_C(R_1 + R_2)$$

$$= 10 - 1.3\ mA\ (10K + 1K)$$

$$V_{CE} = -4.3V$$

$$V_{CB} = -4.3V - 0.7$$

$$= -5V$$

Thus, collector base junction is forward biased (since collector is –ve with respect base)

Thus, transistor is in saturation

Option (b)

5. Group I lists four different semiconductor device. Match each device in Group I with its characteristics property in Group II

Group – I

P. BJT
Q. MOS Capacitor
R. LASER diode
S. JFET

Group – II

1. Population inversion
2. Pinch – off Voltage
3. Early Effect
4. Flat – band Voltage

	P	Q	R	S
(a)	3	1	4	2
(b)	2	4	3	2
(c)	3	4	1	2
(d)	3	2	1	4

[GATE 2006]

Soln. In BJT when base – collector bias voltage increases, then effective base width reduces, the gradient of minority carriers increases, this increases diffusion current. This is known as Early effect.

In JEFT gate to source voltage applied to achieve pinch off is called pinch off voltage.

In LASER population inversion occurs when concentration of electrons is one energy state is greater than that is lower energy state. This is called population inversion

In MOS capacitor, flat band voltage is the gate voltage that must be applied to create flat band condition is which there is no space charge in semiconductor under oxide.

Thus,

BJT - Early effect

MOS capacitor - Flat band voltage

LASER diode - Population inversion

JFET - Pinch off voltage

Thus

Option (c) is correct

6. The DC current gain (β) of a BJT is 50. Assessing that, the emitter junction efficiency is 0.9995, the base transport factor is
(a) 0.980
(b) 0.985
(c) 0.990
(d) 0.995

[GATE 2007]

Soln. Given,

$$\boldsymbol{\beta = 50}$$

In a p – n – p transistor, collector current i_C is proportional to hole component of the emitter current i_{EP}

$$i_C = B.i_{EP} \quad ------(i)$$

Where B is called base transport factor

Emitter injection efficiency $(\gamma) = \frac{i_{EP}}{i_{En}+i_{EP}} \quad --- (2)$

Where, i_{EP} **– hole componet of emitter current**

i_{En} **– electron component due to electron injected from base to emitter**

Current gain α is related as

$$\alpha = B.\gamma \quad ---------- (3)$$

Since transport factor $(B) = \frac{\alpha}{\gamma}$

$$\alpha = \frac{\beta}{\beta+1} = \frac{50}{50+1} = \frac{50}{51}$$

Base transport factor $(B) = \frac{\alpha}{\gamma}$

$$= \frac{50}{51} \times \frac{1}{0.995}$$

$$= 0.985$$

Option (b)

7. In a uniformly doped BJT, assume that N_E, N_B and N_C are the emitter, base and collector doping in atoms / cm^3 respectively. If the emitter injection efficiency of the BJT is close to unity which one of the following is true?

(a) $N_E = N_B = N_C$
(b) $N_E \gg N_B \; and \; N_B > N_C$
(c) $N_E = N_B \; and \; N_B < N_C$
(d) $N_E < N_B < N_C$

[GATE 2010]

Soln. Emitter injection efficiency (γ) **can be written in term of emitter, base doping concentrations.**

$$= \frac{N_E}{N_B + N_E}$$

$$or, \ \gamma = \frac{1}{1 + \frac{N_B}{N_E}}$$

To get $\gamma = 1, \ N_E \gg N_B$

Thus, Option (b)

8. For a BJT, the common – base current gain α = 0.98 and the collector base junction reverse bias saturation current $I_{CO} = 0.6\ \mu A$. This BJT is connected in the common emitter mode and operated in the active region with a base drive current $I_B = 20\ \mu A$. The collector current I_C for this mode of operation is
   (a) 0.98 mA
   (b) 0.99 mA
   (c) 1.0 mA
   (d) 1.01 mA

[GATE 2011]

Soln. Given,

$$\alpha = 0.98$$

$$I_{CO} = 0.6\ \mu A$$

Collector current

$$I_C = \beta\ I_B + (1 + \beta) I_{CO}$$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = 49$$

Thus,

$$I_C = 49 \times 20 + 50 \times 0.6$$

$$= 980 + 30 = 1010\ \mu A$$

$$I_C = 1.01\ mA$$

Option (d)

9. Consider two BJT's biased at the same collector current with area $A_1 = 0.2\ \mu m \times 0.2\ \mu m\ \ and\ \ A_2 = 300\ \mu m \times 300\ \mu m$
Assuming that all other device parameters are identical, $kT/q = 26mV$, the intrinsic carrier concentration is $1 \times 10^{10}\ cm^{-3}$ and $q = 1.6 \times 10^{-19} C$, the difference between the base – emitter voltage (in mV) of the two BJT's $(i.e\ V_{BE1} - V_{BE2})$ _______________

[GATE 2014]

Soln. Note that collector through forward biased, emitter – base junction diode.

It can be written as

$$I_C = \left(I_O\ e^{V_{BE}/\eta\, V_T} - 1\right)$$

Neglecting 1 in the equation

$$I_C = I_0\ e^{V_{BE}/\eta\, V_T}$$

$$I_{C1} = I_{O1}\ e^{V_{BE1}/\eta\, V_T}$$

$$I_{C2} = I_{O2}\ e^{V_{BE2}/\eta\, V_T}$$

Since, $I_{C1} = I_{C2}$

$$I_{O1}\ e^{V_{BE1}/\eta\, V_T} = I_{O2}\ e^{V_{BE2}/\eta\, V_T}$$

$$\frac{I_{O2}}{I_{O1}} = e^{(V_{BE1}/\eta\, V_T\ -\ V_{BE2}/\eta\, V_T)}$$

$$or,\ \frac{V_{BE1} - V_{BE2}}{\eta\, V_T} = \ln\left[\frac{I_{O2}}{I_{O1}}\right]$$

$$or,\ V_{BE1} - V_{BE2} = \eta\, V_T \ln\left[\frac{I_{O2}}{I_{O1}}\right]$$

$$= \eta\, V_T \ln\left[\frac{A_2}{A_1}\right]$$

$$= 1 \times 0.026 \ln\left(\frac{300 \times 300}{0.2 \times 0.2}\right)$$

$V_{BE1} - V_{BE2} = 380.3\ mV$ **Answer 380.3 mV**

10. An npn BJT having reverse saturation current $I_S = 10^{-15}$ A is biased in the forward active region with V_{BE} = 700 mV and the current gain (β) may vary from 50 to 150 due to manufacturing variations. The maximum emitter current (in μA) is ____________

[GATE 2015]

Soln. Given,

$$\boldsymbol{I_s = 10^{-15}\ A}$$

$$\boldsymbol{V_{BE} = 0.7}$$

$$\boldsymbol{V_T = 25\ mV}$$

$\boldsymbol{\beta}$ **range from 50 to 150**

$$\boldsymbol{I_C = I_O\ e^{V_{BE}/V_T}}$$

$$\boldsymbol{I_E = \frac{\beta+1}{\beta}\ I_C}$$

$$\boldsymbol{I_E = \frac{\beta+1}{\beta}\ I_s\ e^{V_{BE}/V_T}}$$

I_E will be maximum when β is 50

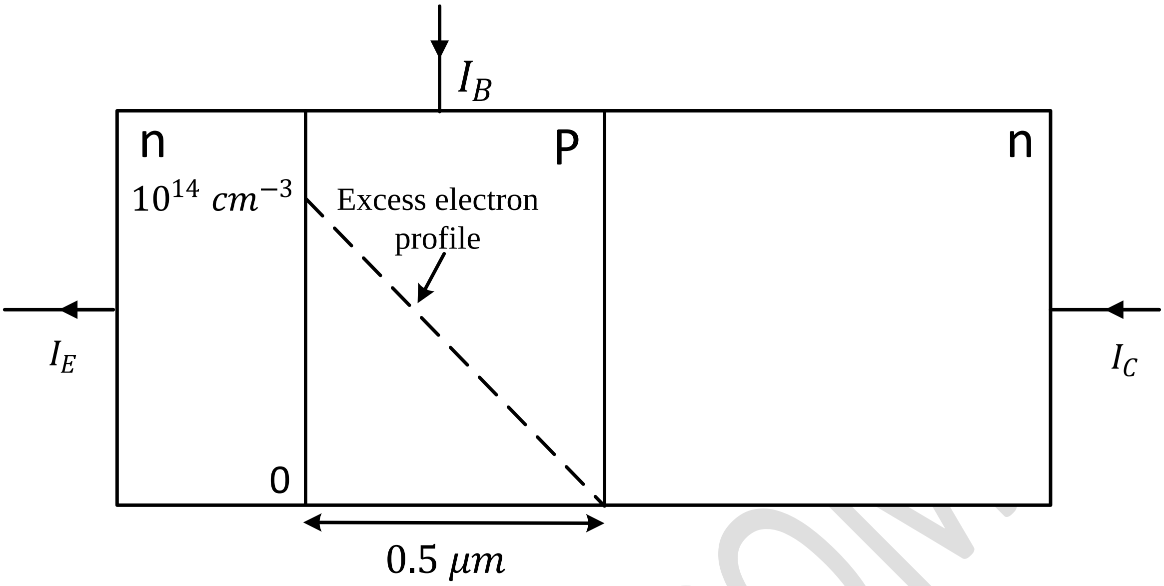
$$\boldsymbol{= 1.02 \times 10^{-15} \times e^{700\times10^{-3}/25\times10^{-3}}}$$

$$\boldsymbol{I_E = 1475\ \mu A}$$

Answer:- 1475 μA

11. The injected excess electron concentration profile in the base region of an npn BJT, biased in the active region, is linear, as shown in the figure. If the area of the emitter – base junction is 0.001 $cm^2, \mu_n = 800\ cm^2/(V-s)$ in the base region and depletion layer widths are negligible, then the collector current I_C (in mA) at room temperature is __

(Given: thermal voltage $V_T = 26mV$ at room temperature, electronic charge $q = 1.6 \times 10^{-19}\ C$)



[GATE 2016]

Soln. Given,

Emitter base junction area $= \mathbf{0.001\ cm^2}$

$$\mu_n = 800\ cm^2/v - s$$

The diffusion current crossing the unit area $= qD_n \frac{dn}{dx}$

So,

$$I_C = A\ q\ D_n\ \frac{dn}{dx}$$

$$= A\ q\ \mu_n V_T\ \frac{dn}{dx}$$

Since, $\frac{D}{\mu} = V_T$

$$= 0.001 \times 1.6 \times^{-19} \times 800 \times 0.026 \times \left(\frac{10^{14} - 0}{0.5 \times 10^{-4}}\right)$$

$$I_C = 6.656\ mA.$$

Answer:- $I_C = 6.656\ mA$