ESc201 : Introduction to Electronics

Transistor

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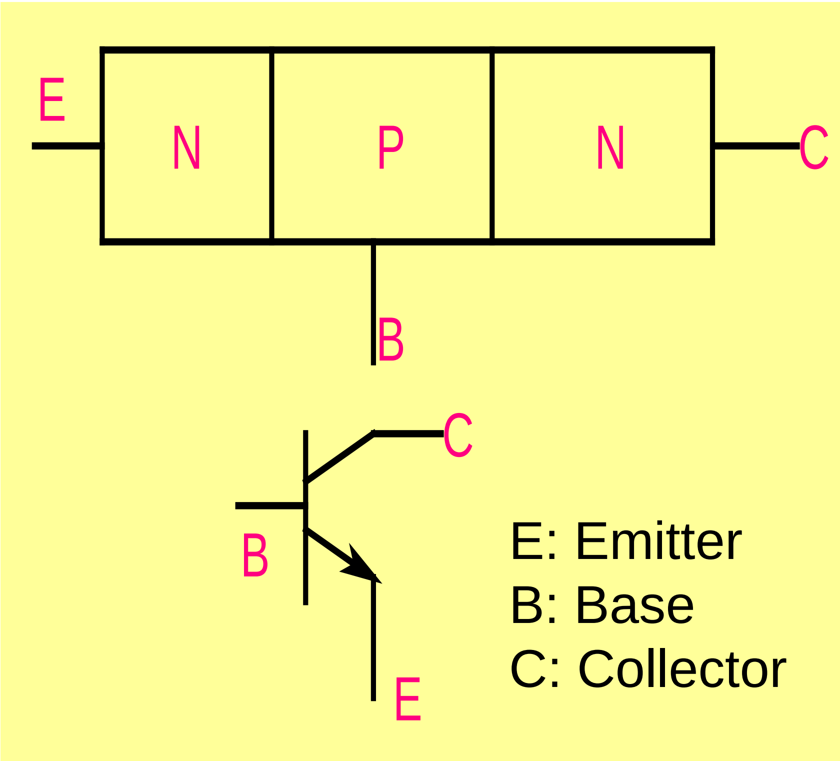
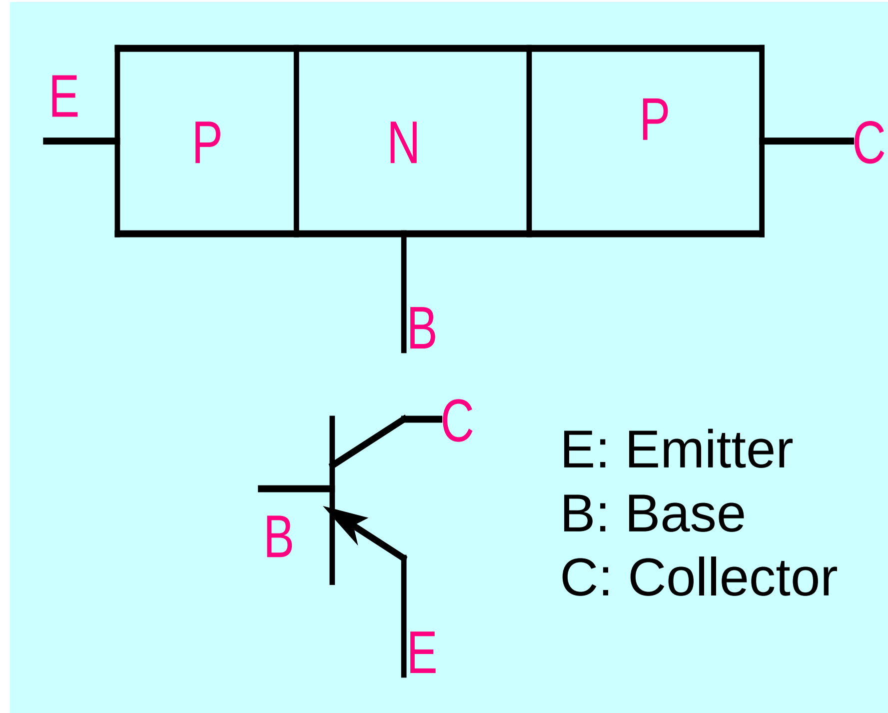
Bipolar Junction Transistor (BJT)

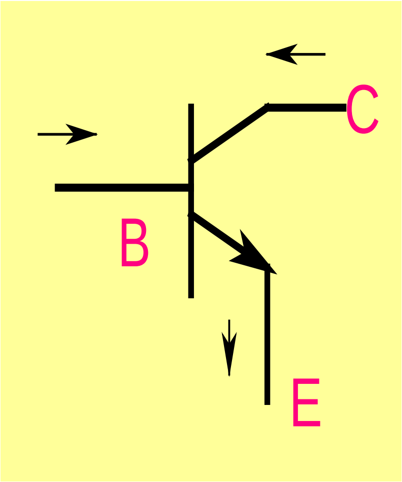


NPN



PNP

DC current-voltage Characteristics of NPN Transistor



$$I_C + I_B = I_E$$

Two independent currents

Let them be I_B and I_C

There can be three voltages:

$$V_{BE}, V_{BC}, V_{CE}$$

Again, only two are independent. Often V_{BE} and V_{CE} are chosen.

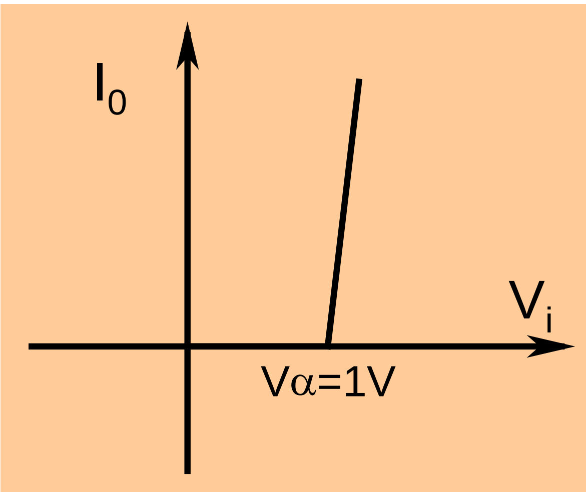
$$V_{BE} = V_B - V_E; V_{BC} = V_B - V_C; V_{CE} = V_C - V_E$$

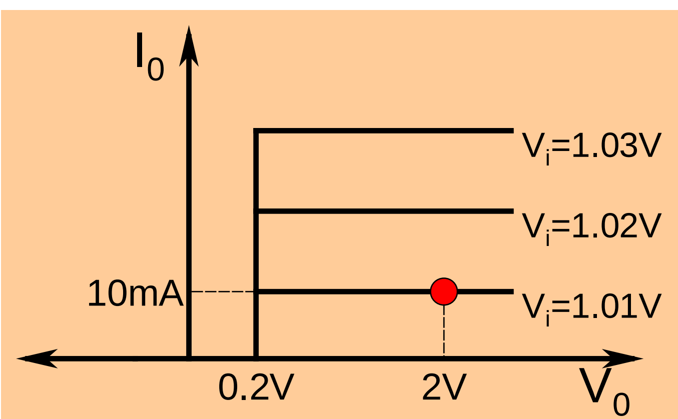
$$V_{BC} = V_{BE} - V_{CE}$$

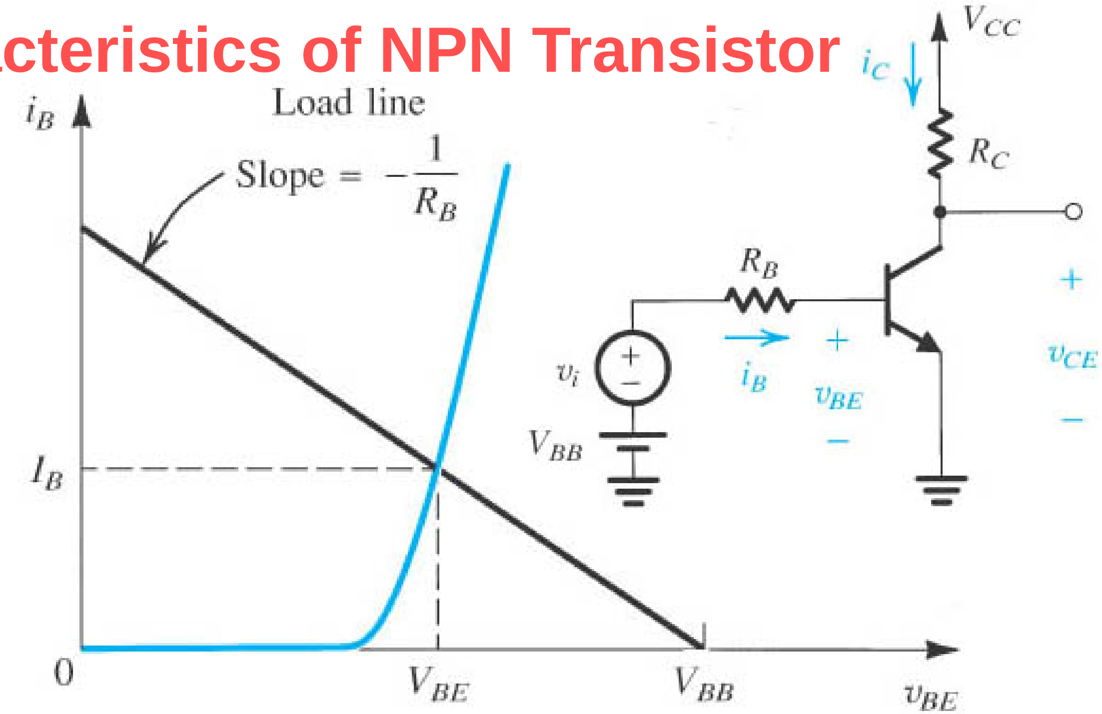
$$V_{CE} = V_{BE} - V_{BC}$$

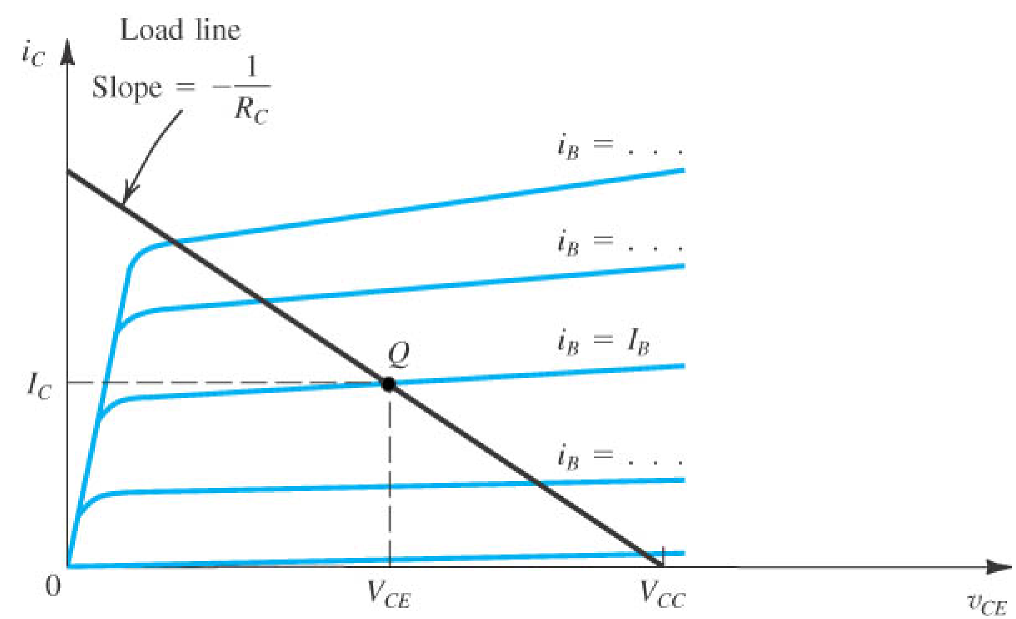
Dc current-voltage Characteristics of NPN Transistor

$$I_C = \beta_F I_B$$

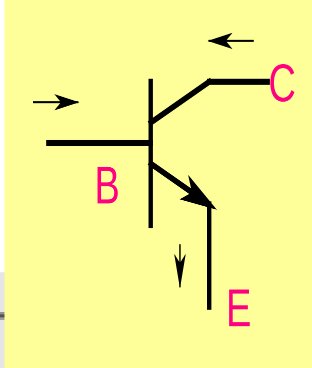




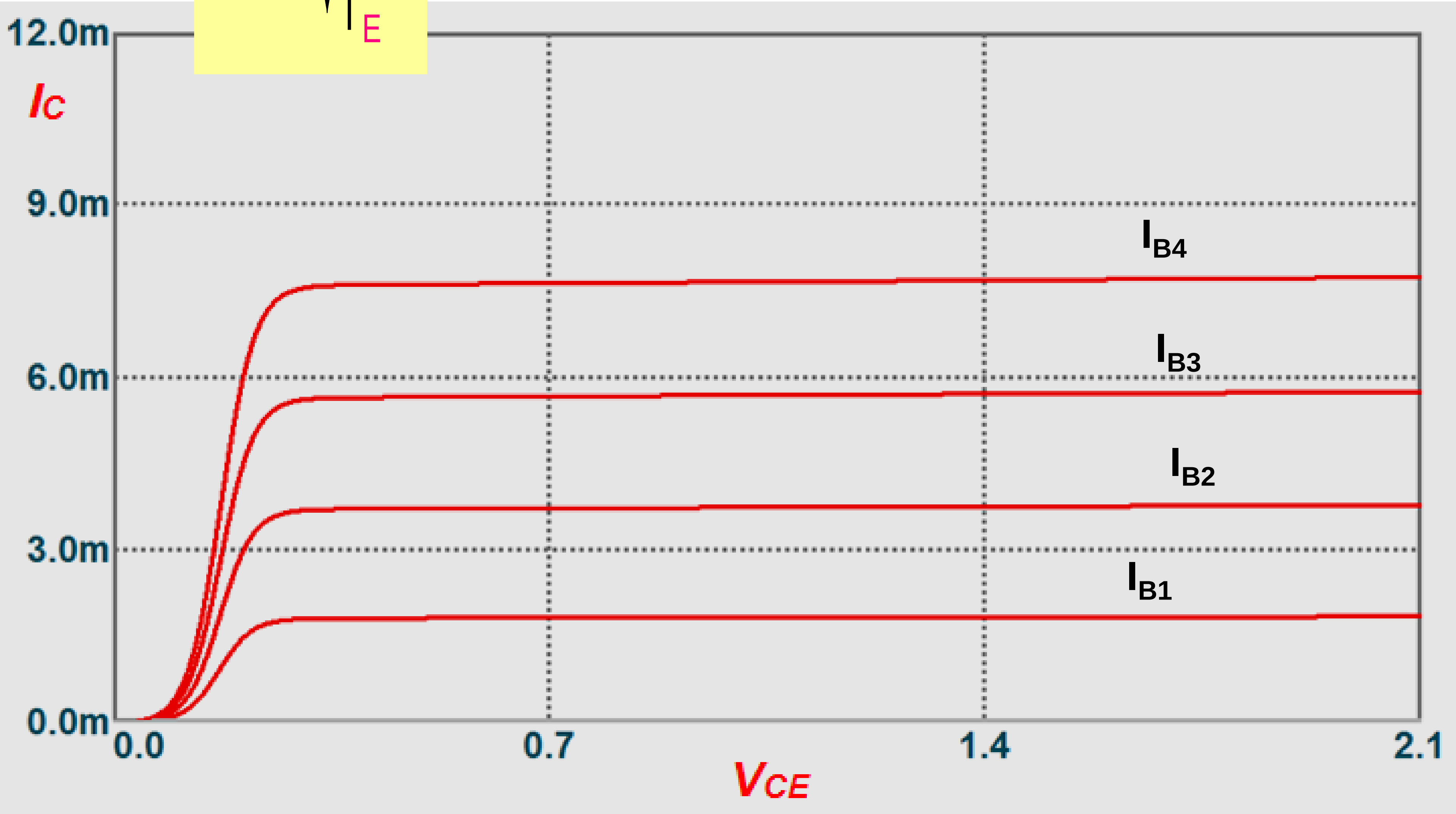


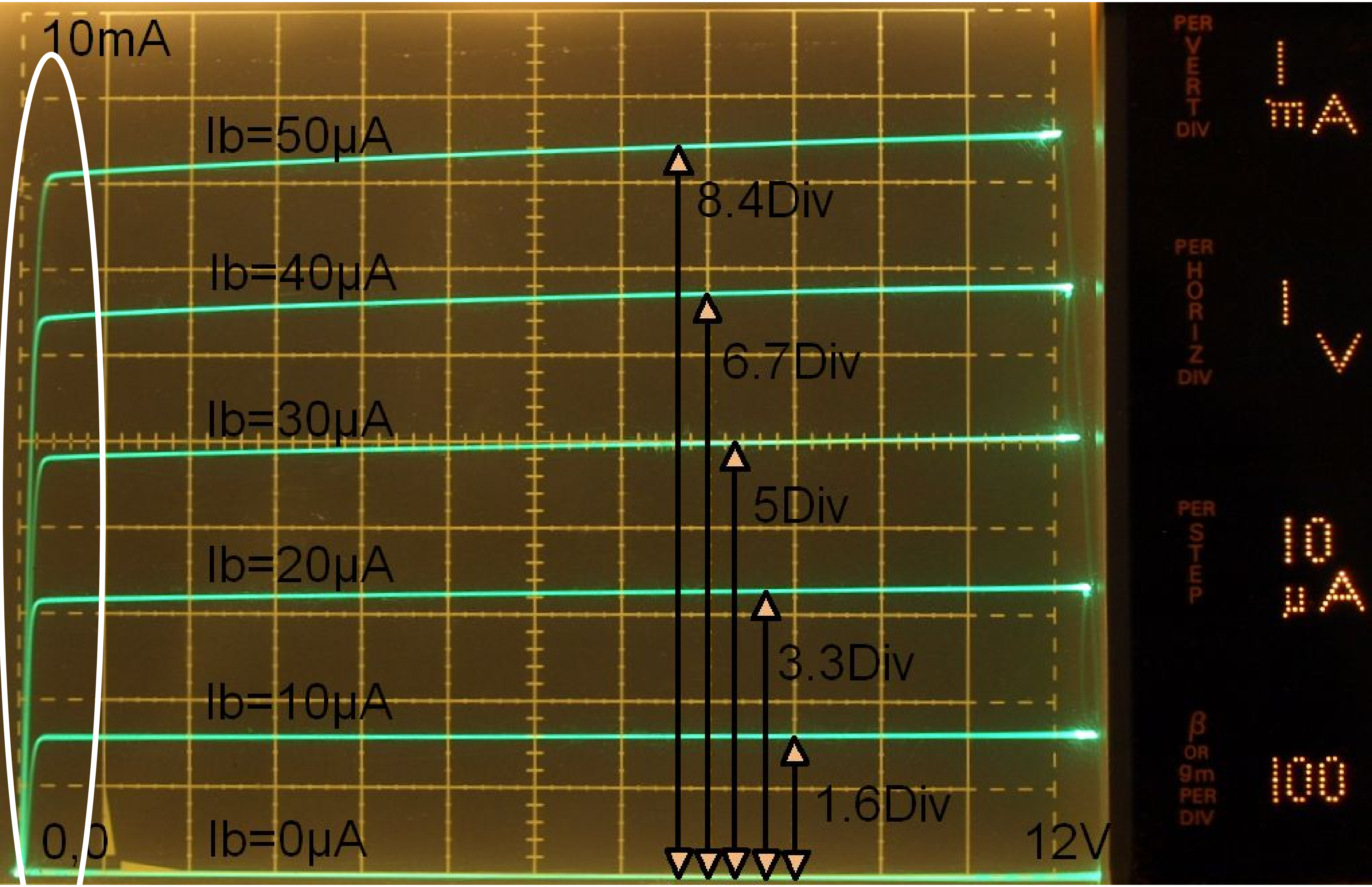


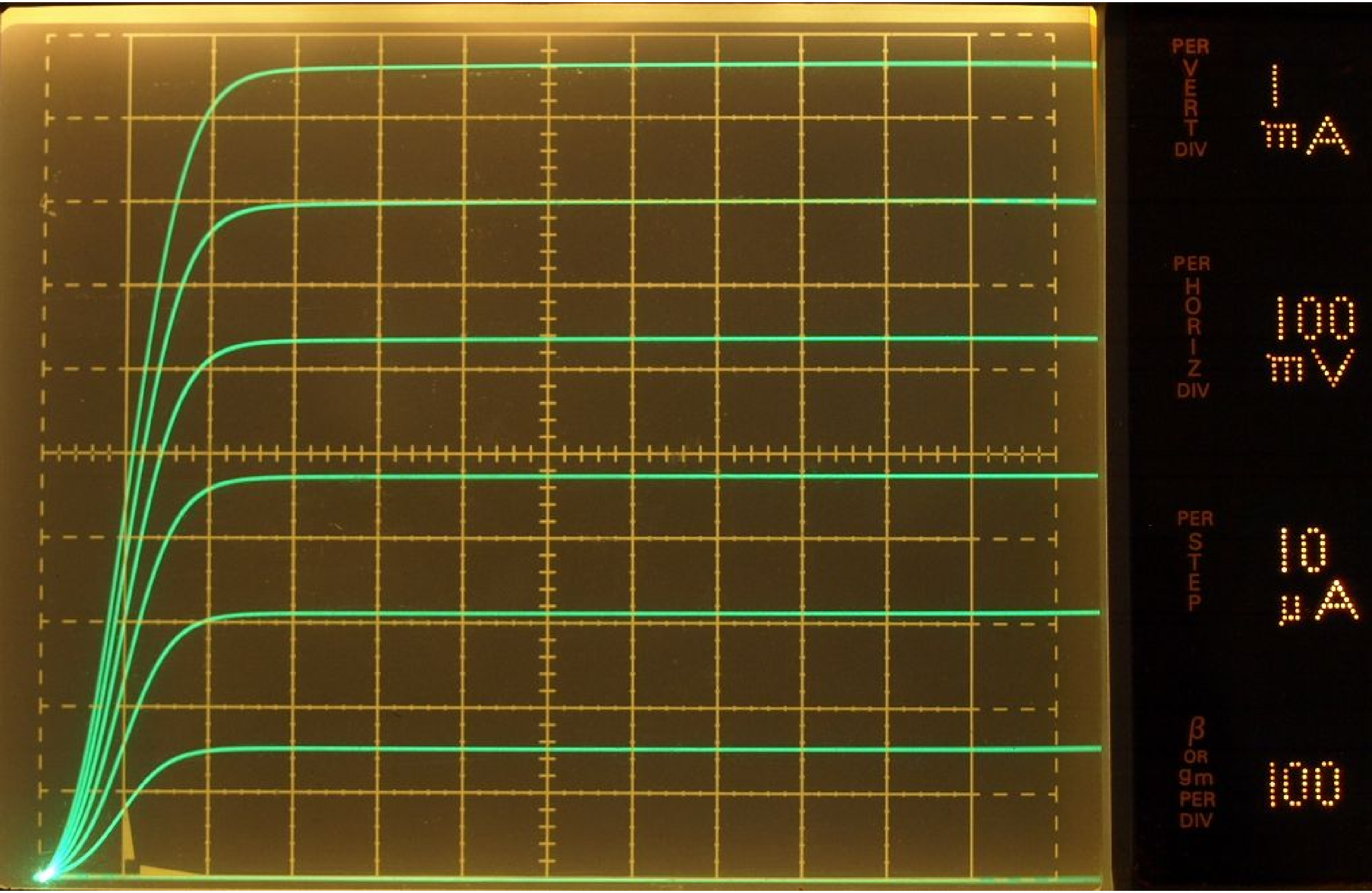
Dc current-voltage Characteristics of NPN Transistor



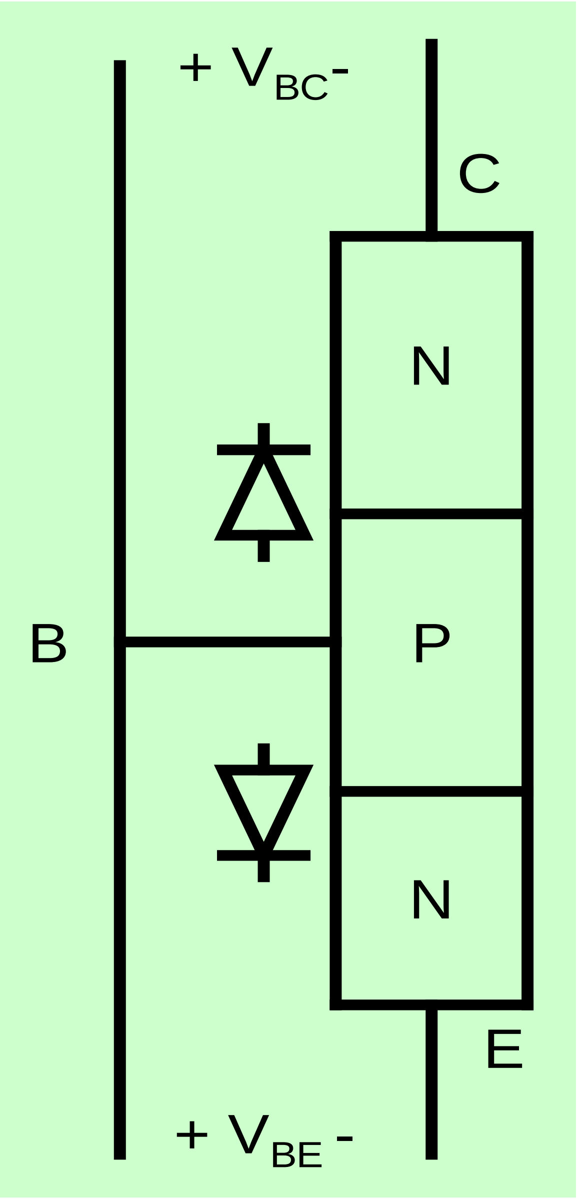
$$(I_C, I_B)\ ;\ (V_{BE}, V_{CE})$$

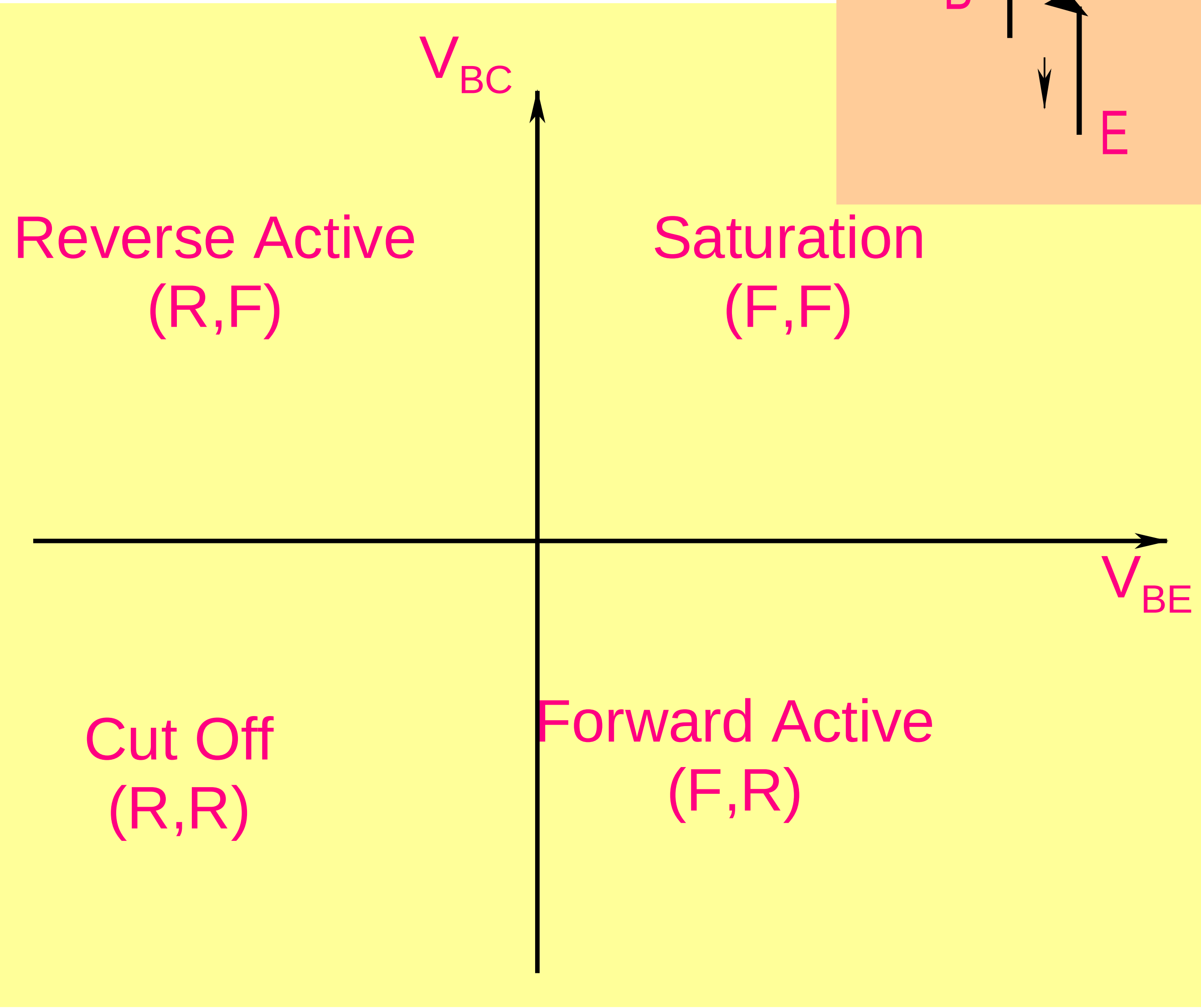


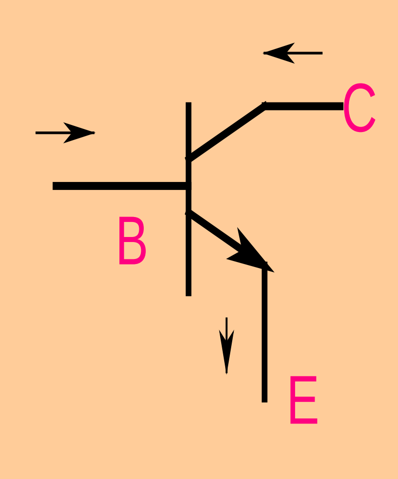

10mA
Ib=50µA
8.4Div
Ib=40µA
6.7Div
Ib=30µA
5Div
Ib=20µA
3.3Div
Ib=10µA
1.6Div
0,0
Ib=0µA
12V
PER VERT DIV
1 mA
PER HORIZ DIV
1 V
PER STEP
10 µA
β OR gm PER DIV
100

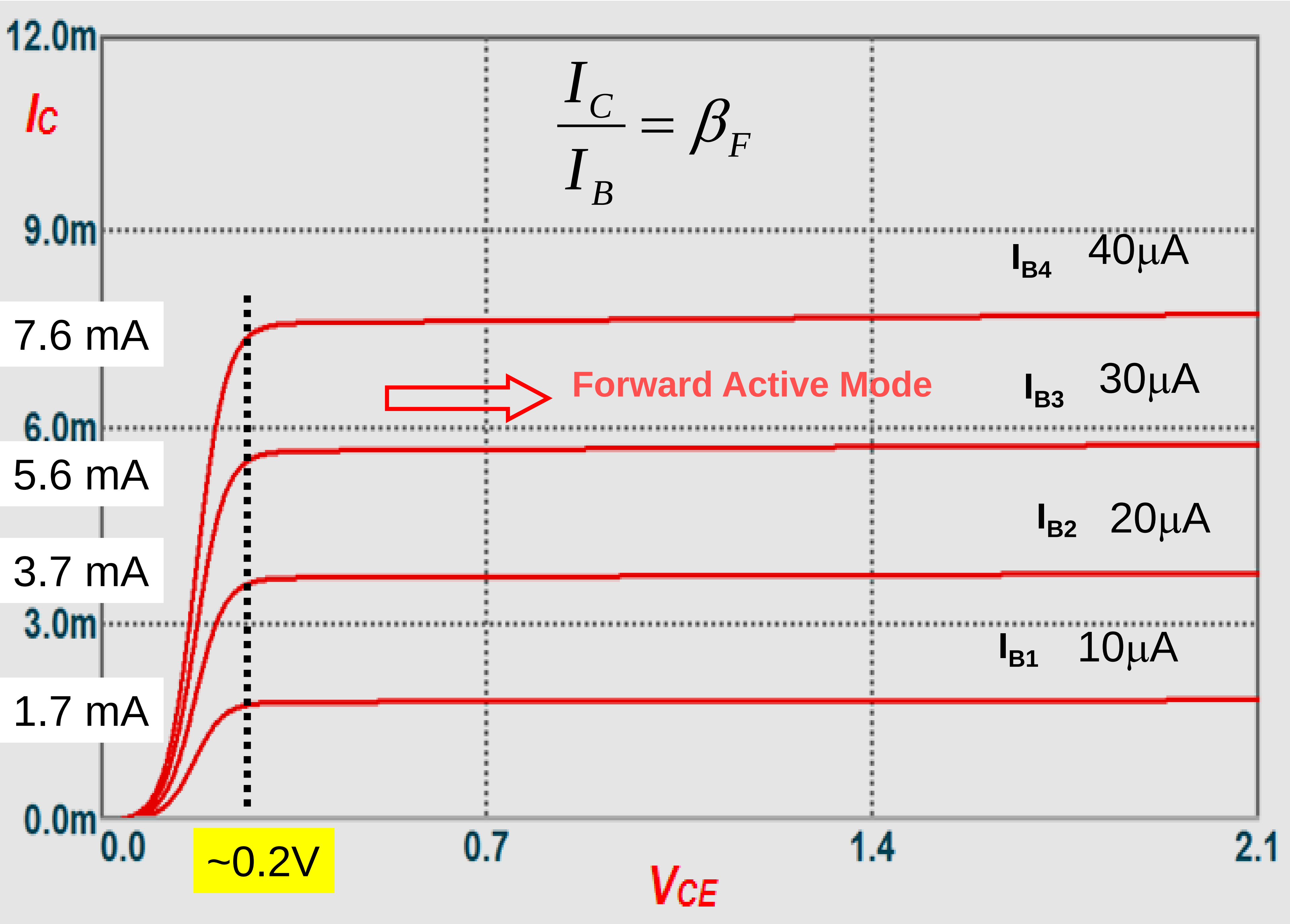

PER VERT DIV
1 mA
PER HORIZ DIV
100 mV
PER STEP
10 µA
β OR gm PER DIV
100

Modes of Operation





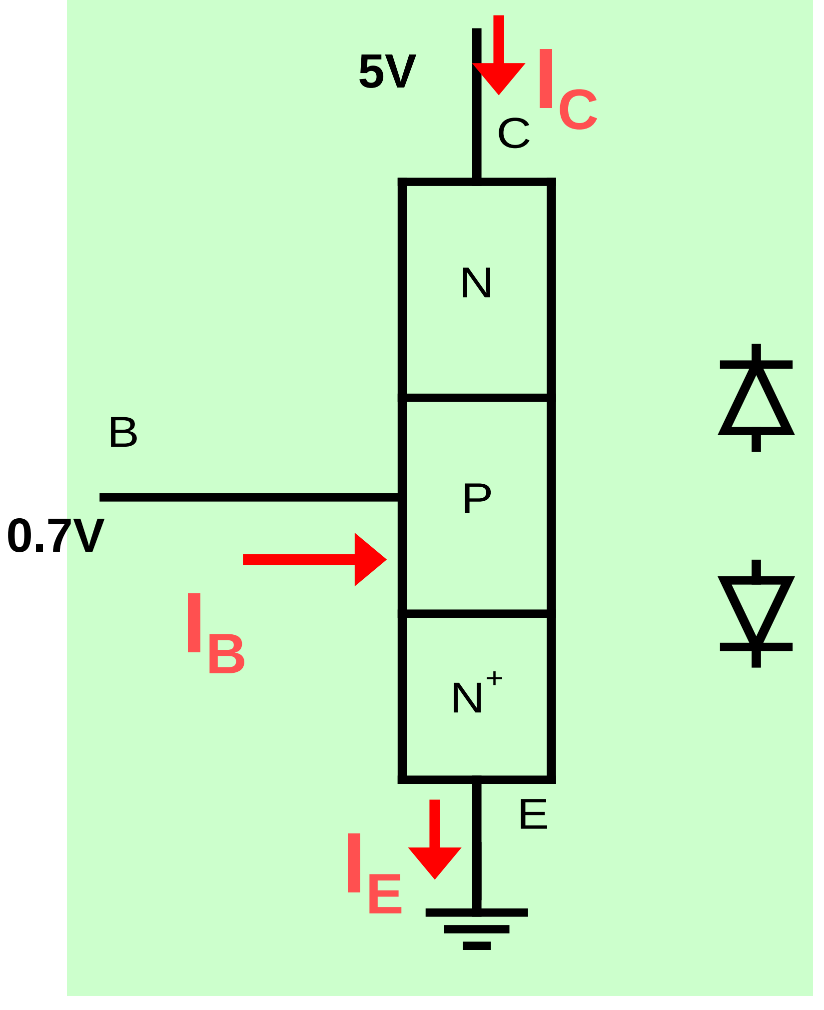




12.0m
I_C
$\frac{I_C}{I_B} = \beta_F$
9.0m
I_{B4} 40µA
7.6 mA
Forward Active Mode
I_{B3} 30µA
6.0m
5.6 mA
I_{B2} 20µA
3.7 mA
3.0m
I_{B1} 10µA
1.7 mA
0.0m
0.0
~0.2V
0.7
1.4
2.1
V_{CE}

Forward Active Mode

Base Emitter (BE) junction is forward biased and
Base Collector (BC) junction is reverse biased

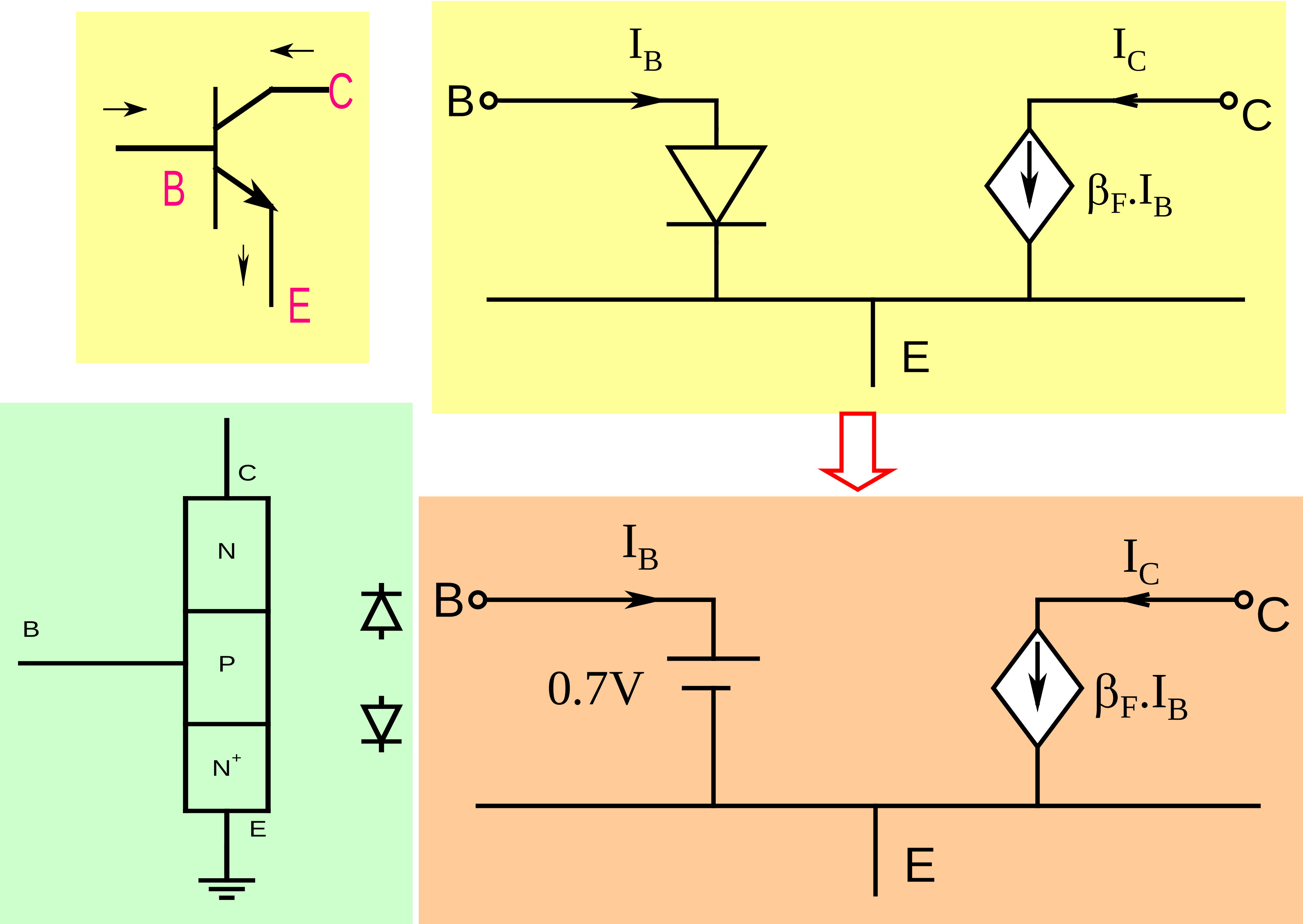


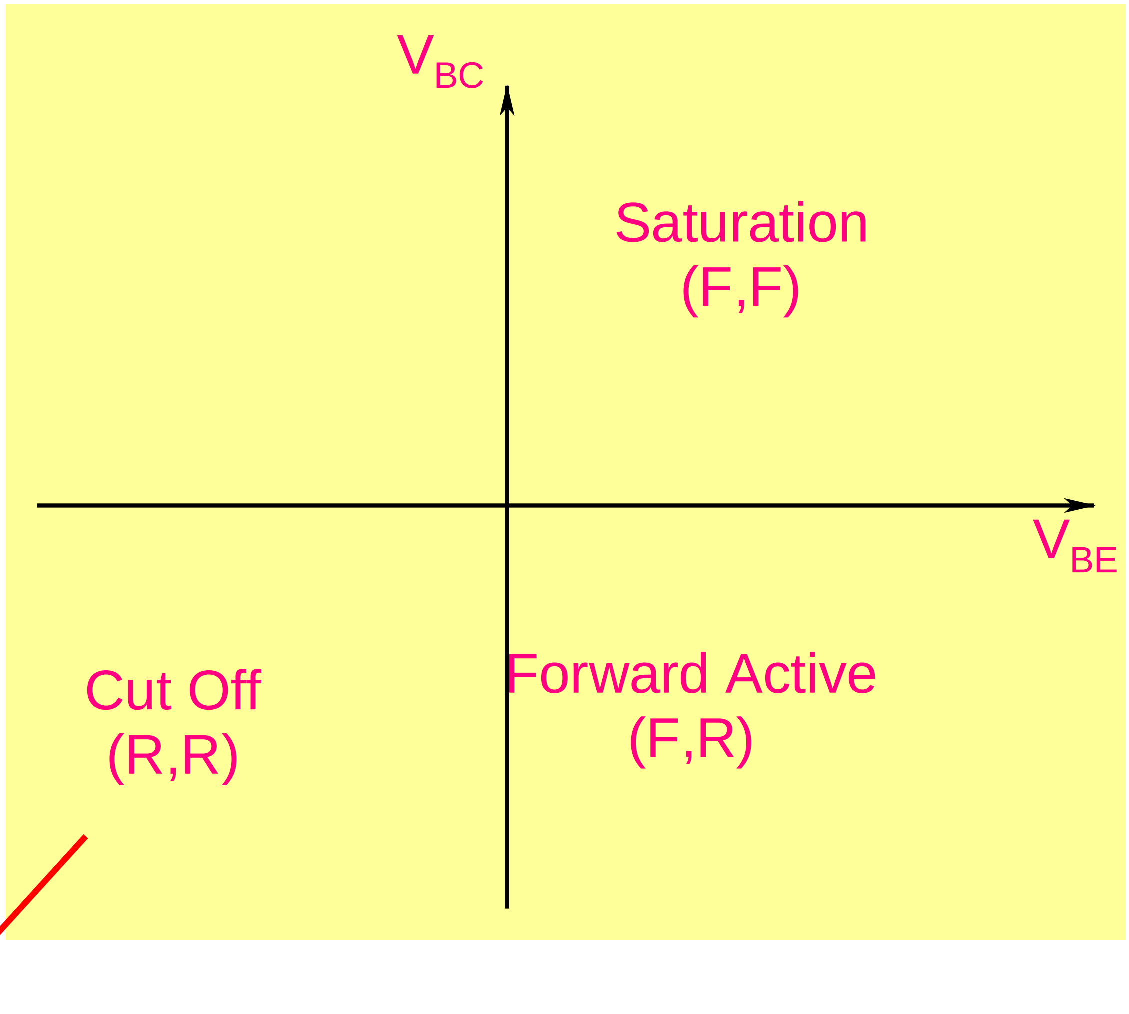
Current Gain

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

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

Forward Active Mode



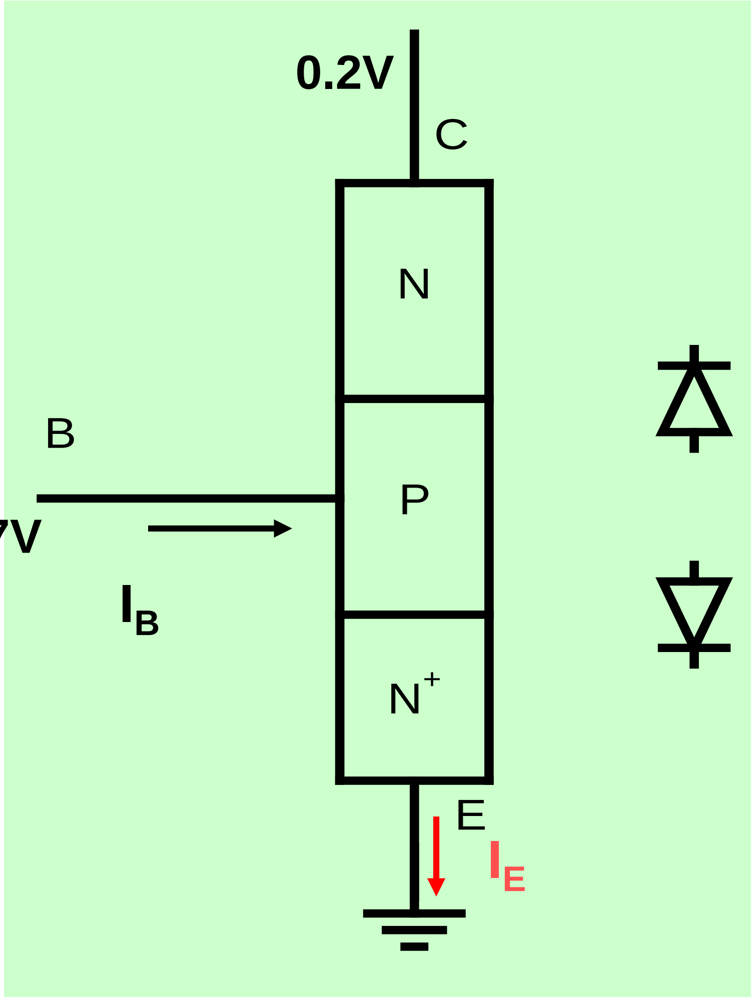


$$I_B \cong 0;\ I_C \cong 0;\ I_E \cong 0$$

Transistor acts like an open circuit

Saturation Mode

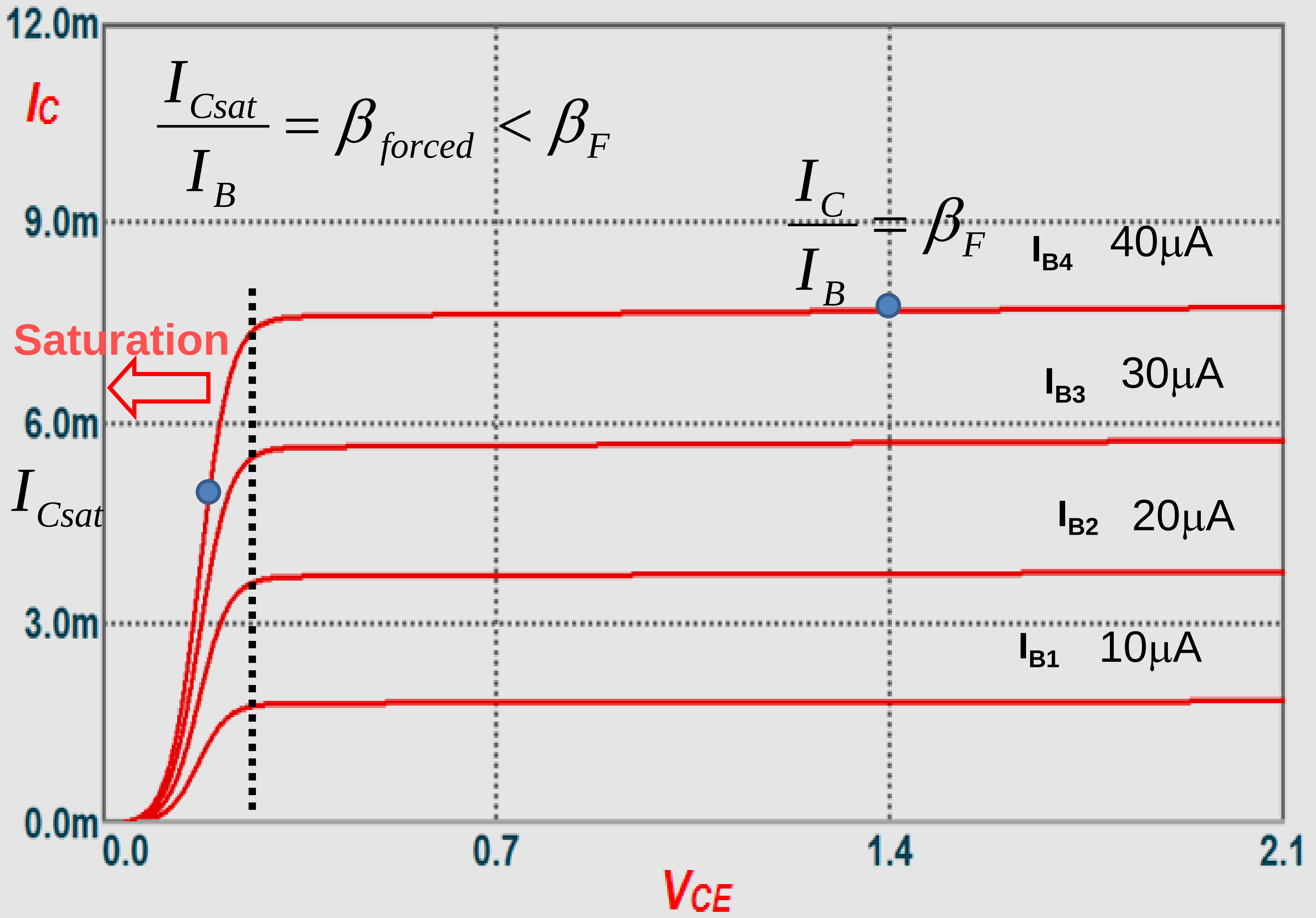
Both BE and BC junctions are forward biased



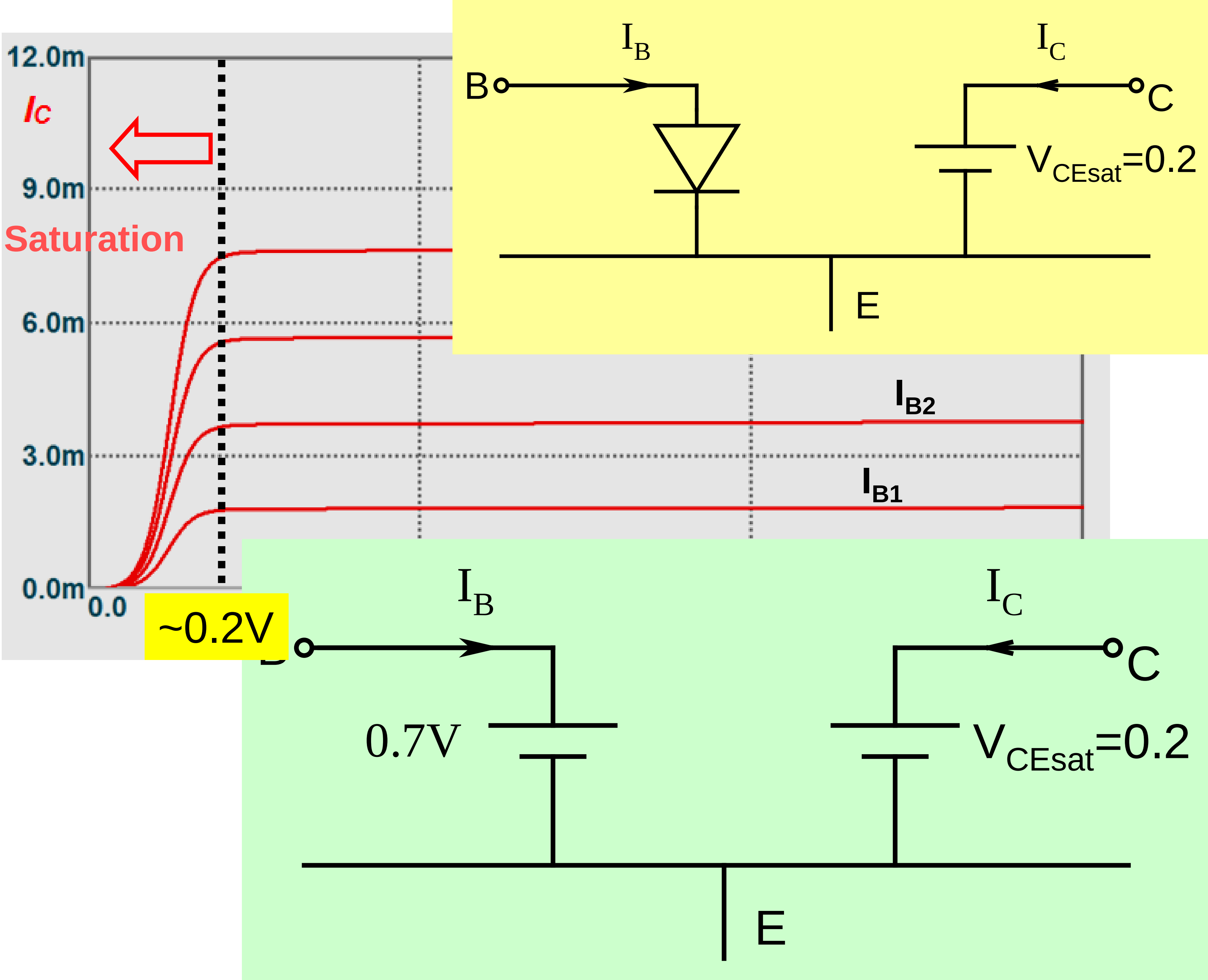
$$V_{BE} \cong 0.7V$$

$$V_{BC} \cong 0.5V$$

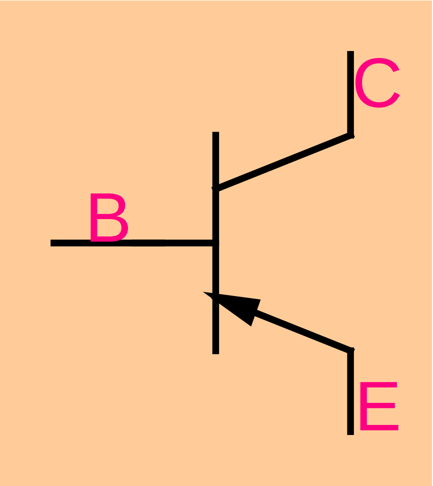
$$V_{BE} - V_{BC} \cong 0.2V$$

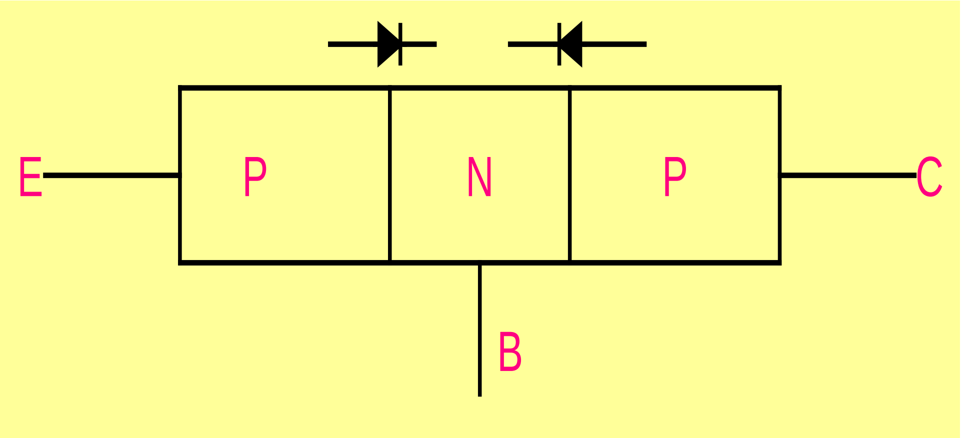


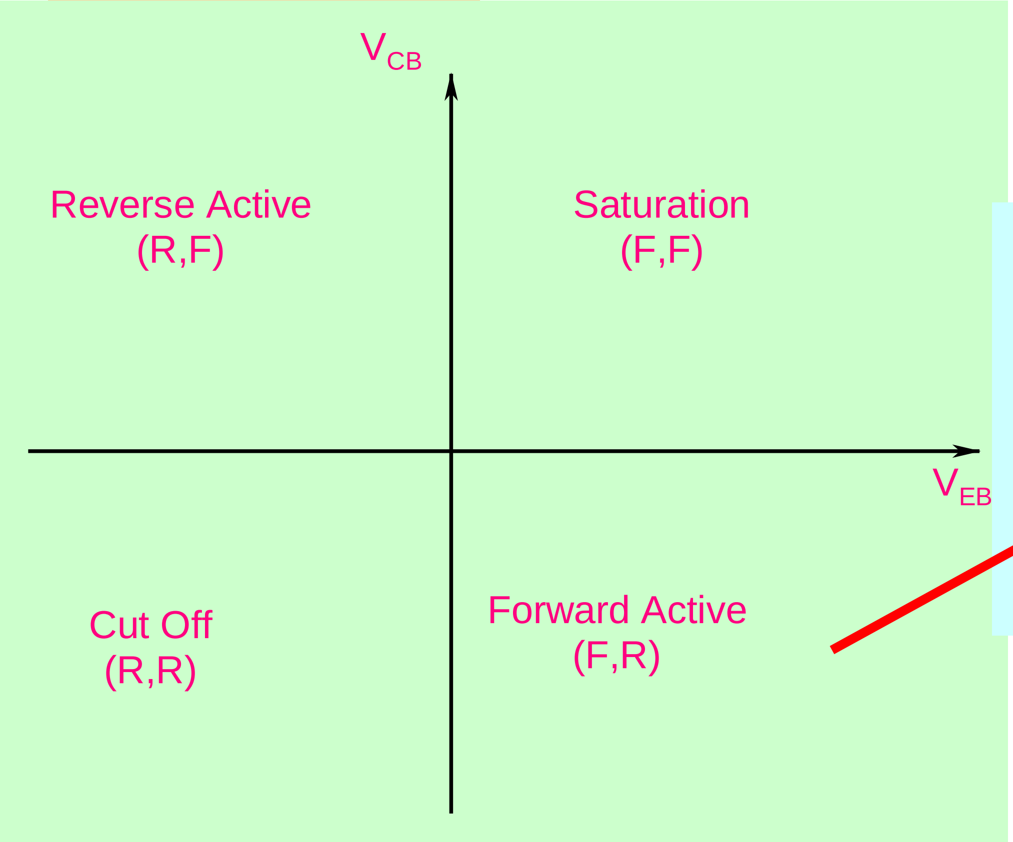
12.0m
9.0m
6.0m
3.0m
0.0m
I_C
$\frac{I_{Csat}}{I_B} = \beta_{forced} < \beta_F$
$\frac{I_C}{I_B} = \beta_F$
I_{B4} 40µA
I_{B3} 30µA
I_{B2} 20µA
I_{B1} 10µA
Saturation
I_{Csat}
0.0
0.7
1.4
2.1
V_{CE}

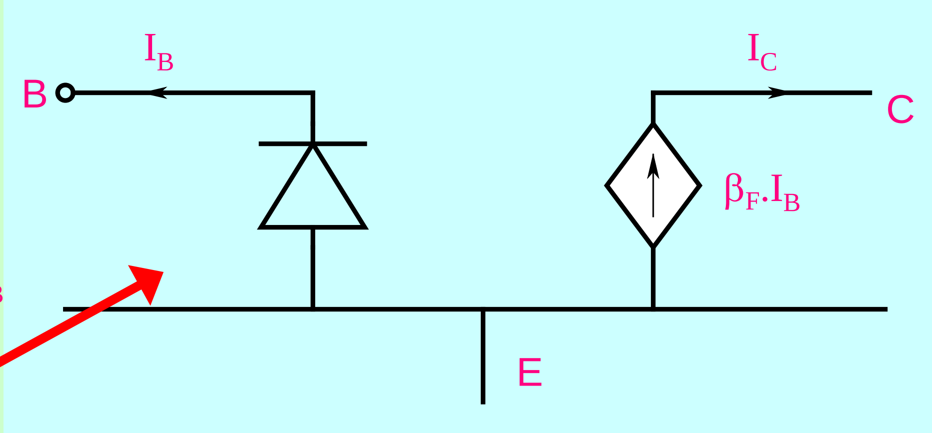

12.0m
9.0m
6.0m
3.0m
0.0m
0.0
I_C
Saturation
I_{B2}
I_{B1}
~0.2V
I_B
I_C
B
C
V_{CEsat}=0.2
E
I_B
I_C
C
0.7V
V_{CEsat}=0.2
E

PNP Transistor







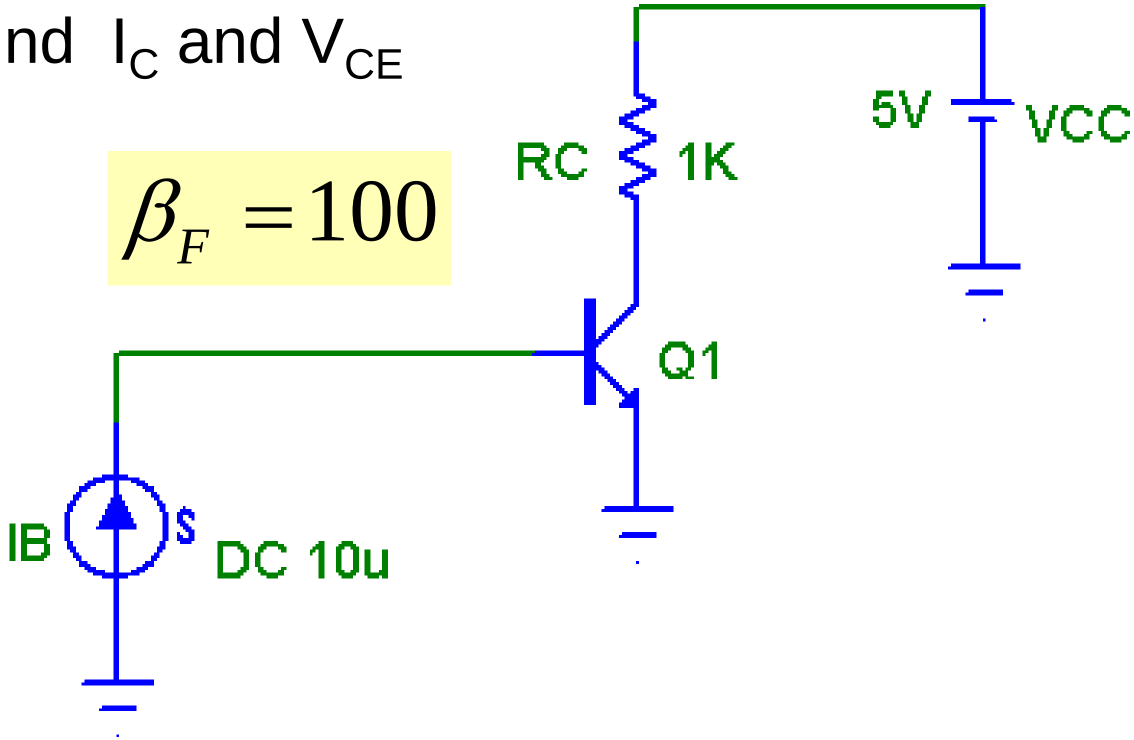


Transistor Circuit Analysis

DC Transistor Circuit Analysis Example-1

Find I_C and V_{CE}

$$\beta_F = 100$$



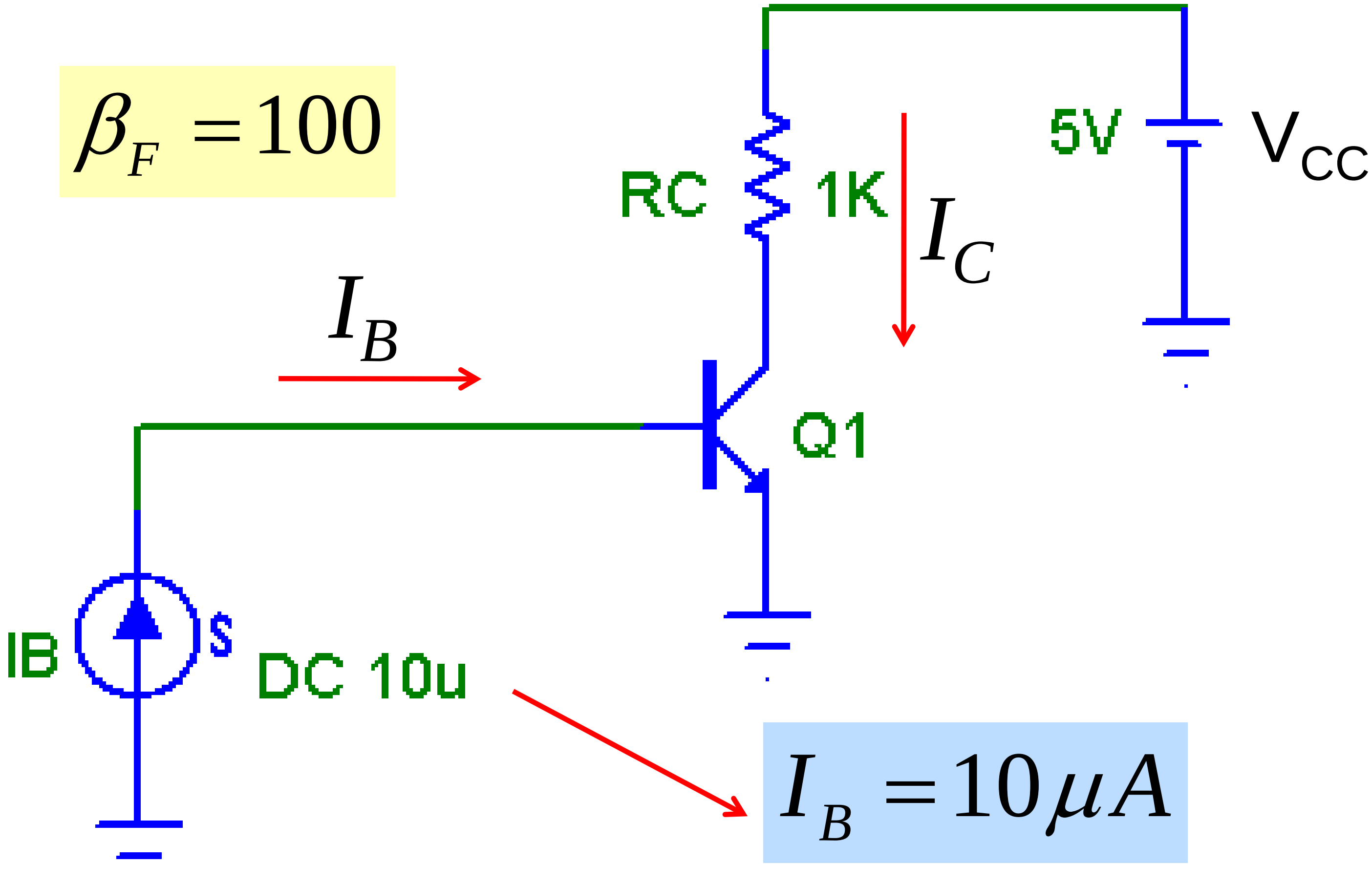
Base current is flowing into the transistor so transistor cannot be in cutoff mode.

Therefore transistor can be either in forward active or saturation mode of operation.

Let us assume that transistor is in forward active mode and carry out analysis.

Need to check if our assumption is correct.

$$\beta_F = 100$$



$$I_B = 10\mu A$$

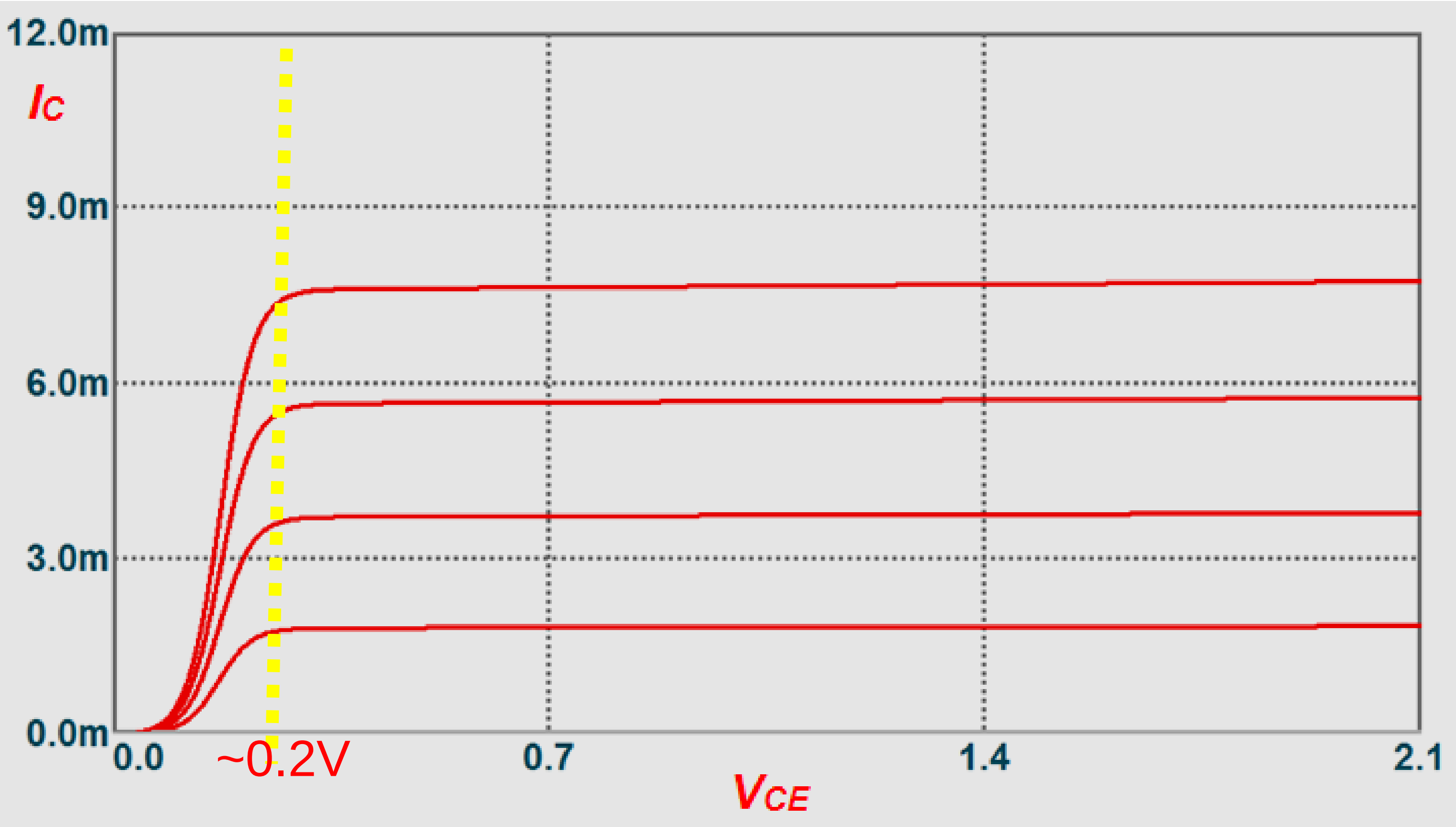
$$I_C = \beta_F I_B = 1mA$$

$$V_{CE} = 5 - I_C \times R_C = 4V$$

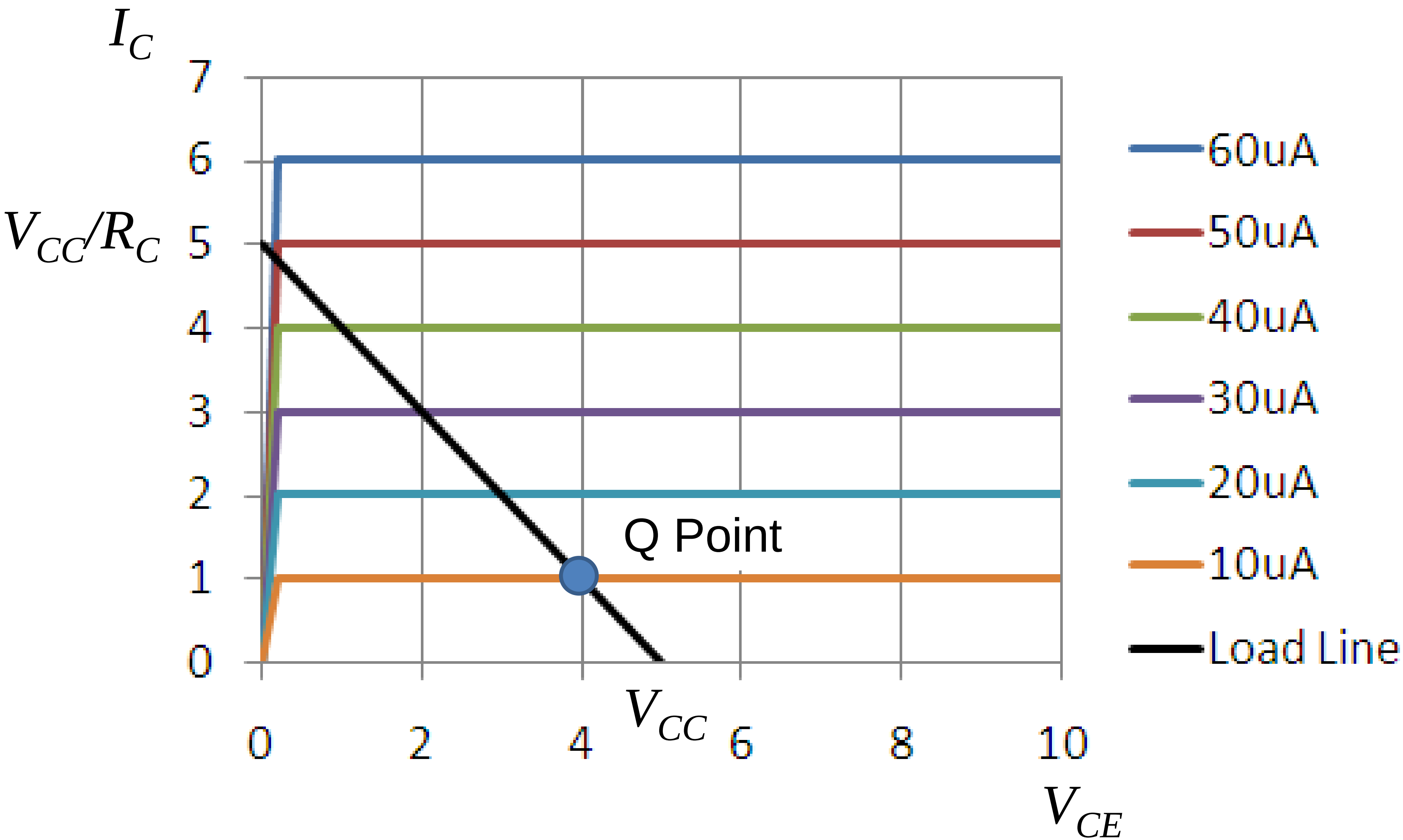
How do we check if transistor is indeed in forward active mode?

We check if $V_{CE} > 0.2V$

Since this is true for our circuit, the analysis is correct and our answers are right



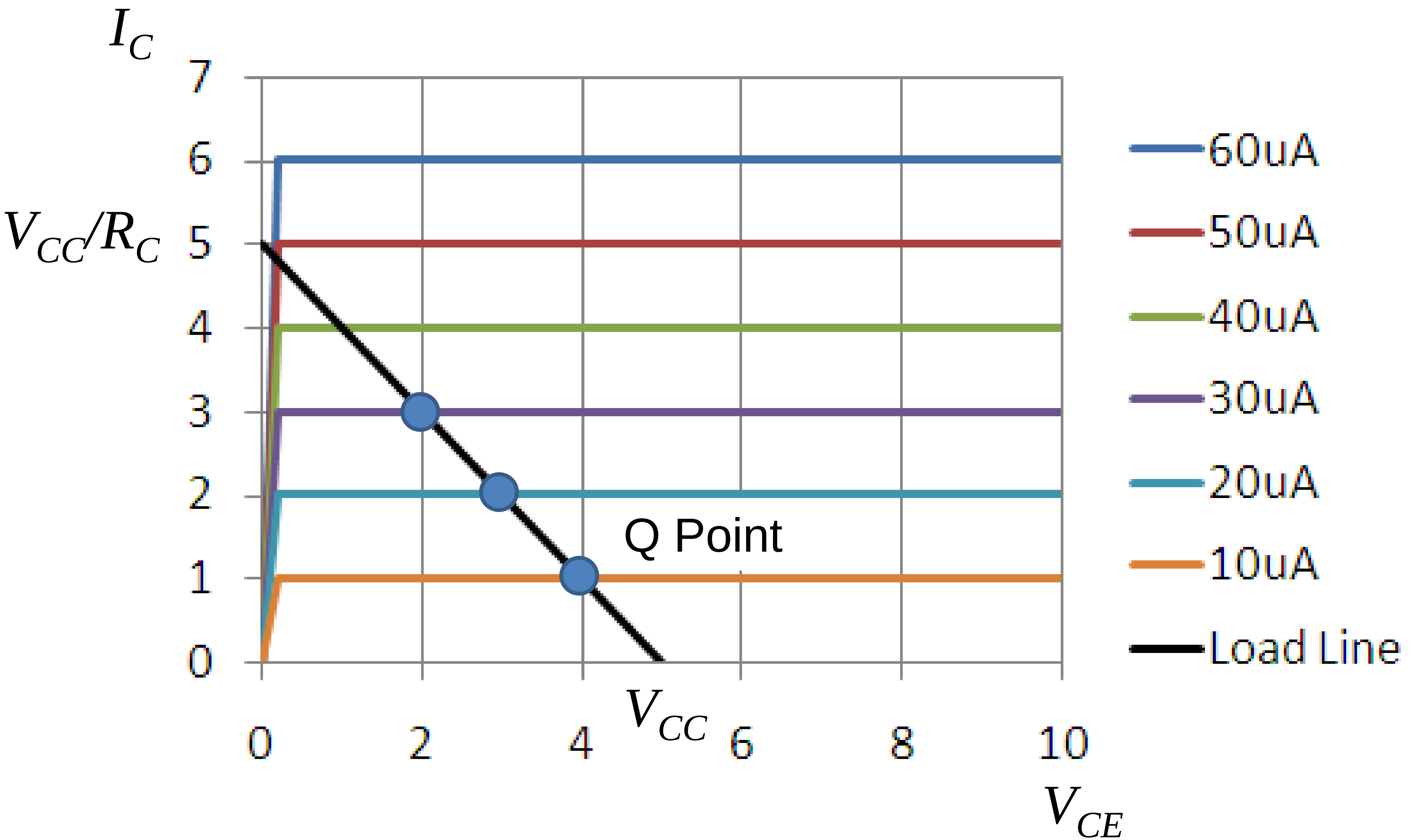
$$V_{CE} = V_{CC} - I_C R_C$$



I_C
V_{CC}/R_C
7
6
5
4
3
2
1
0
0
2
4
6
8
10
V_{CC}
V_{CE}
Q Point
60uA
50uA
40uA
30uA
20uA
10uA
Load Line

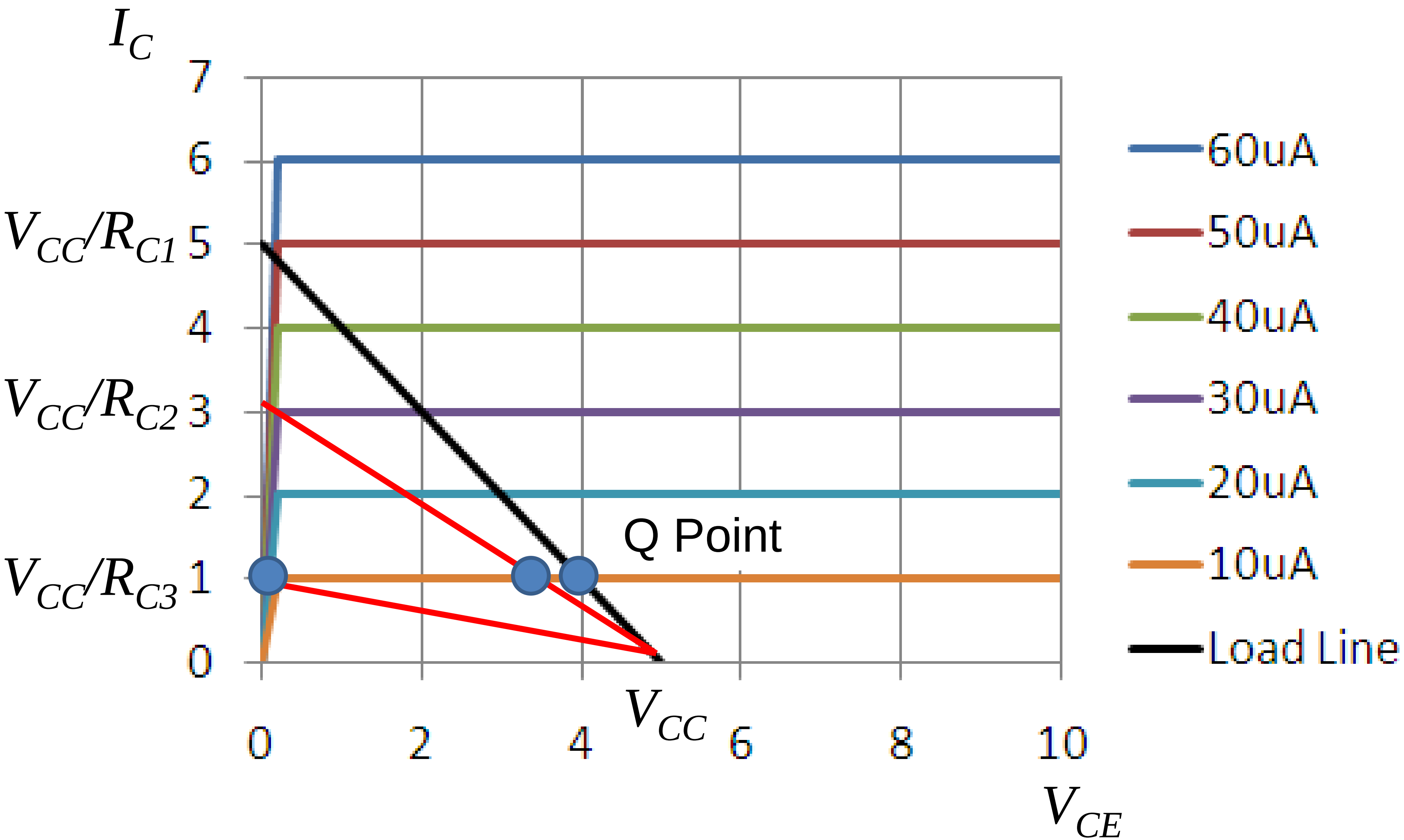
Changing I_B

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

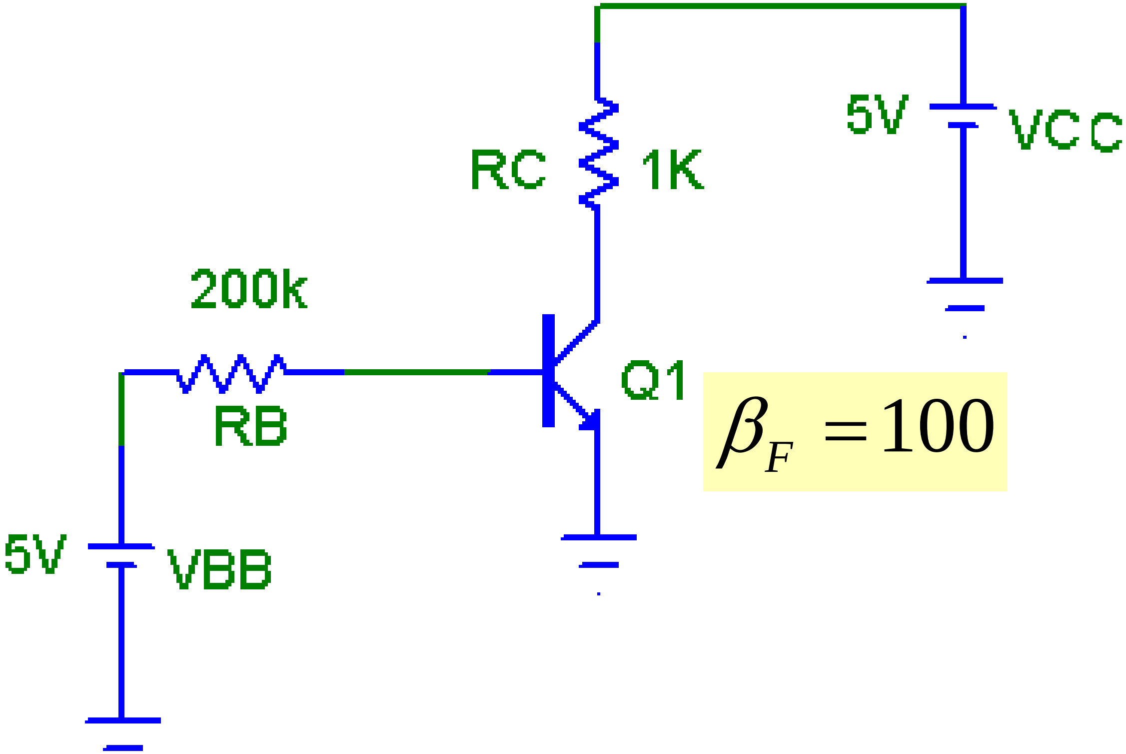


Changing R_C

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

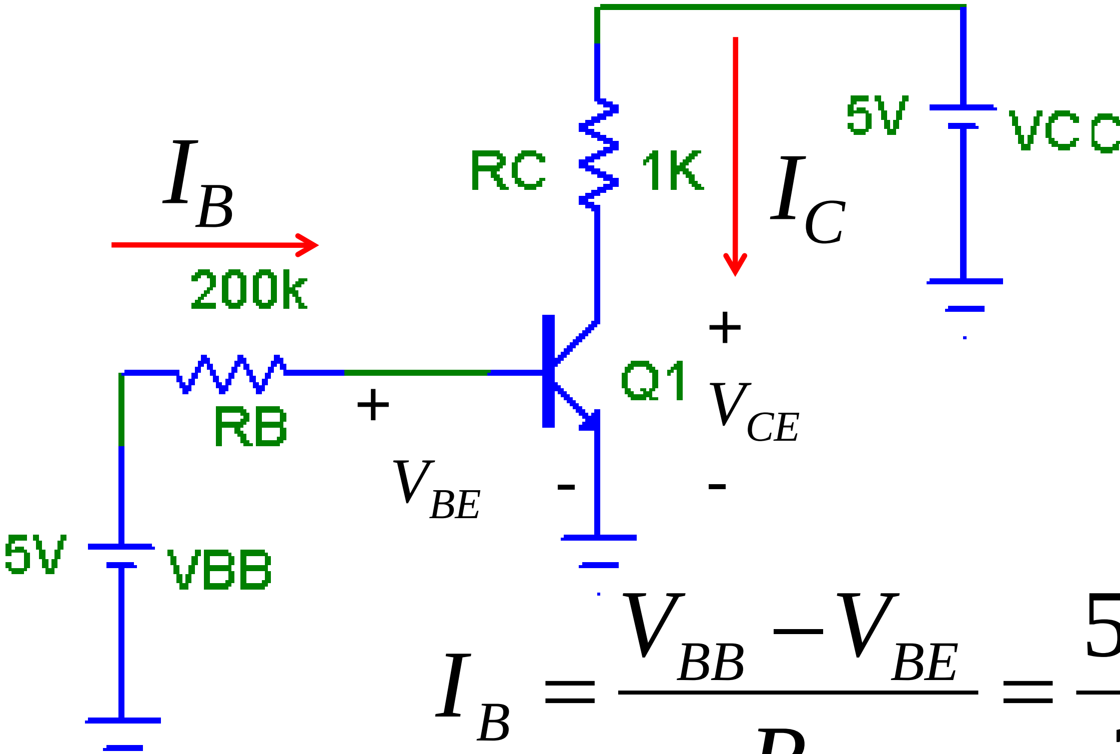


Example-2 Find I_C and V_{CE}



$$\beta_F = 100$$

Let us assume that transistor is in forward active mode and carry out analysis but we must check later on to make sure that our assumption is correct.



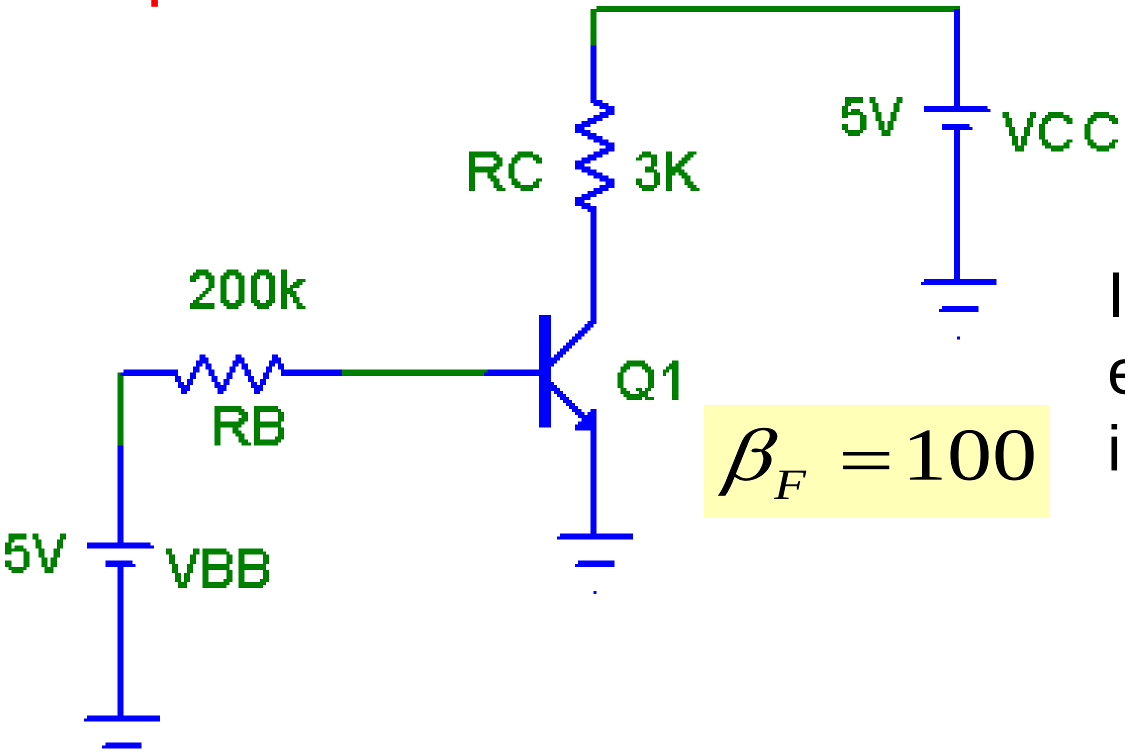
$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5 - 0.7}{200k} = 21.5\mu A$$

$$I_C = \beta_F I_B = 2.15mA$$

$$V_{CE} = 5 - I_C \times R_C = 2.85V$$

Since V_{CE} > 0.2V, our analysis is correct and Tr. is in active mode.

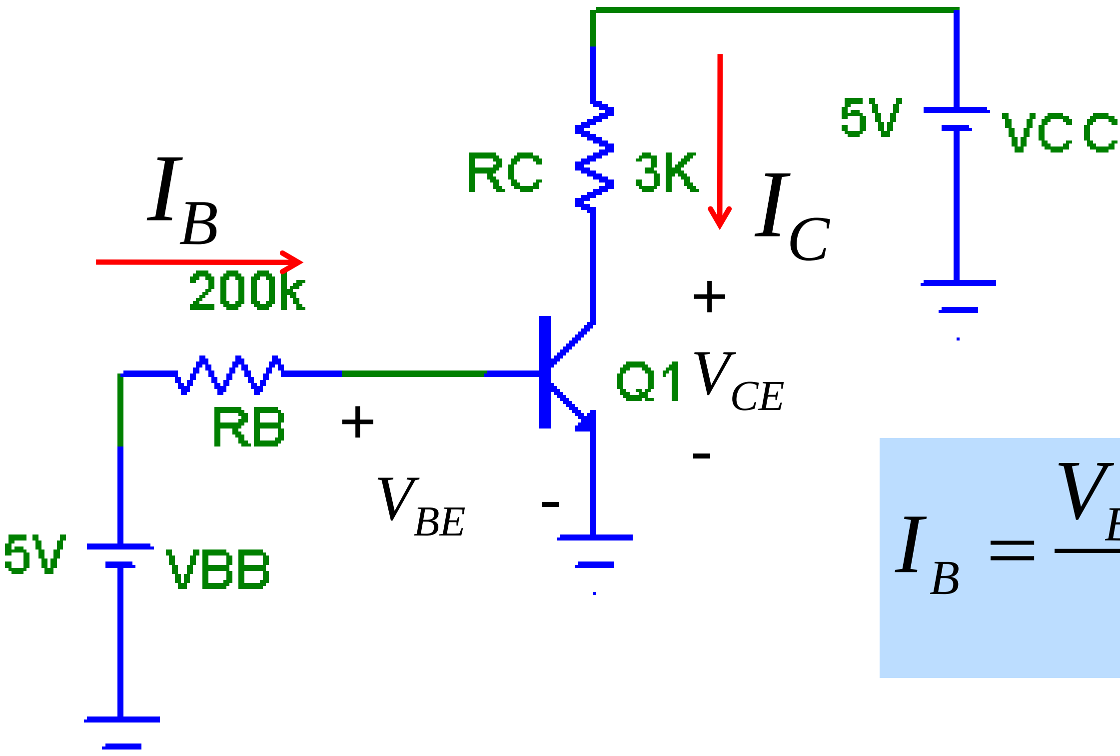
Example-3



$$\beta_F = 100$$

It is same as example-2 except that RC has been increased to 3K.

As before we assume that transistor is in forward active mode and carry out analysis



$$I_B = \frac{V_{BB} - 0.7}{R_B} = 21.5\mu A$$

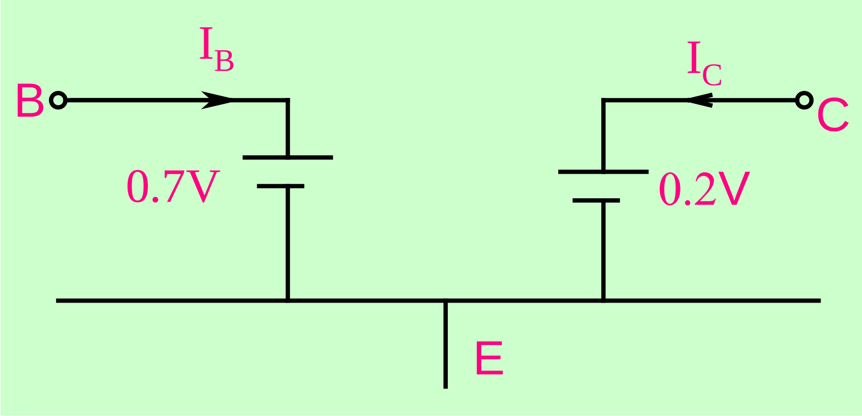
$$I_C = \beta_F I_B = 2.15mA$$

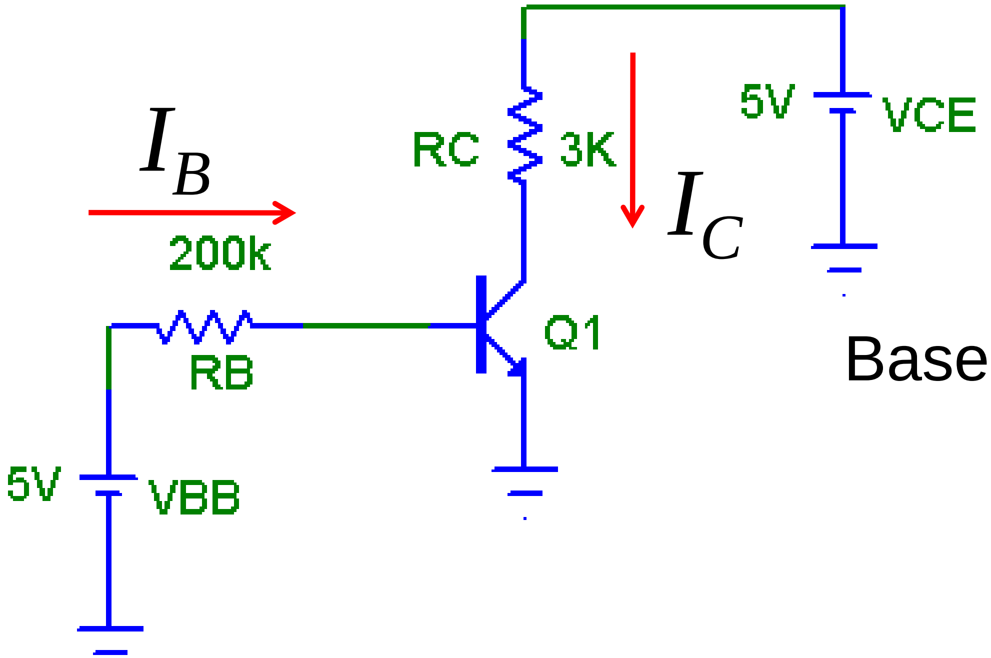
$$V_{CE} = 5 - I_C \times R_C = -1.45V$$

Since V_{CE} < 0.2V, our assumption is incorrect and transistor is actually in saturation mode.

In saturation mode: $I_C \neq \beta_F I_B$

The transistor model in saturation is





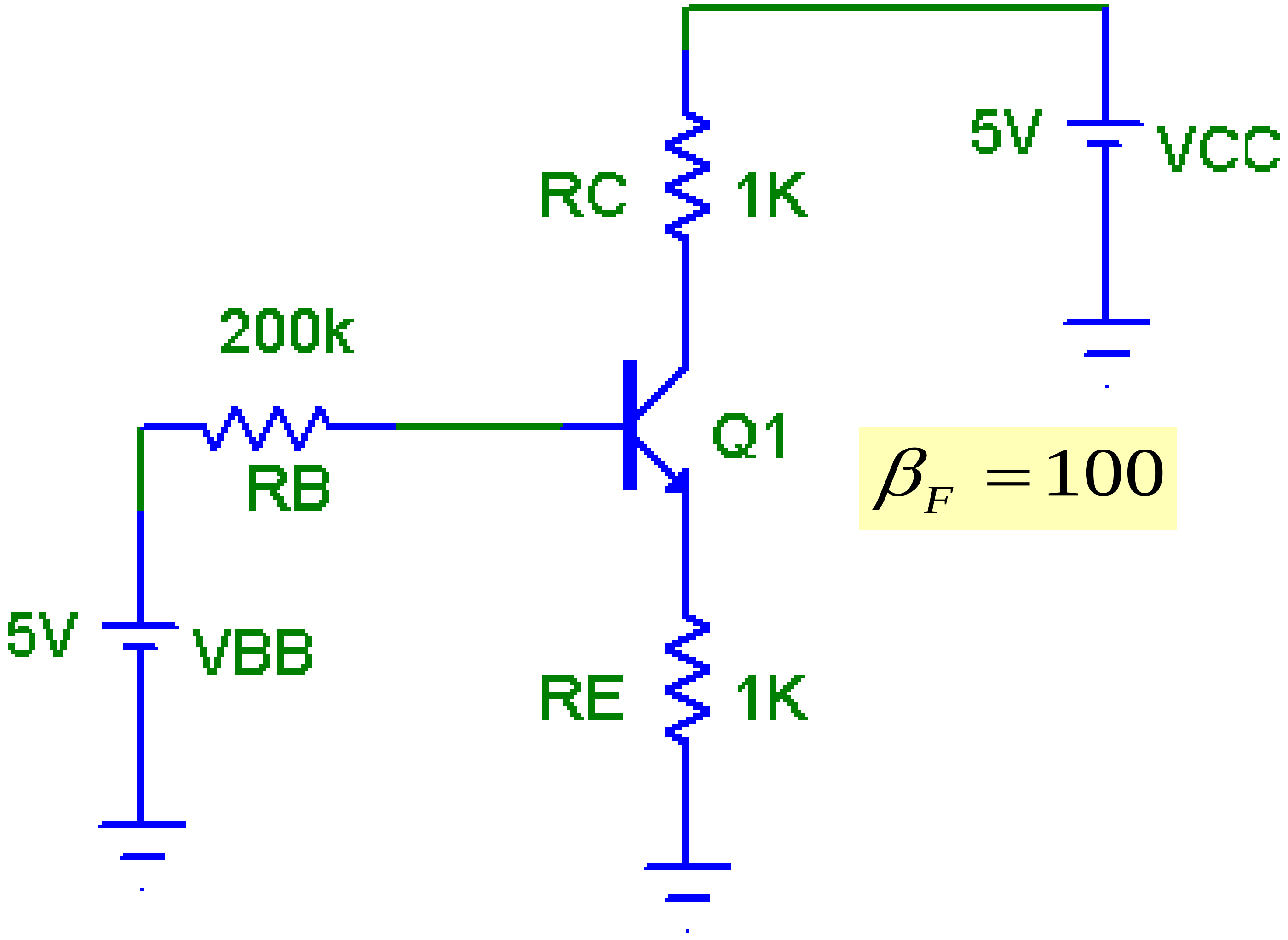
$$I_C = \frac{5-0.2}{3K} = 1.6mA$$

Base current is same as before:

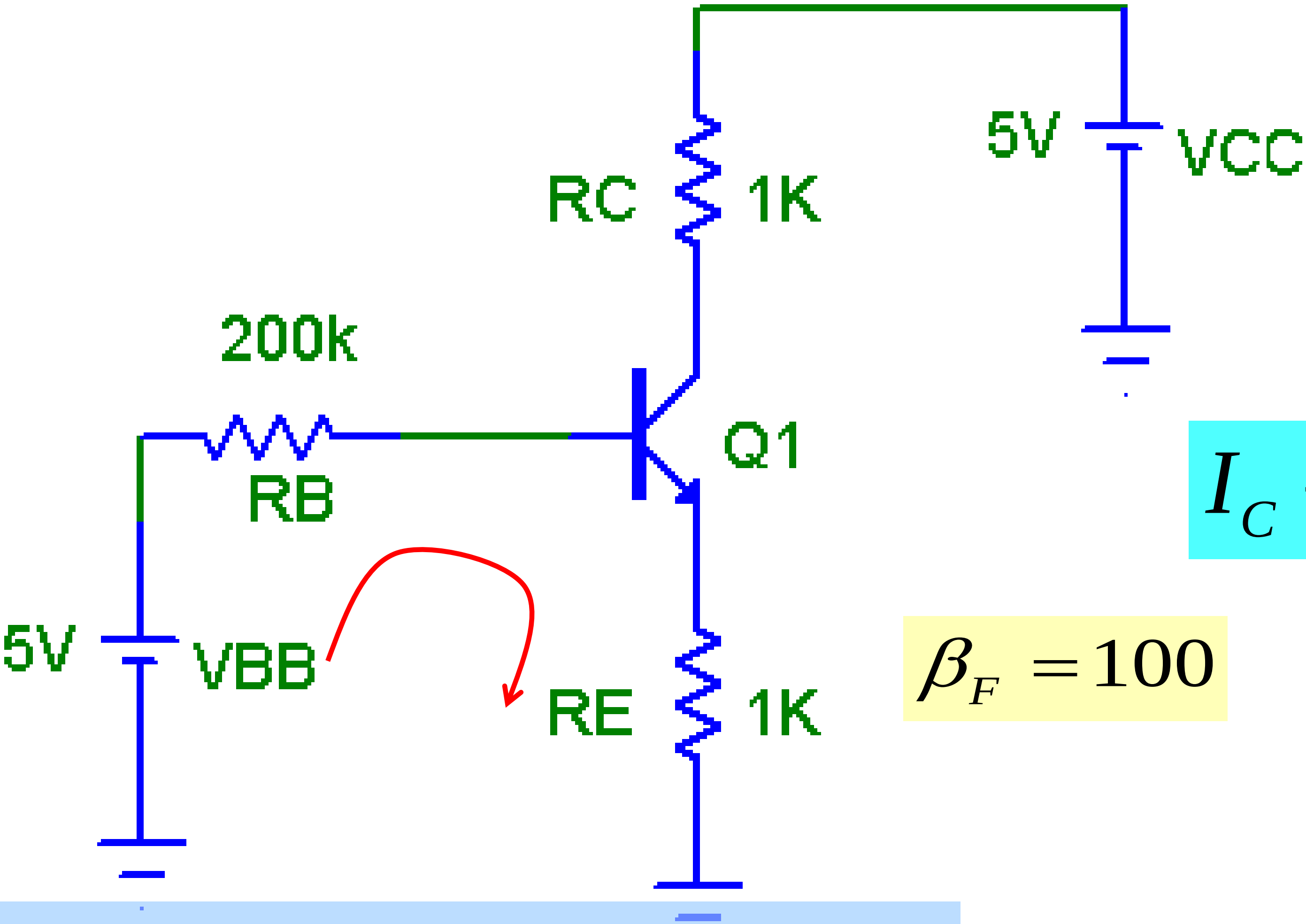
$$I_B = 21.5\mu A$$

$$\beta_{forced} = \frac{I_C}{I_B} = \frac{1.6mA}{21.5\mu A} = 74.4$$

Example-4 Find I_C and V_{CE}



$$\beta_F = 100$$



$$I_C + I_B = I_E$$

$$\beta_F = 100$$

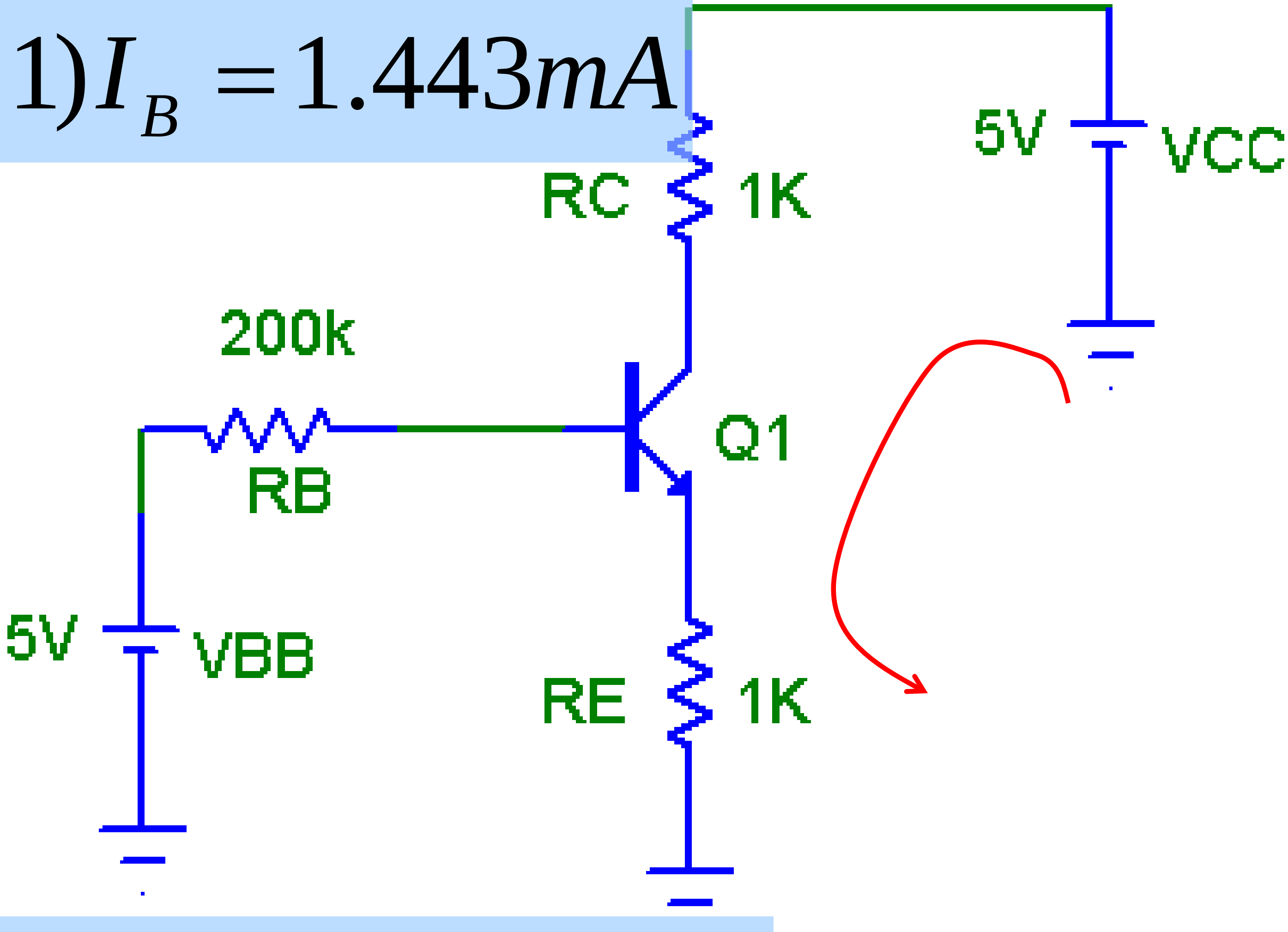
$$-V_{BB} + I_B R_B + 0.7 + I_E R_E = 0$$

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

$$I_B = \frac{V_{BB} - 0.7}{R_B + (1+\beta) R_E} = 14.29\mu A$$

$$I_C = \beta_F I_B = 1.429mA$$

$$I_E = (\beta_F + 1) I_B = 1.443mA$$

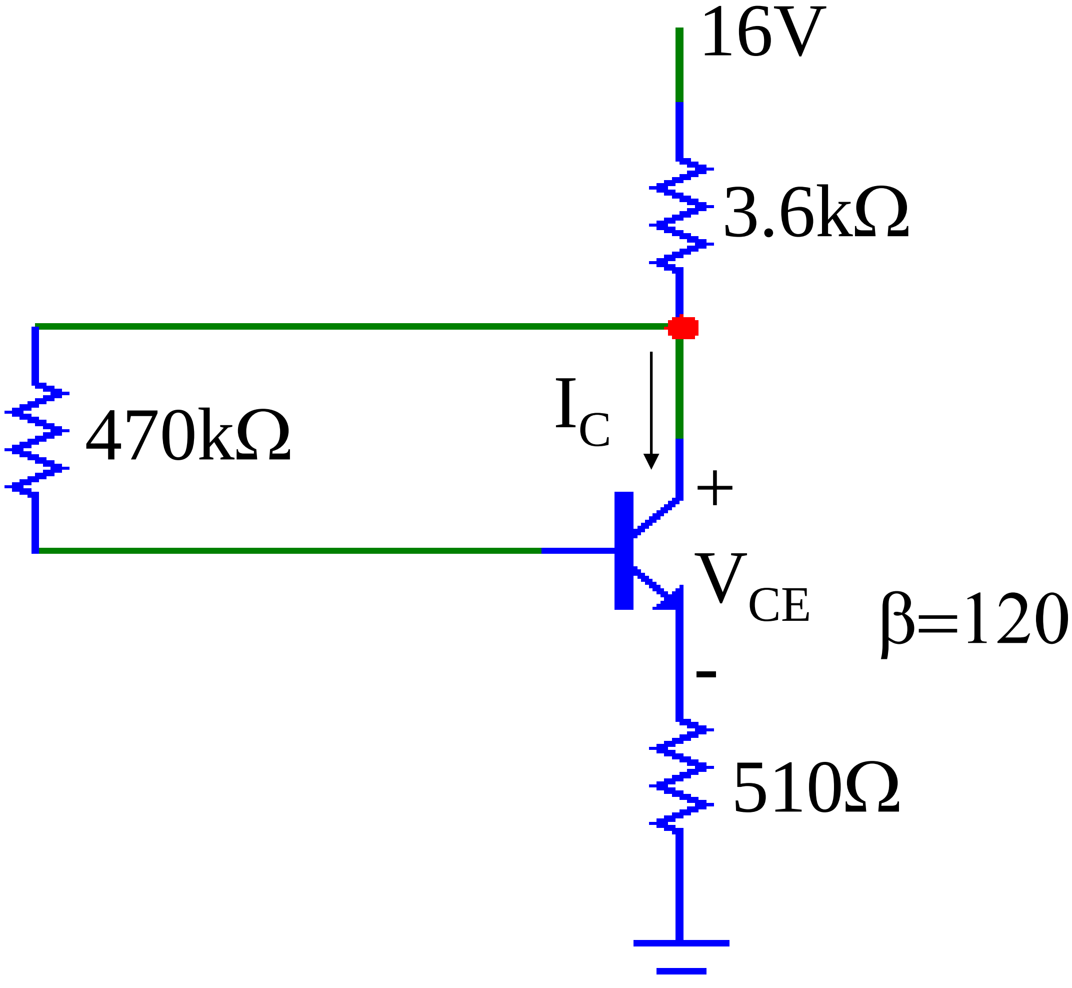


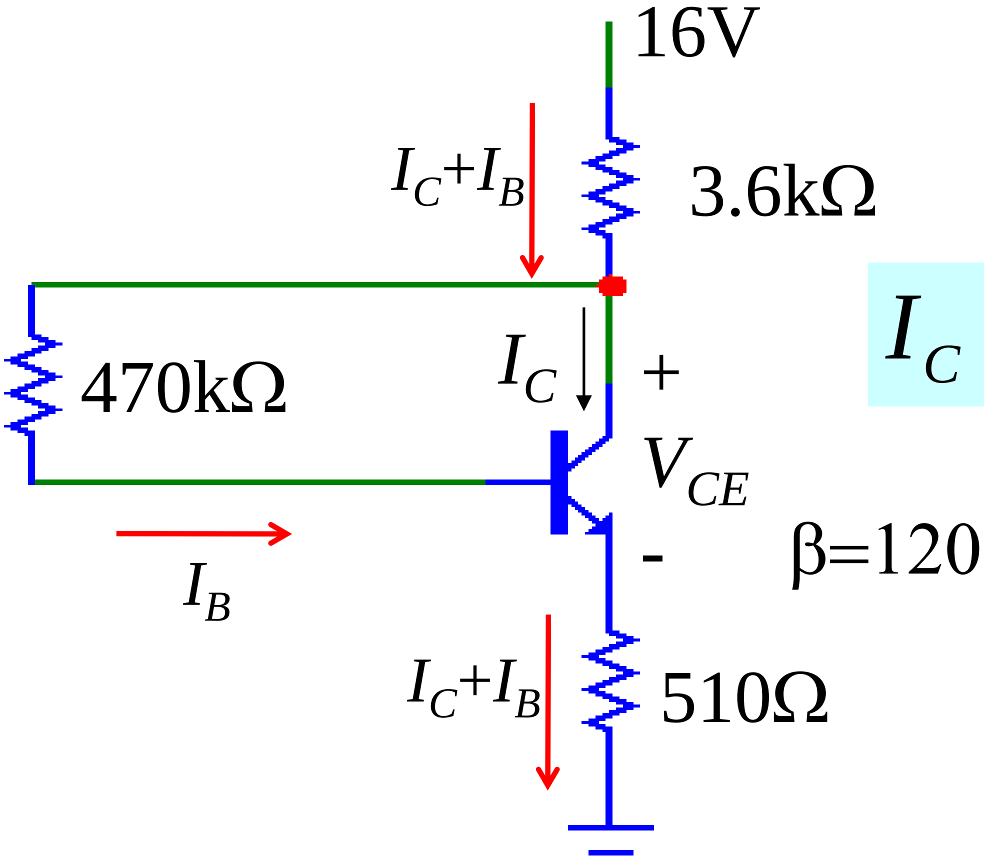
$$-V_{CC} + I_C R_C + V_{CE} + I_E R_E = 0$$

$$V_{CE} = 2.129V$$

Example-5

Find I_C and V_{CE}



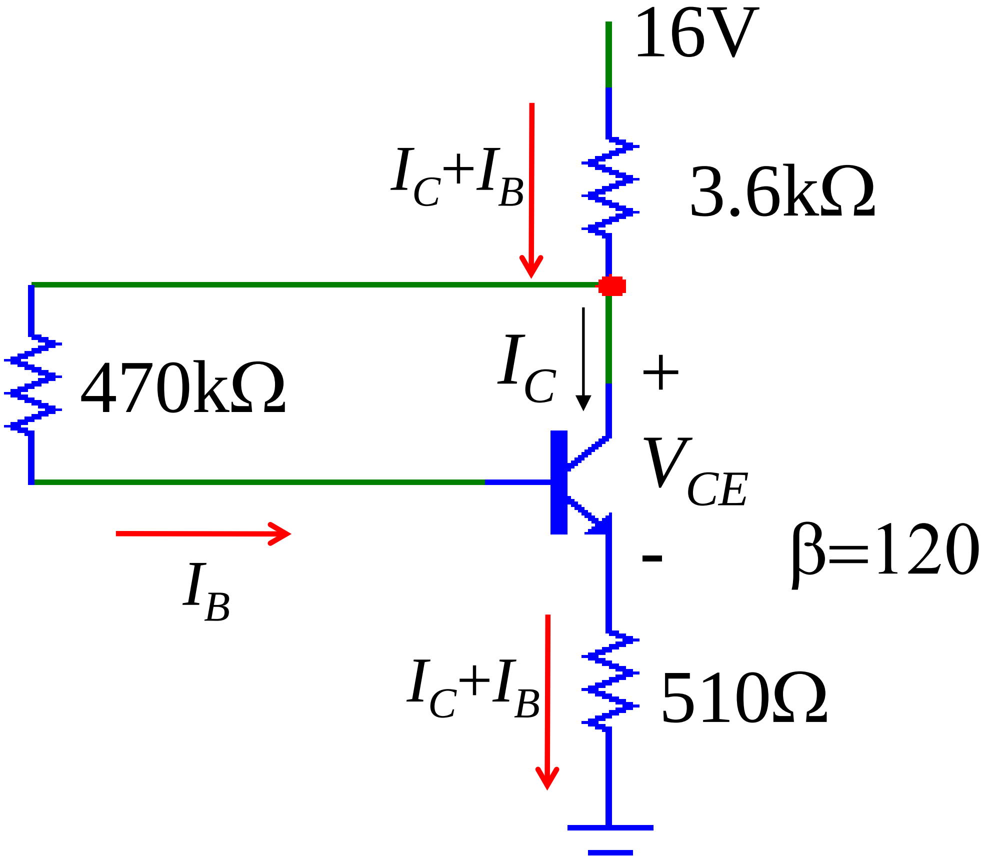


$$I_C + I_B = (\beta + 1)I_B = 121 I_B$$

$$-16 + (121 I_B)3.6k + I_B 470k + 0.7 + (121 I_B)510 = 0$$

$$I_B = \frac{16 - 0.7}{121 \times 3.6k + 470k + 121 \times 510} = 0.0158mA$$

$$I_C = \beta I_B = 120 \times 0.0158mA = 1.9mA$$



$$I_B = 0.0158mA$$

$$I_C = 1.9mA$$

$$I_B 470k + 0.7 - V_{CE} = 0$$

$$V_{CE} = 0.0158 \times 470 + 0.7 = 8.13V$$