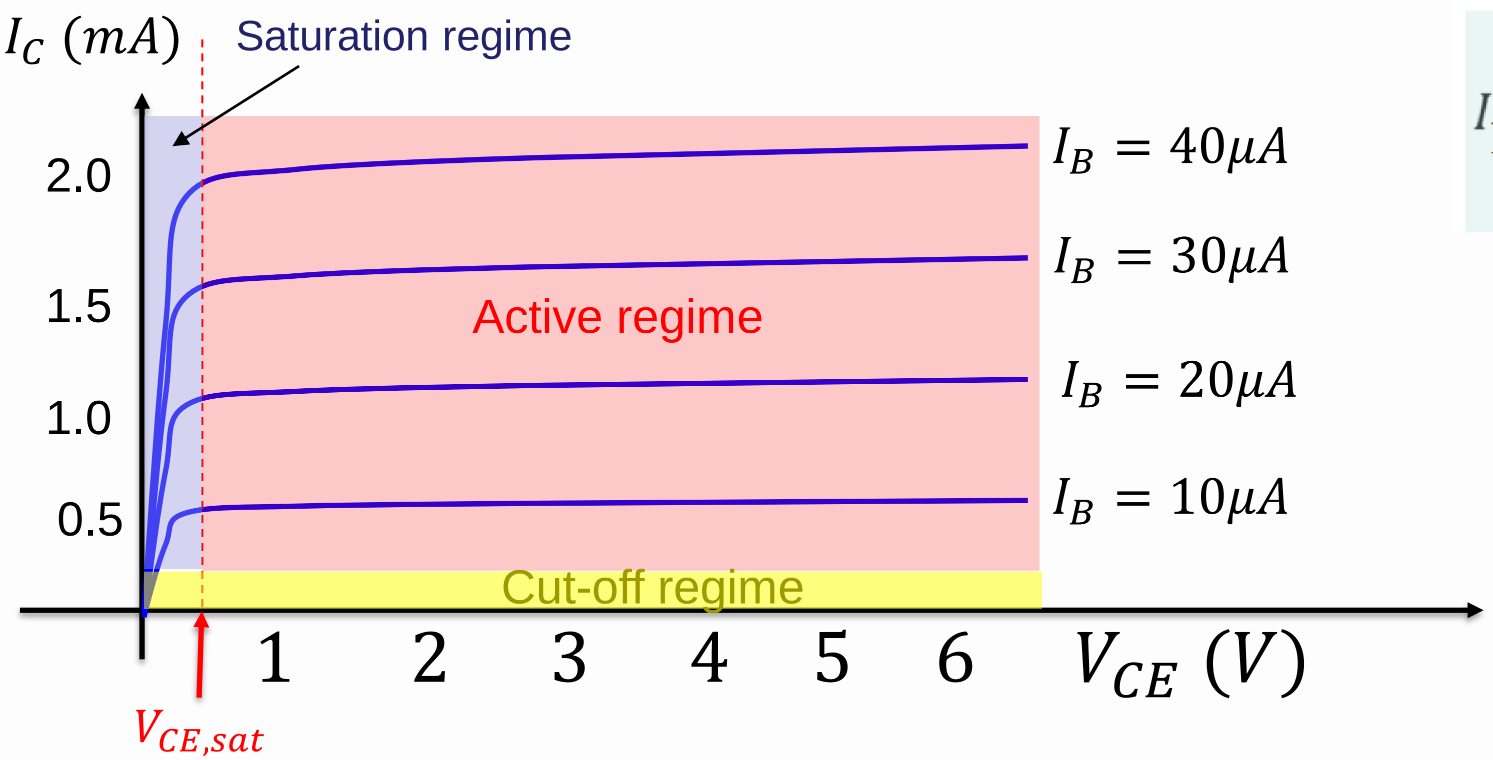
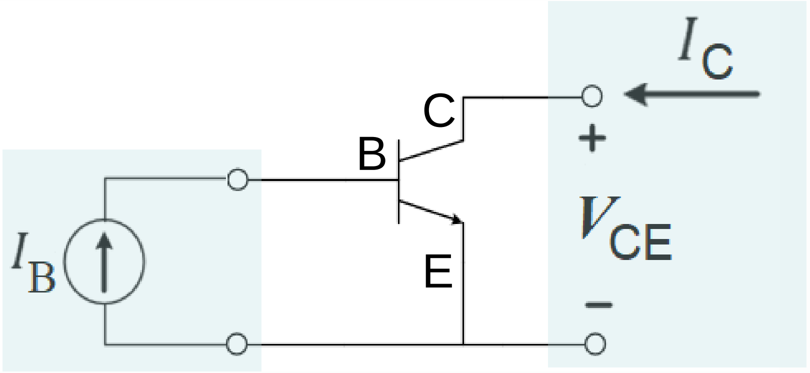
Lecture 20: BJT IV Characteristics

- Interpreting CE junction IV curves for transistor parameters
- Interpreting load line IV curves
- Analysis of IV curves for the (I,V) operating point
- Explore the saturation condition
- Solving transistor-regime problems

I-V curves of BJT





1. Cut-off regime

   When $V_{BE} < V_{on}$, thus $I_c \approx 0$

2. Active regime

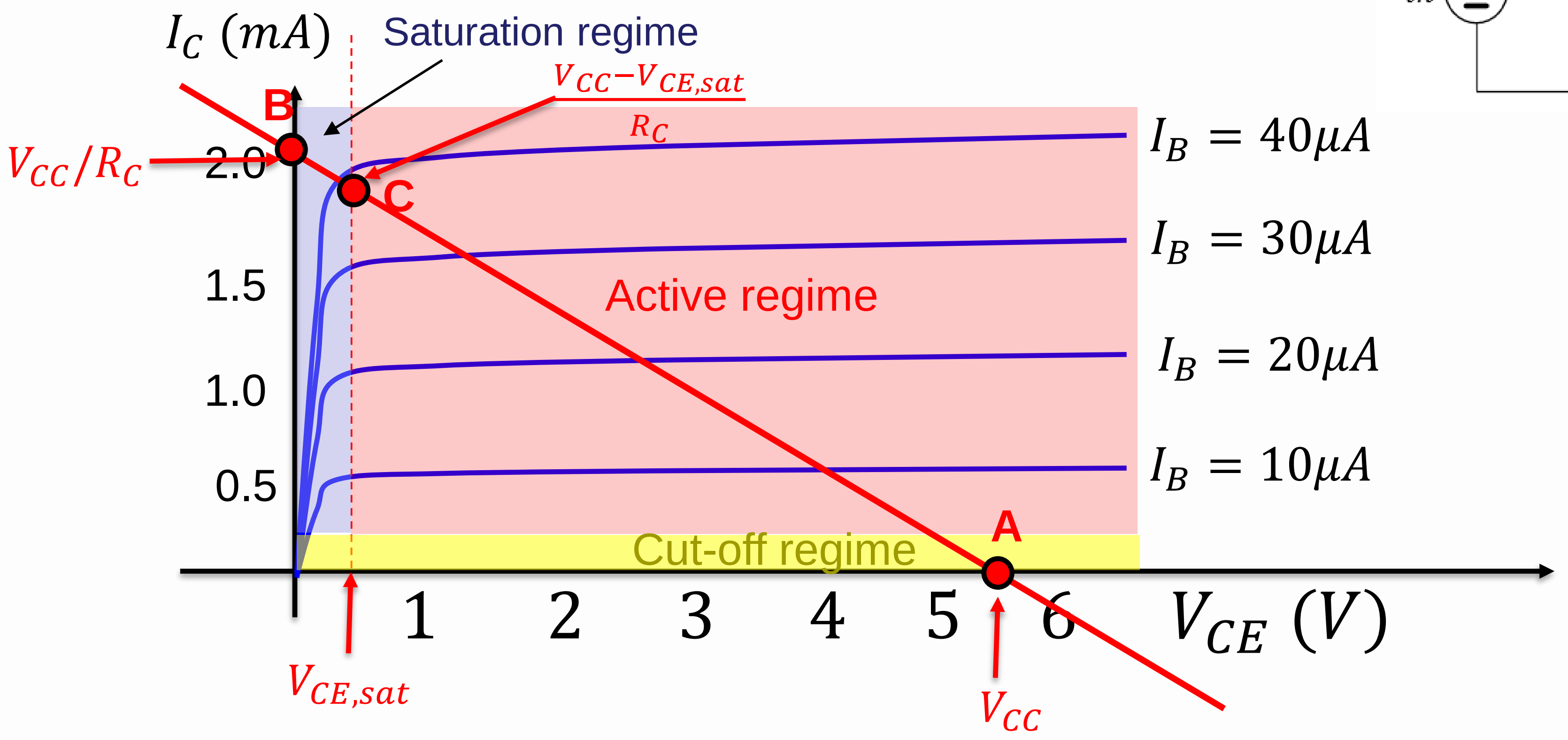
   When $V_{BE} \geq V_{on}$, thus $I_c = \beta I_B$

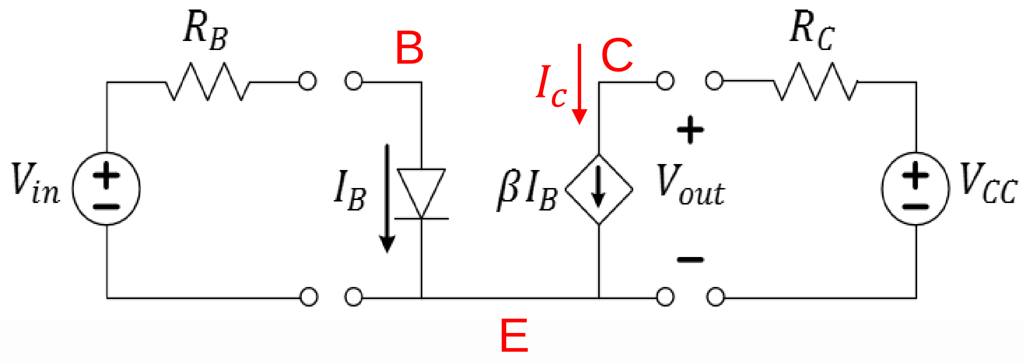
3. Saturation regime

   When $V_{BE} \geq V_{on}$, and $V_c < V_B$

   Thus $V_{CE} = V_{on,sat}$, typically 0.3 V

I-V curves of BJT & load line





IV formula for load

$$\boxed{I_c = \frac{V_{CC} - V_{CE}}{R_C}}$$

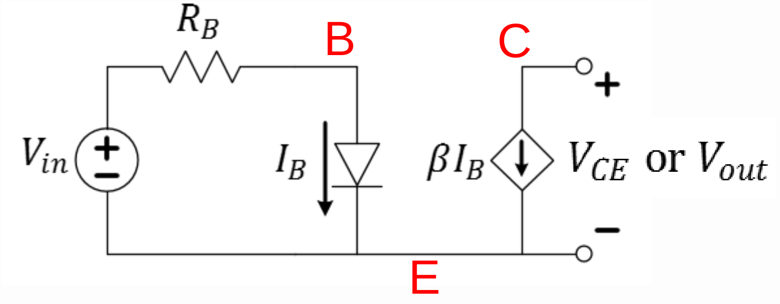
A = (V_{cc},0)

B = (0,V_{cc}/R_c)

C = ($V_{CE,sat}$,(V_{cc}-$V_{CE,sat}$)/R_c)

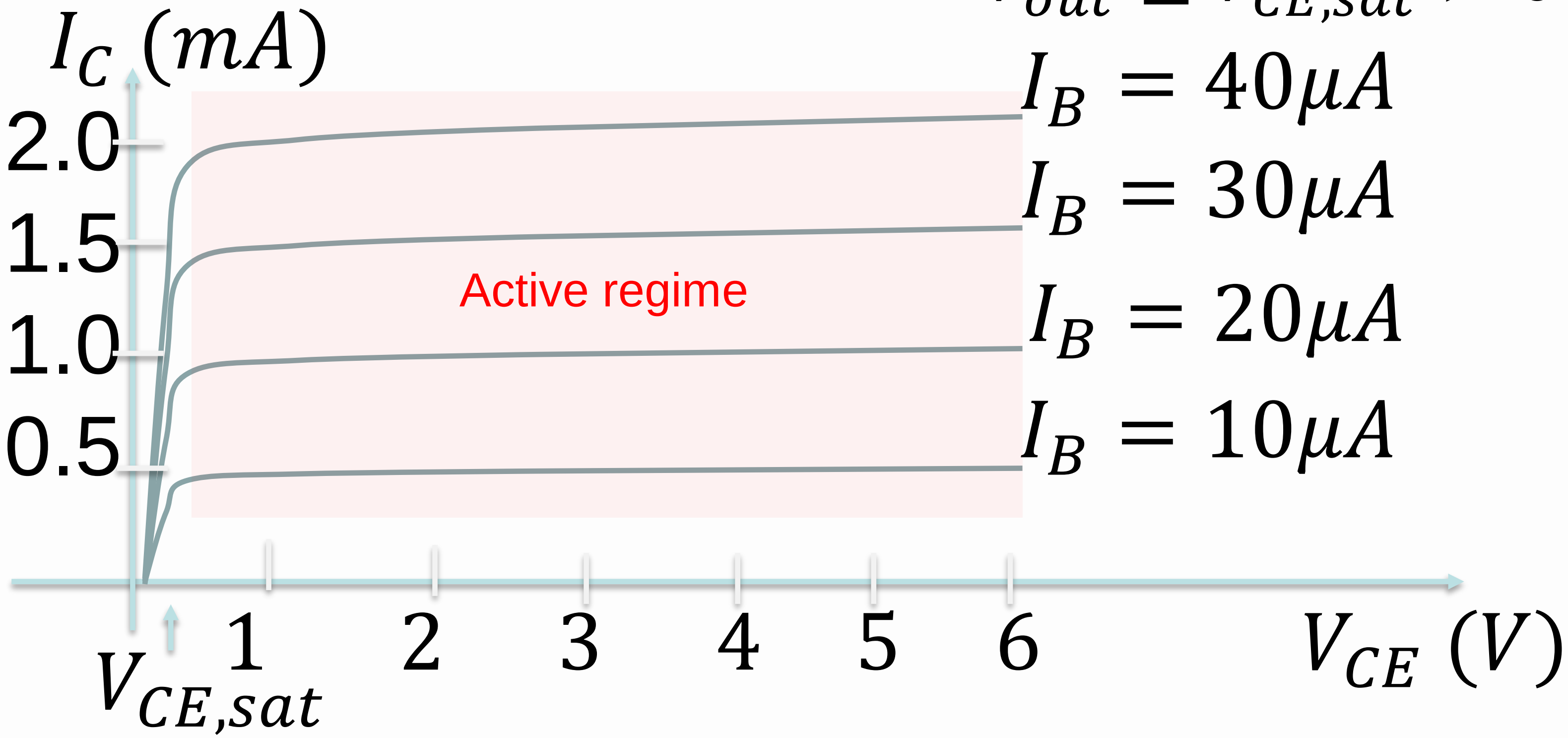
$$I_{c,sat} = \frac{V_{CC}-V_{CE,sat}}{R_C}$$

BJT IV curves of the CE junction



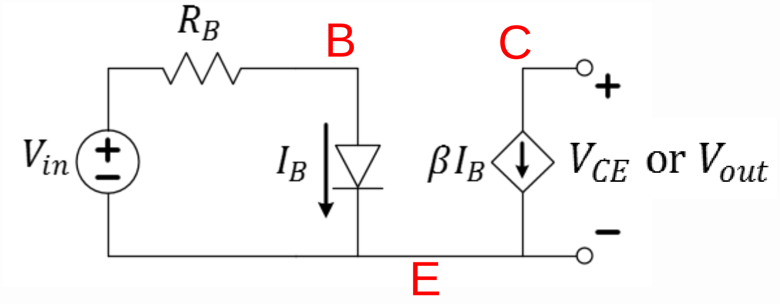
Constraints: In active regime

- $0 \leq \beta I_B \leq I_{C,sat}$
- $V_{out} \geq V_{CE,sat} > 0$



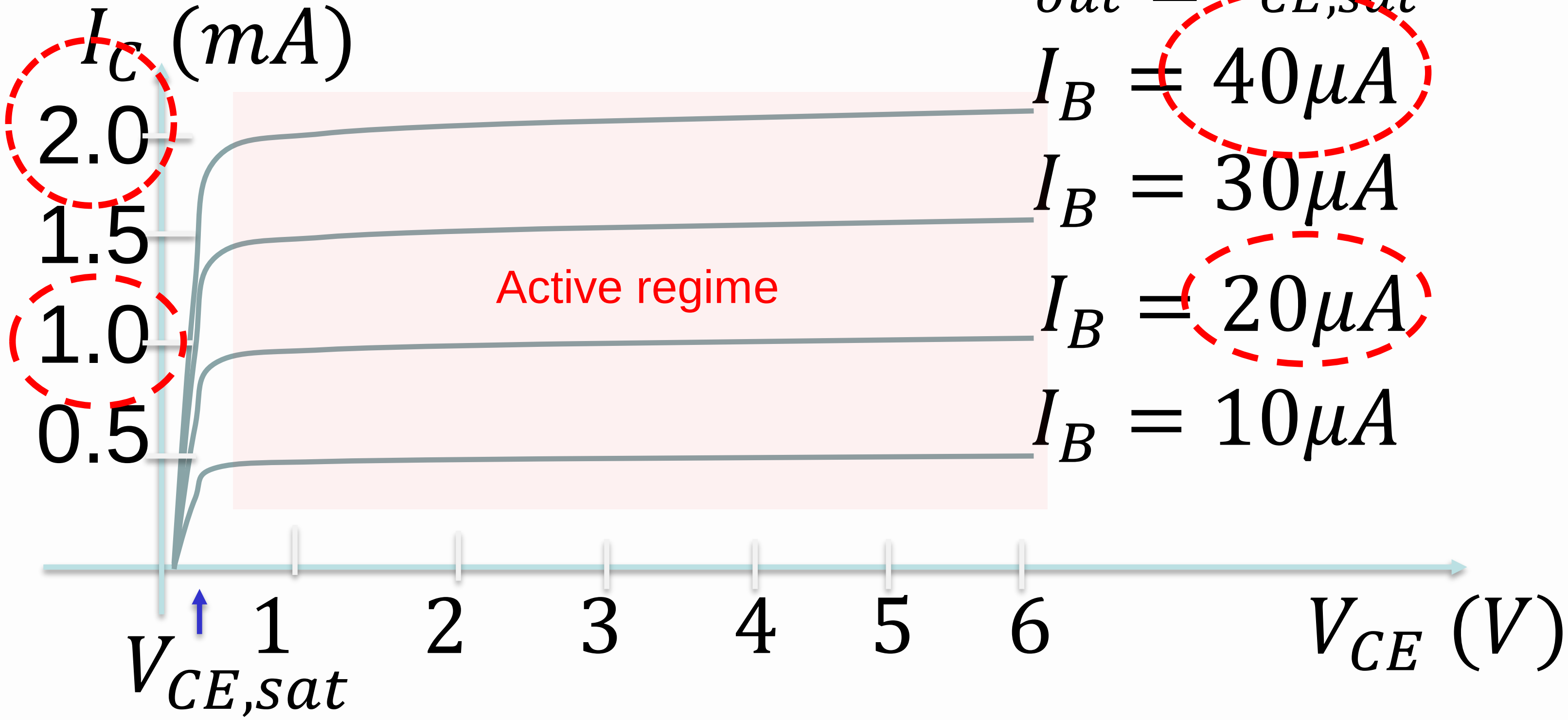
L20Q1: Use the IV plots above to estimate the value of β.

BJT IV curves of the CE junction



Constraints:

- $0 \leq \beta I_B \leq I_{C,sat}$
- $V_{out} \geq V_{CE,sat} > 0$

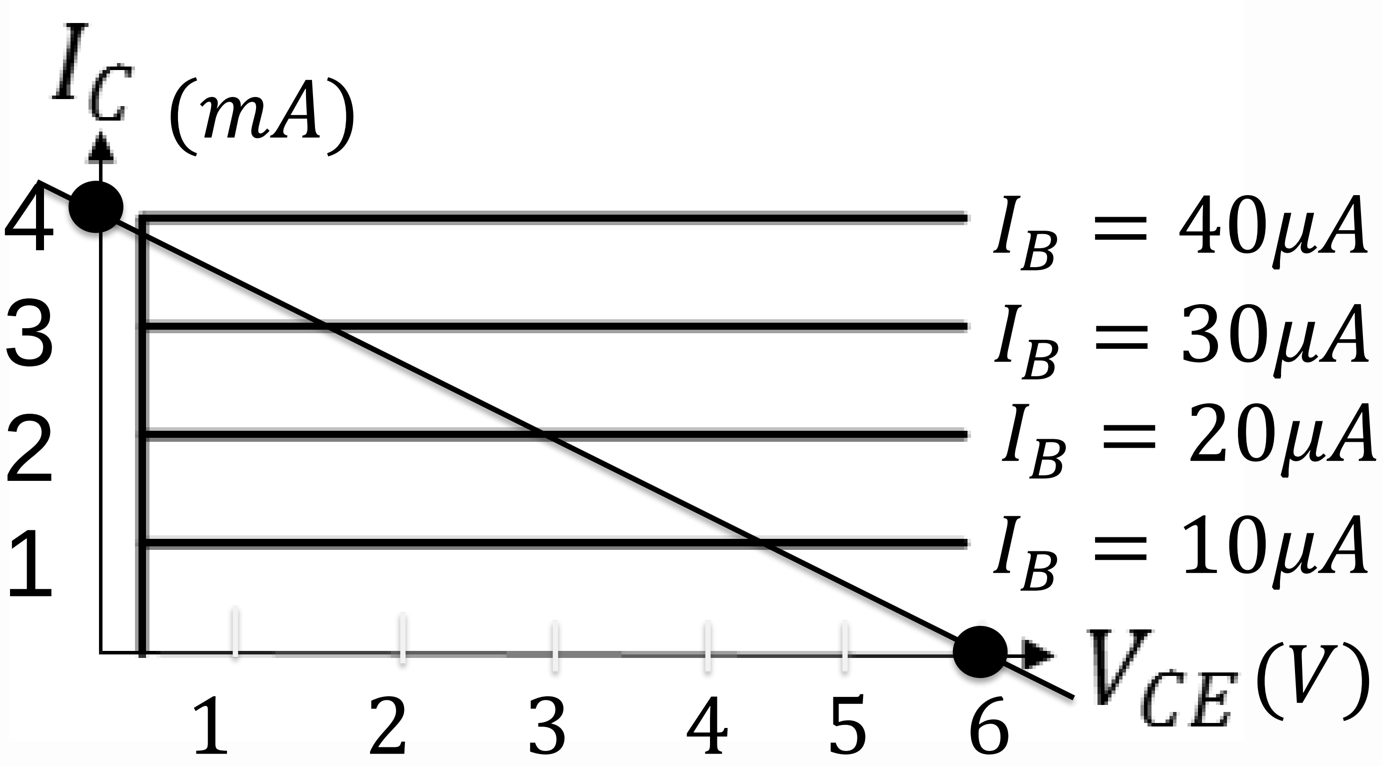


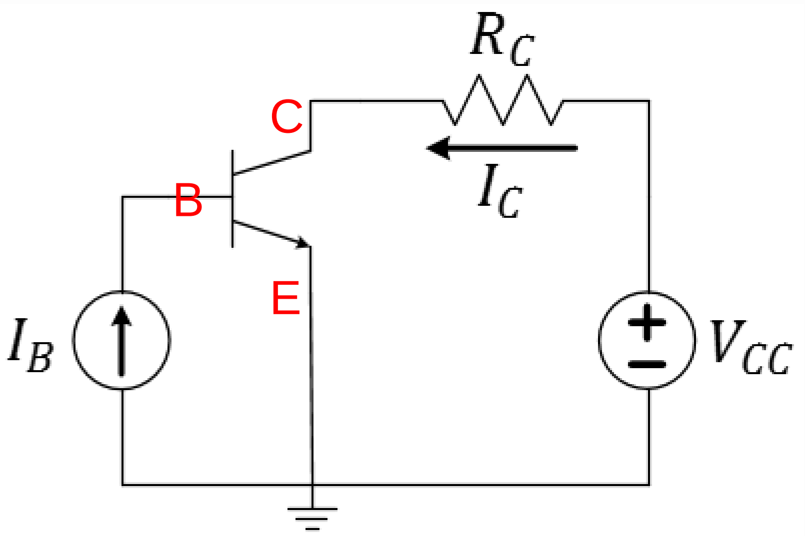
$$\beta = \frac{I_C}{I_B} = \frac{2m}{40\mu}$$
$$\beta = 50$$

$$\beta = \frac{I_C}{I_B} = \frac{1m}{20\mu}$$
$$\beta = 50$$

L20Q1: Use the IV plots above to estimate the value of β.

Extracting information from the IV curve(s)

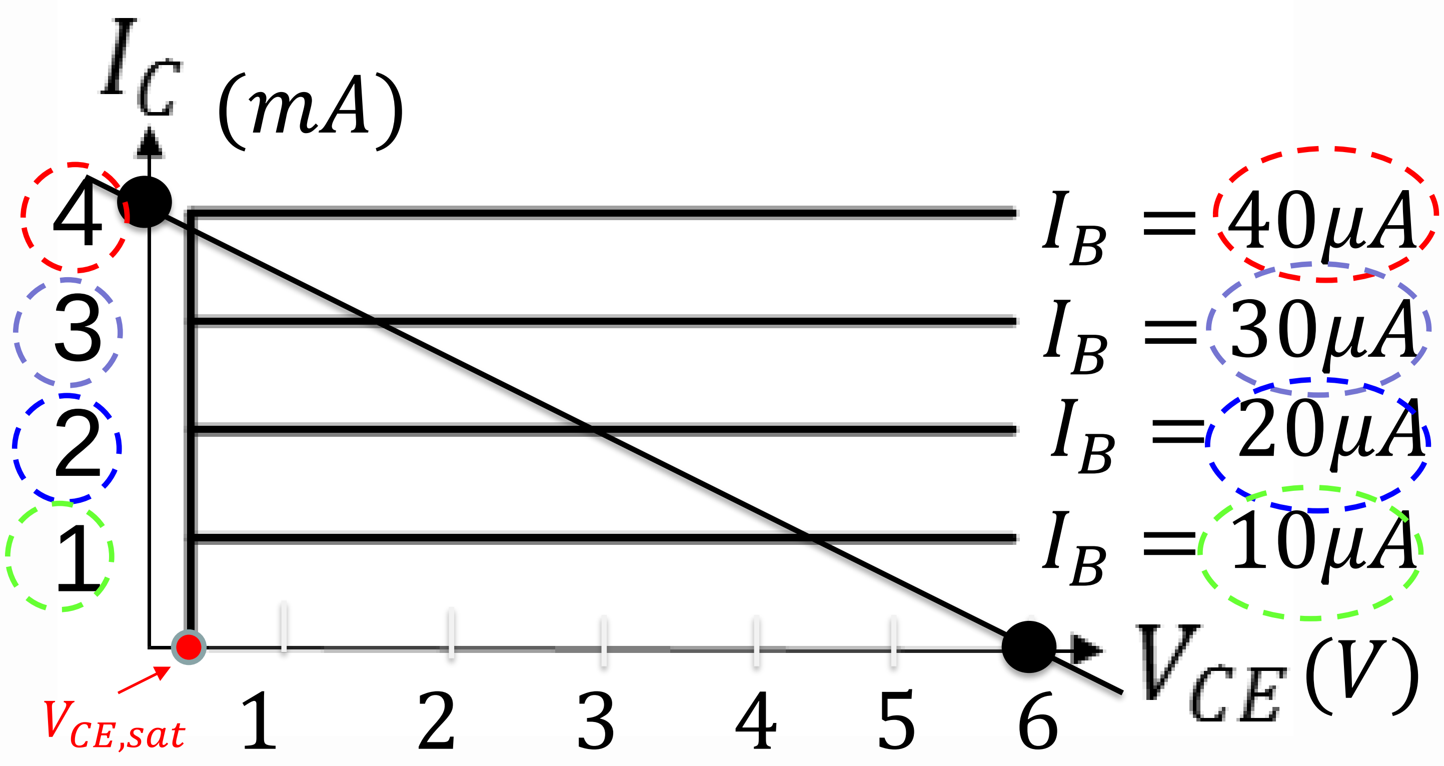


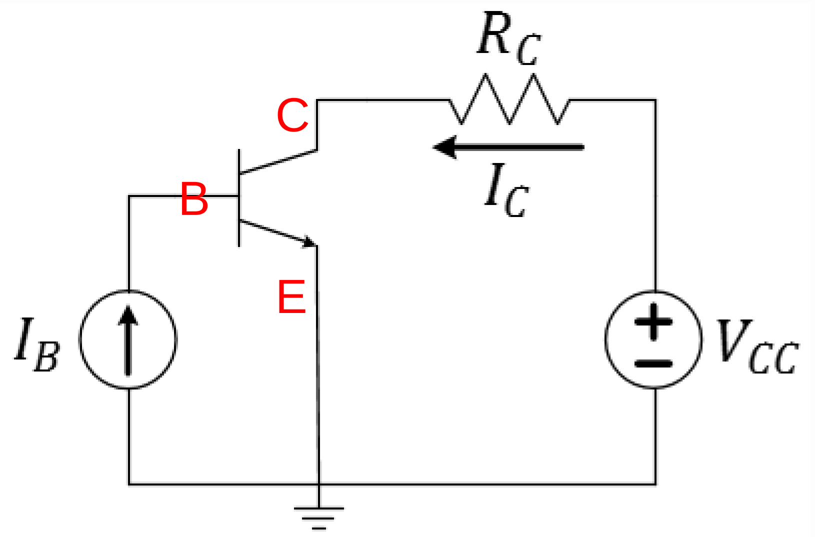


L20Q2: What is β and $V_{CE,sat}$?
L20Q3: What is V_{CC}?
L20Q4: What is R_C?
L20Q5: What is $I_{C,sat}$?
L20Q6: Which I_B results in saturation?

Q6:
A. $I_B = 40\mu A$
B. $I_B = 30\mu A$
C. $I_B = 20\mu A$
D. $I_B = 10\mu A$
E. $I_B = 0\mu A$

Extracting information from the IV curve(s)





$$\boxed{\beta = \frac{I_C}{I_B} = \frac{4m}{40\mu} = 100}$$

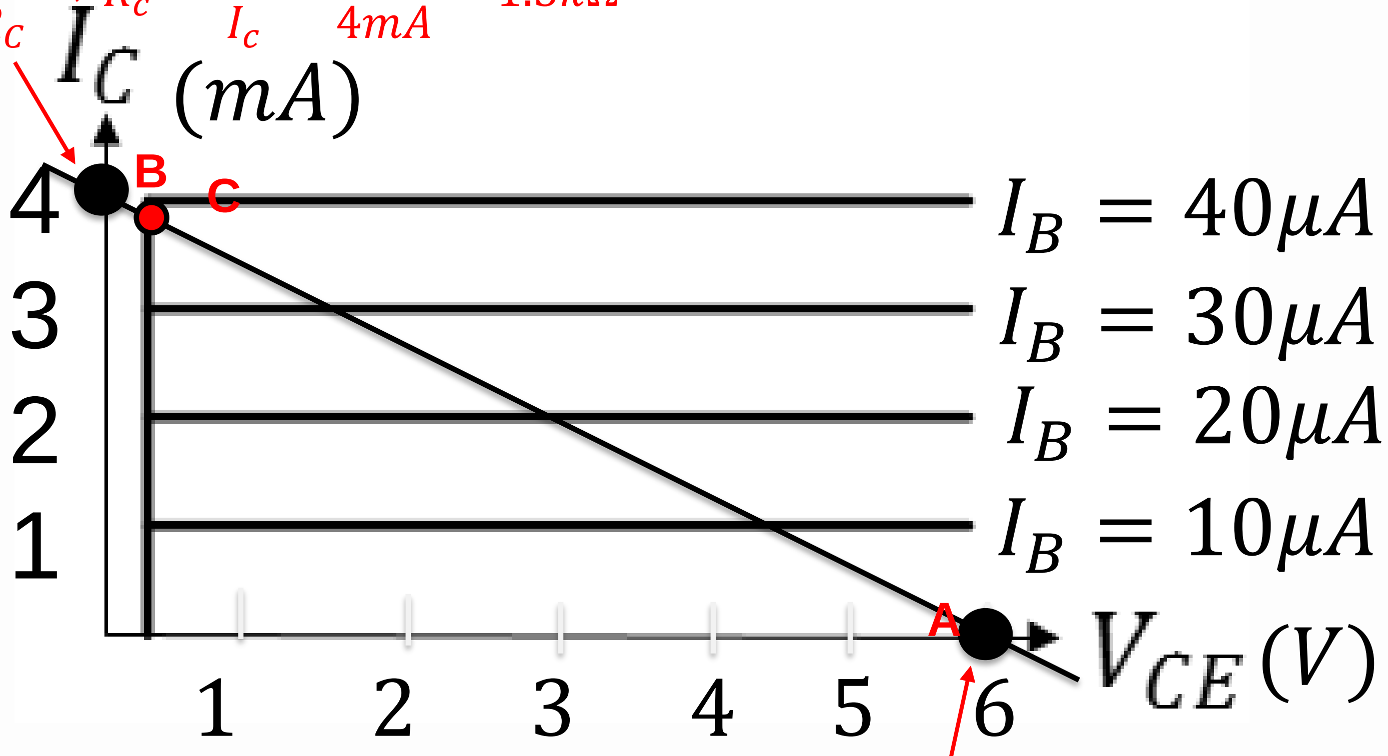
$$\boxed{V_{CE,sat} \approx 0.3V}$$

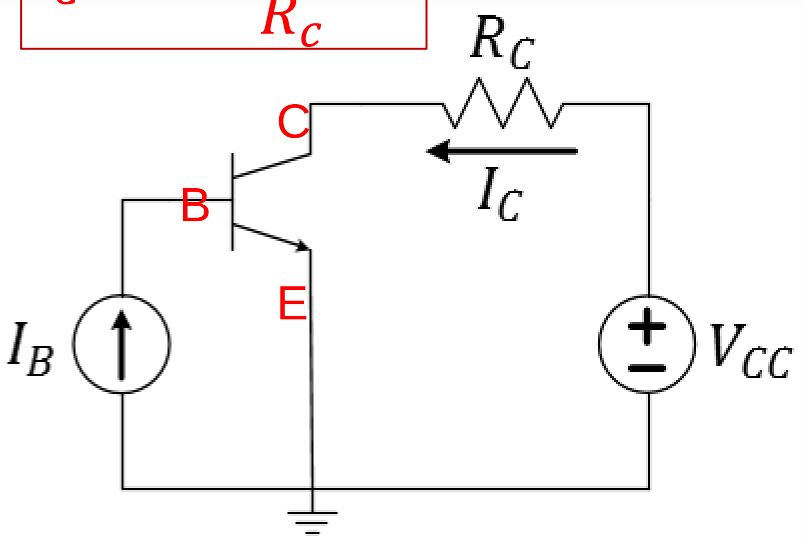
L20Q2: What is β and $V_{CE,sat}$?

Extracting information from the IV curve(s)

$I_C = \frac{V_{CC}}{R_C} \rightarrow R_c = \frac{V_{cc}}{I_c} = \frac{6V}{4mA} = 1.5k\Omega$

$$\boxed{I_C = \frac{V_{cc} - V_{CE}}{R_c}}$$





When $V_{CE} = V_{CC}, I_C = 0$

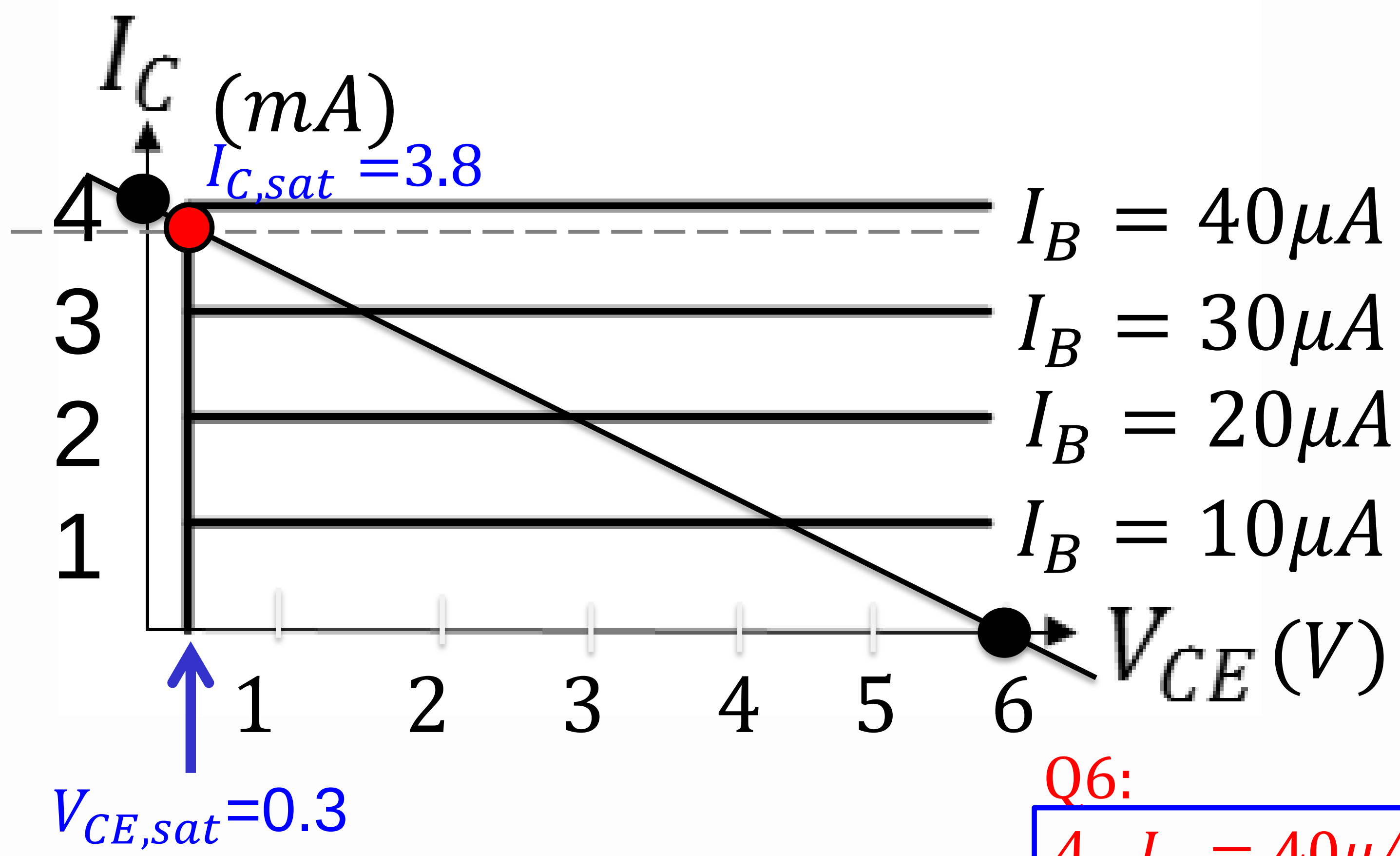
L20Q3: What is V_{CC}?
L20Q4: What is R_C?
L20Q5: What is $I_{C,sat}$?

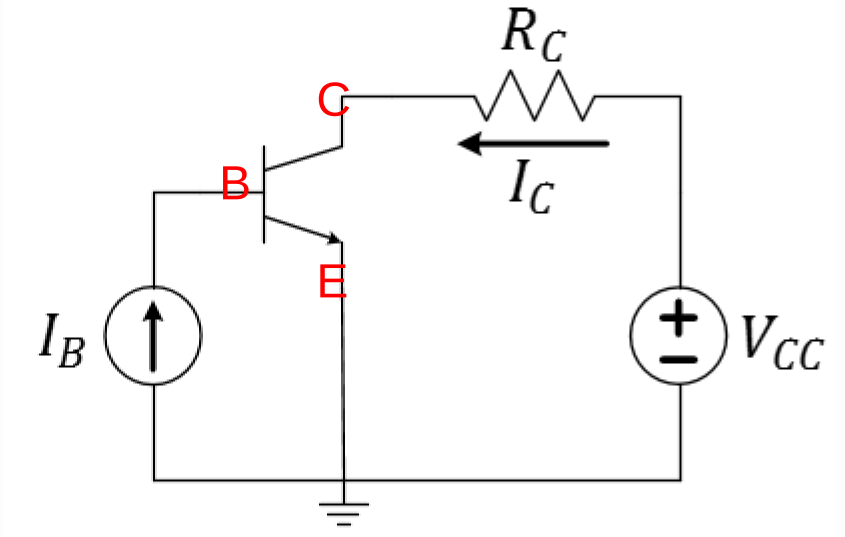
$$\boxed{V_{CC} = 6V}$$

$$\boxed{R_C = 1.5k\Omega}$$

$$\boxed{I_{C,sat} = \frac{V_{cc} - V_{CE,sat}}{R_c} = \frac{6 - 0.3}{1.5k} = 3.8mA}$$

Extracting information from the IV curve(s)





(3.8mA, 0.3V)

L20Q6: Which I_B results in saturation?

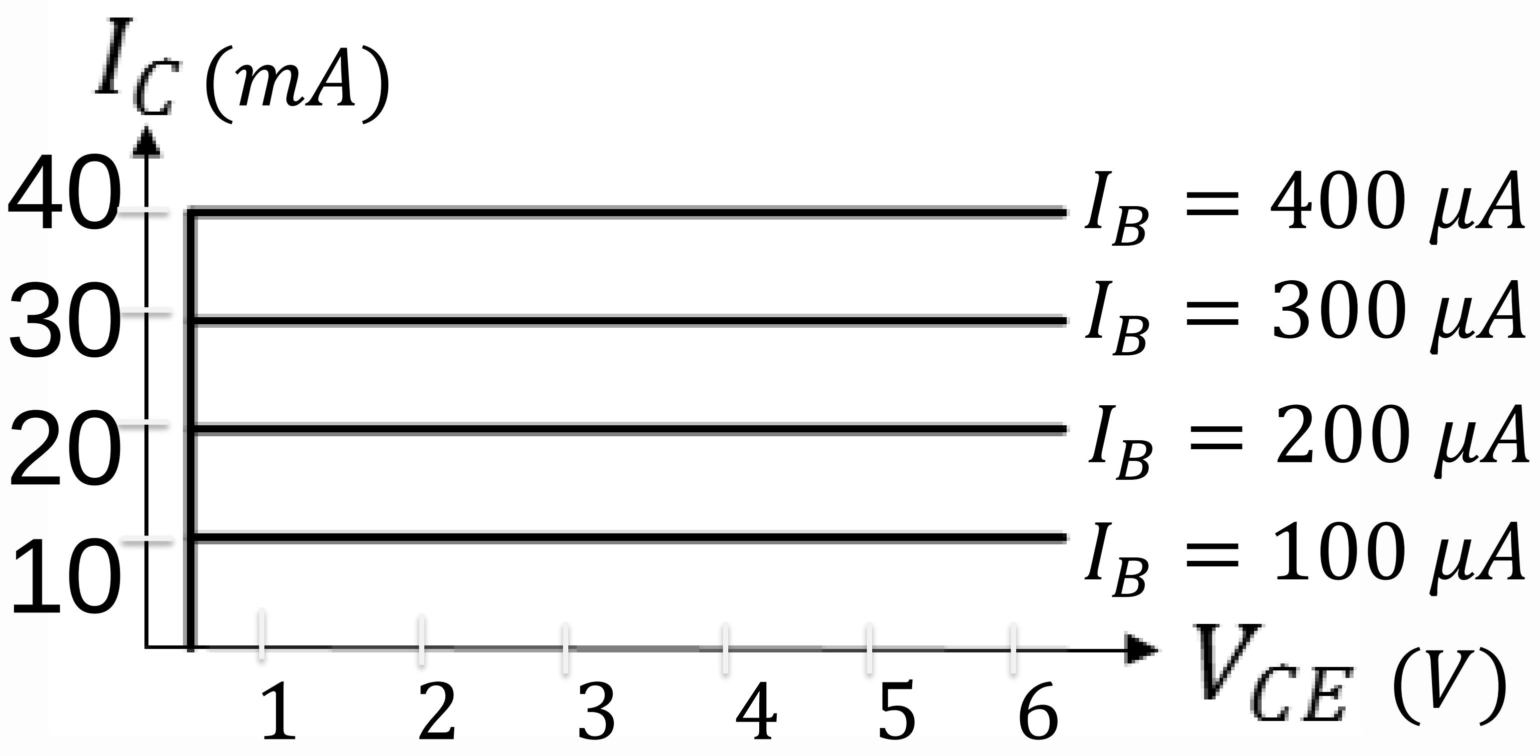
Q6:

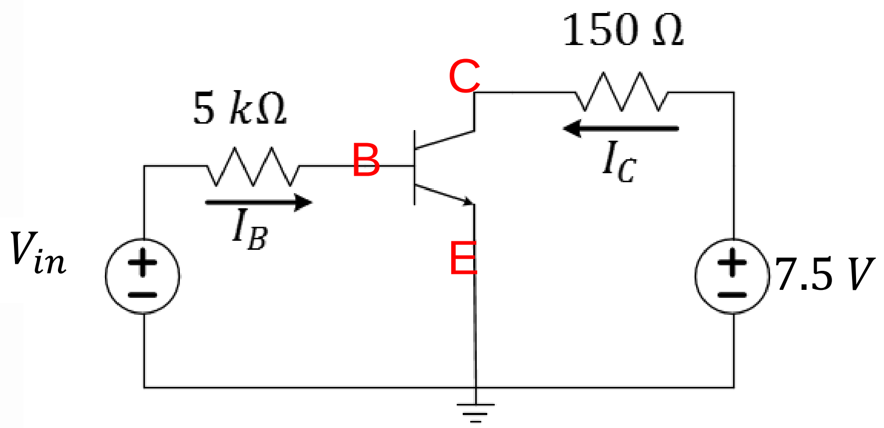
A. $\boxed{I_B = 40\mu A}$
B. $I_B = 30\mu A$
C. $I_B = 20\mu A$
D. $I_B = 10\mu A$
E. $I_B = 0\mu A$

$$I_{B,sat} \approx \frac{I_{C,sat}}{\beta} = \frac{3.8mA}{100}$$
$$= 38\mu A$$

BJT Exercise

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





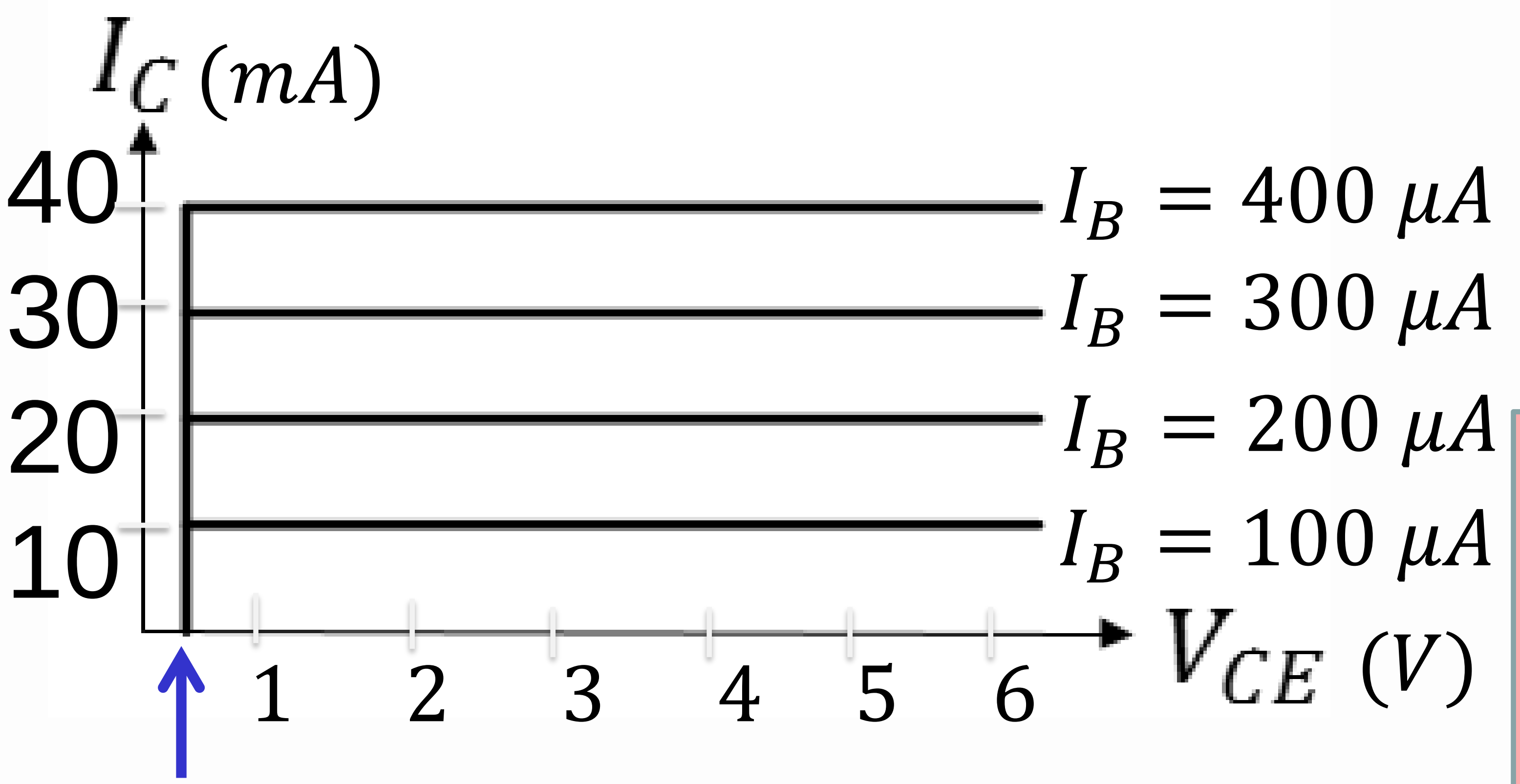
L20Q7: Estimate the operating point (I_C, V_{CE}) when $V_{in} = 1.7\ V$.

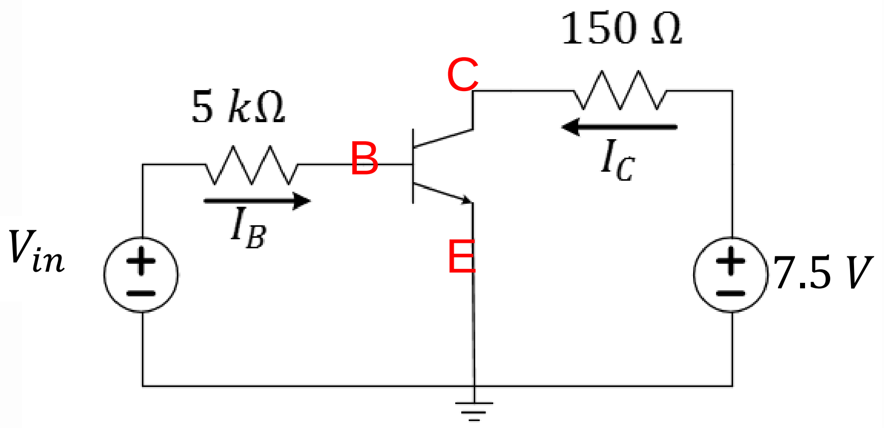
L20Q8: What value of V_{in} would drive the transistor to the edge of saturation?

Method 1--Analytical

BJT Exercise

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





$V_{CE,sat}$=0.3

L20Q7: Estimate the operating point (I_C, V_{CE}) when $V_{in} = 1.7\ V$.

Operating point (I_C, V_{CE}) = (20mA, 4.5V)

$V_{in} > V_{BE,on}$, active or saturation

$$\beta = \frac{I_C}{I_B} = \frac{40mA}{400\mu A} = 100$$

$$I_B = \frac{V_{in} - V_{BE,on}}{5k\Omega} = \frac{1.7V - 0.7V}{5k\Omega} = 200\mu A$$

$$I_C = \beta I_B = 20mA$$

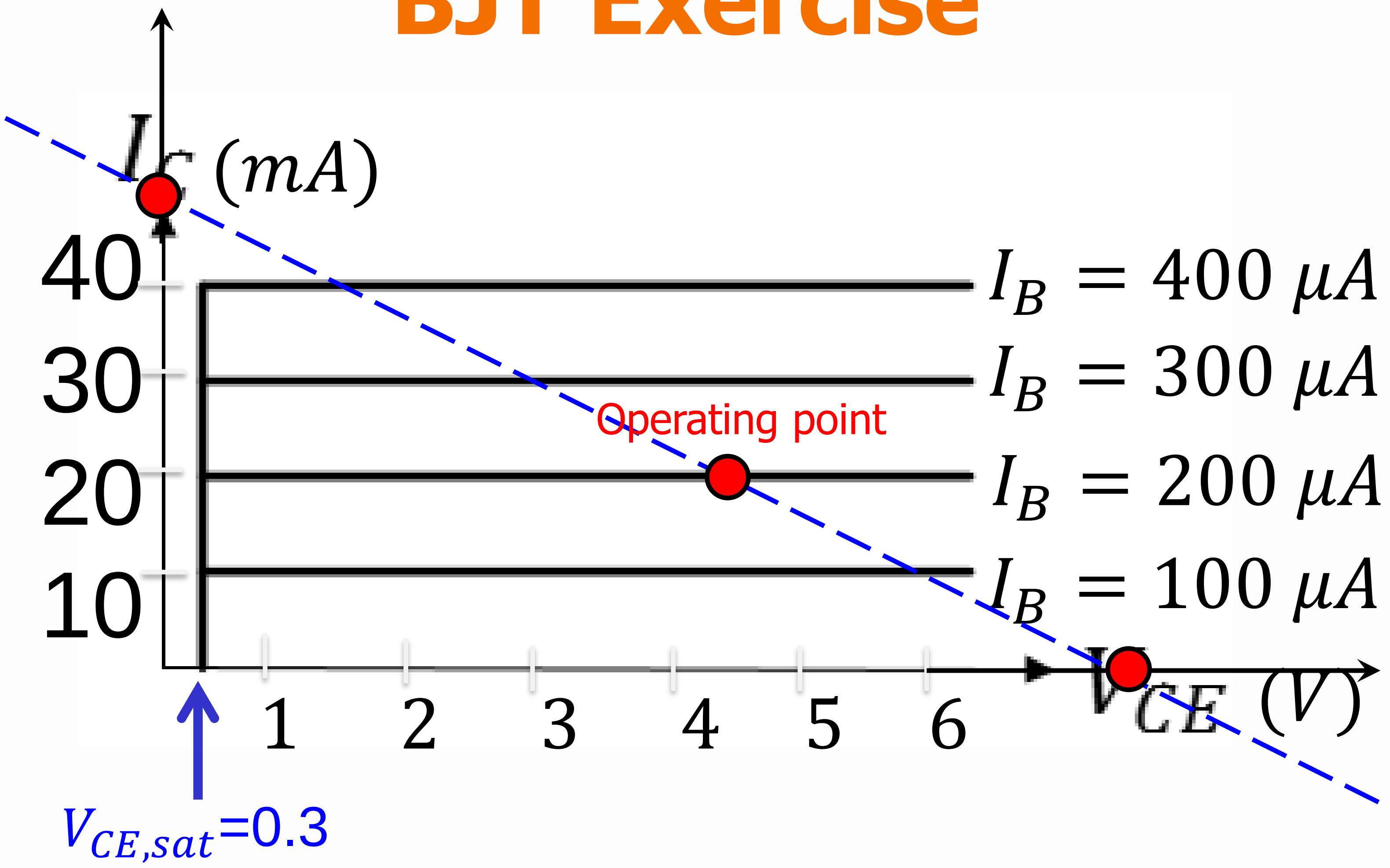
$$V_{CE} = 7.5V - 150\Omega \times I_c = 4.5V$$

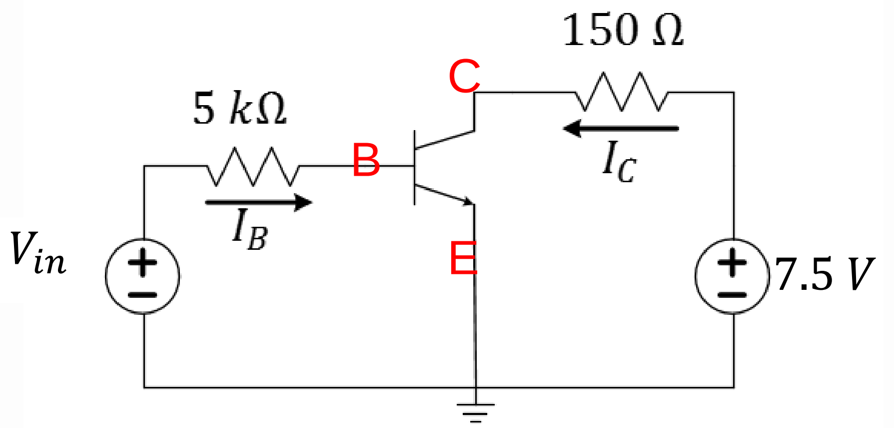
$V_{CE} > V_{CE,sat}$, active regime

Method 2--Graphic

BJT Exercise

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





$$I_B = \frac{V_{in} - V_{BE,on}}{5k\Omega} = \frac{1.7V - 0.7V}{5k\Omega} = 200\mu A$$

$$I_C = \frac{7.5 - V_{CE}}{150}$$

$$V_{CE} = 7.5 - 150 \times I_C$$

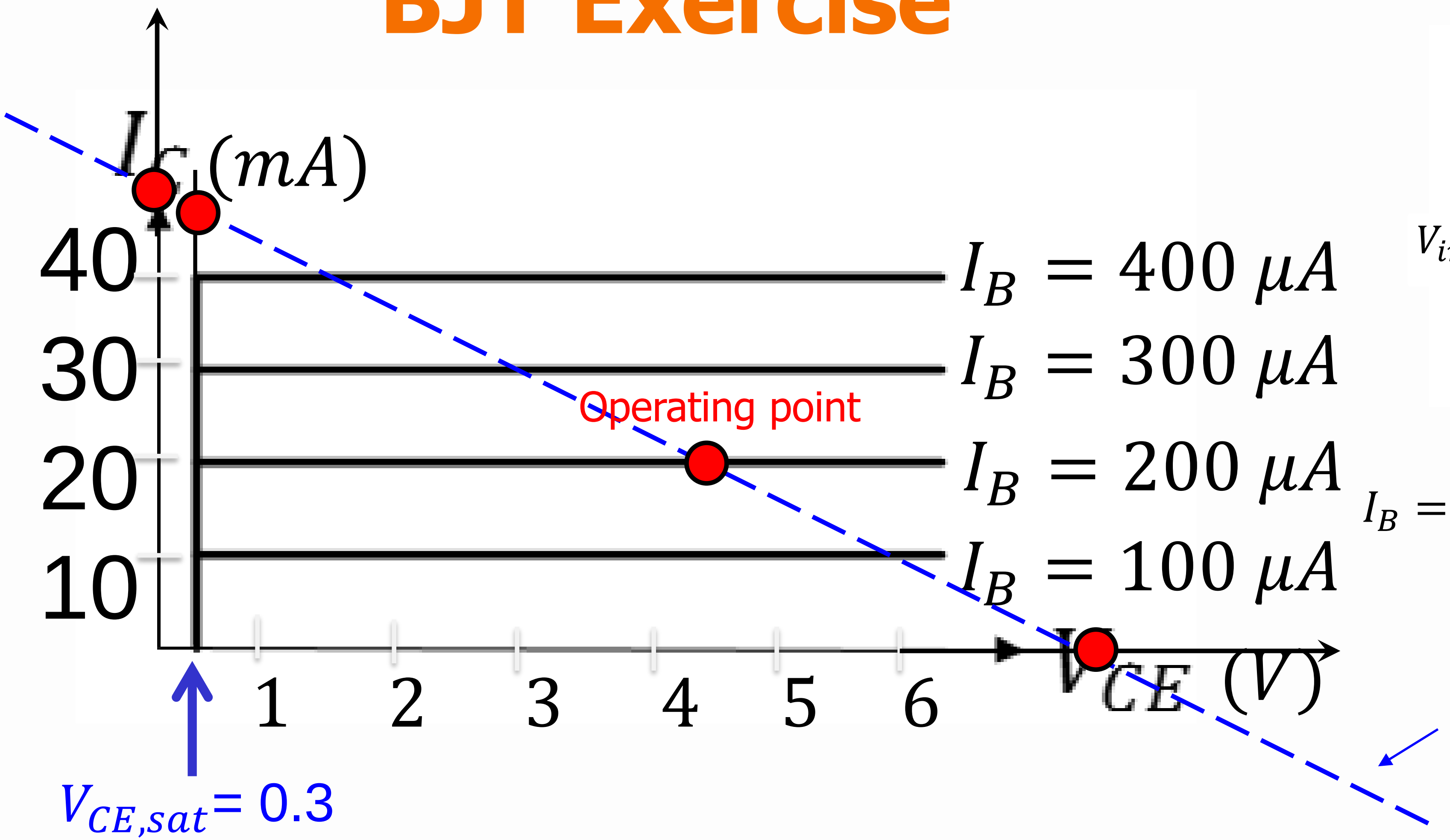
L20Q7: Estimate the operating point (I_C, V_{CE}) when $V_{in} = 1.7\ V$.

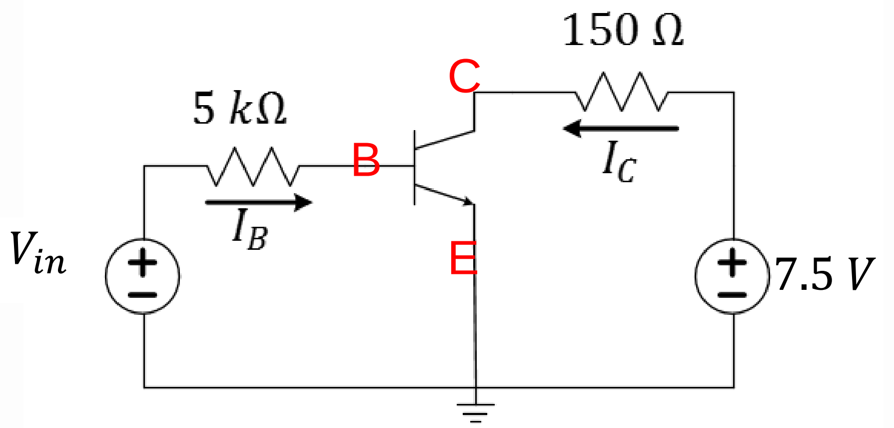
Operating point (I_C, V_{CE}) = (20mA, 4.5V)

Method 2--Graphic

BJT Exercise

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





$$I_B = \frac{V_{in} - V_{BE,on}}{5k\Omega} = \frac{1.7V - 0.7V}{5k\Omega} = 200\mu A$$

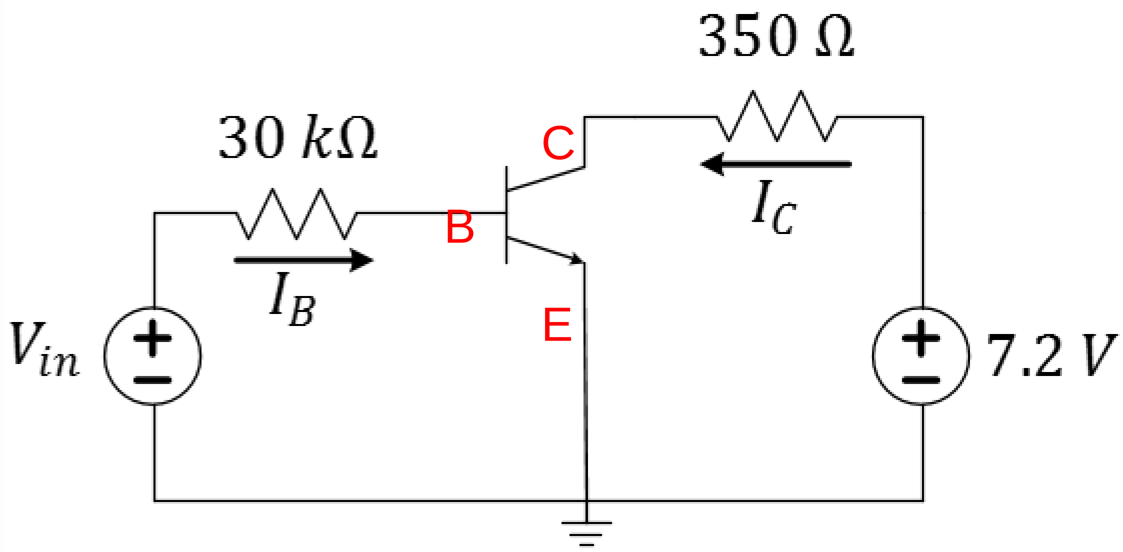
$$I_C = \frac{7.5 - V_{CE}}{150}$$

$V_{CE,sat} = 0.3$

L20Q8: What value of V_{in} would drive the transistor to the edge of saturation?

$$I_{C,sat} = (7.5 - 0.3)/150 = 48mA \quad V_{in} = \frac{48mA}{\beta} \times 5k\Omega + 0.7 = 3.1V$$

BJT Exercise



BJT datasheet parameters:

- $\beta = 100$
- $V_{BE,on} = 0.7\ V$
- $V_{CE,sat} = 0.2\ V$

L20Q9: What value of V_{in} would drive the transistor to the edge of saturation?

L20Q10: How does your answer change if $30\ k\Omega$ were replaced with $60\ k\Omega$?

L20Q11: How does your answer change if, instead, $350\ \Omega \rightarrow 700\ \Omega$?

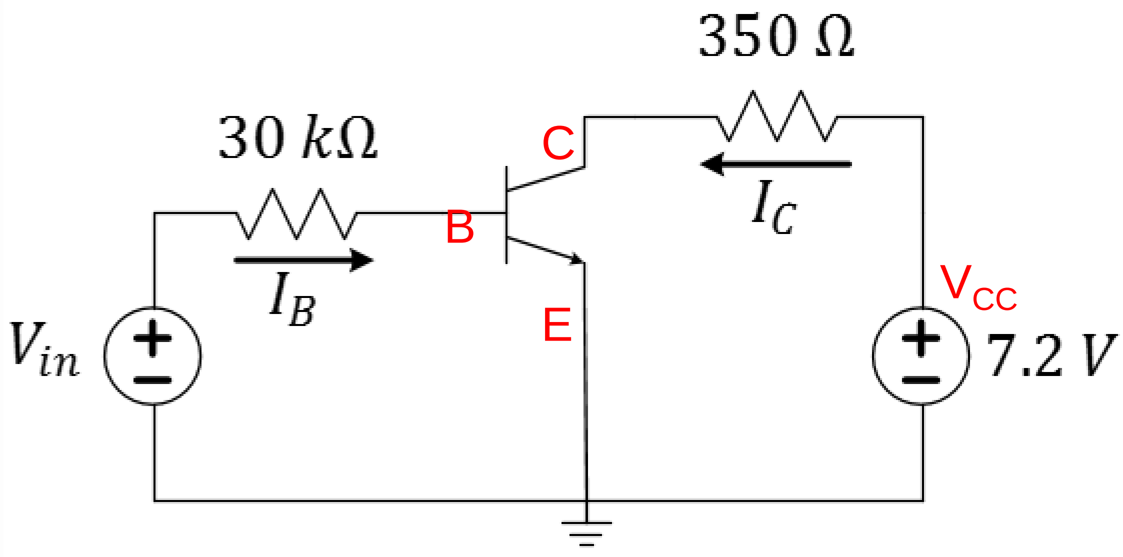
Q10:

A. $V_{in@sat}$ goes up
B. $V_{in@sat}$ goes down
C. $V_{in@sat}$ stays the same

Q11:

A. $V_{in@sat}$ goes up
B. $V_{in@sat}$ goes down
C. $V_{in@sat}$ stays the same

L20Q9: What value of V_{in} would drive the transistor to the edge of saturation?



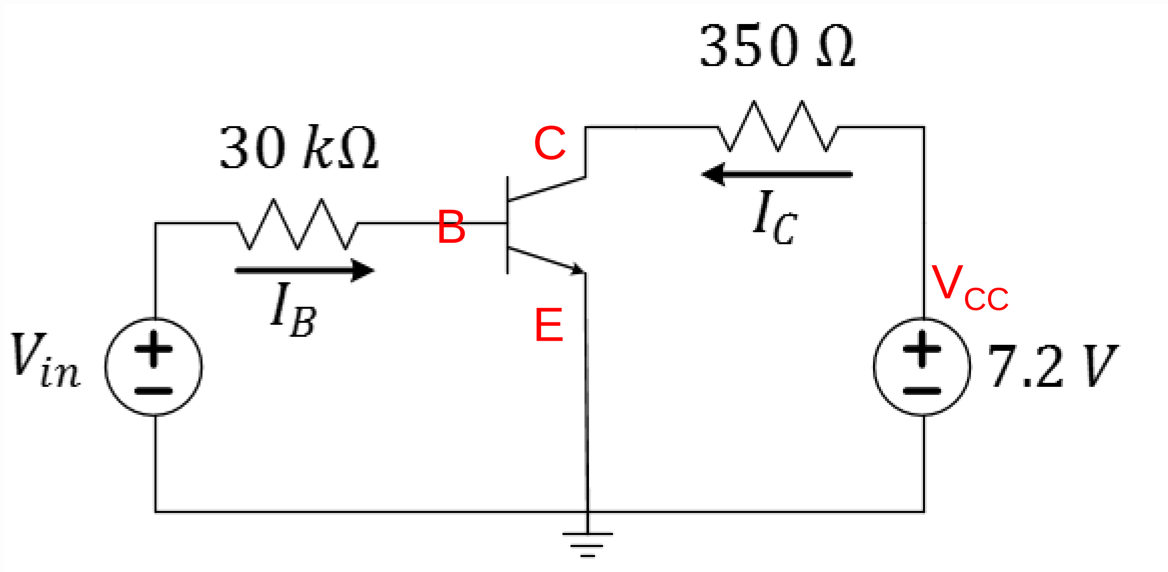
BJT datasheet parameters:

- $\beta = 100$
- $V_{BE,on} = 0.7\ V$
- $V_{CE,sat} = 0.2\ V$

$$I_{C,sat} = (V_{CC} - V_{CE,sat})/350 = (7.2 - 0.2)/350 = 20mA$$

$$I_{B,sat} = I_{C,sat}/\beta = 200\mu A$$

$$V_{in} = 30k \times I_{B,sat} + V_{BE,on} = 30k \times 200\mu + 0.7 = 6.7V$$



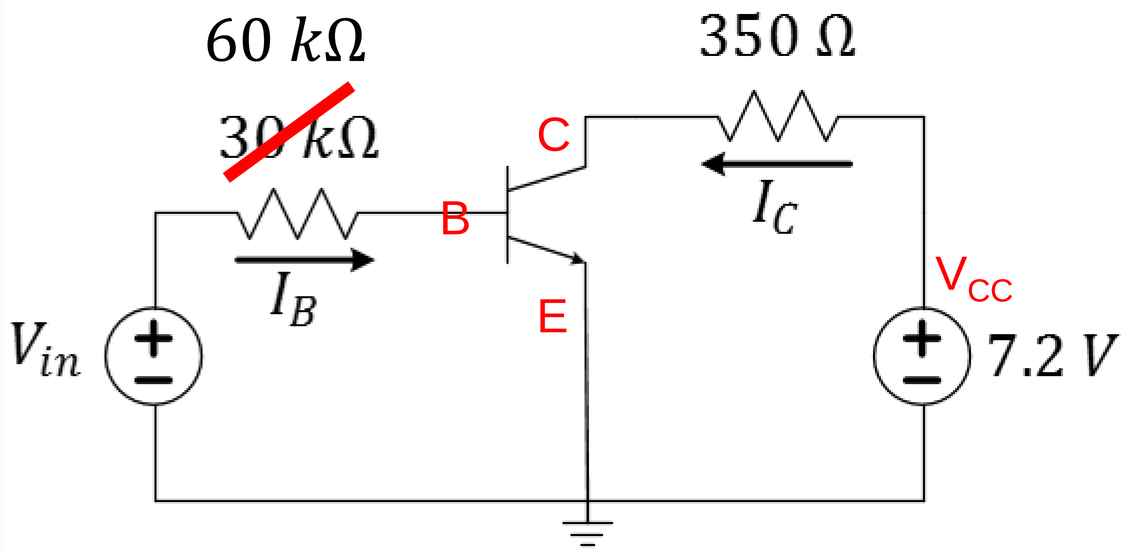
BJT datasheet parameters:

- $\beta = 100$
- $V_{BE,on} = 0.7\ V$
- $V_{CE,sat} = 0.2\ V$

L20Q10: How does your answer change if $30\ k\Omega$ were replaced with $60\ k\Omega$?

Q10:

A. $V_{in@sat}$ goes up
B. $V_{in@sat}$ goes down
C. $V_{in@sat}$ stays the same



BJT datasheet parameters:

- $\beta = 100$
- $V_{BE,on} = 0.7\ V$
- $V_{CE,sat} = 0.2\ V$

L20Q10: How does your answer change if $30\ k\Omega$ were replaced with $60\ k\Omega$?

($V_{in} - V_{BE,sat}$ has to be double)

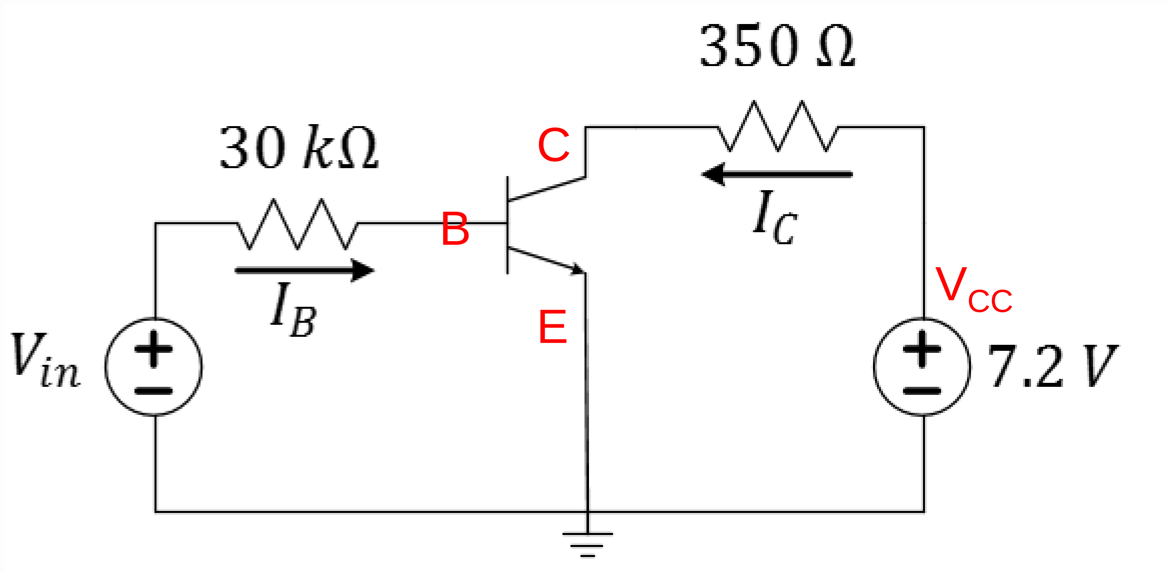
Q10:

A. $V_{in@sat}$ goes up
B. $V_{in@sat}$ goes down
C. $V_{in@sat}$ stays the same

$I_{C,sat} = (7.2 - 0.2)/350 = 20mA$

$I_{B,sat} = I_{C,sat}/\beta = 200\mu A$

$V_{in} = 60k \times 200\mu + 0.7 = 12.7V$



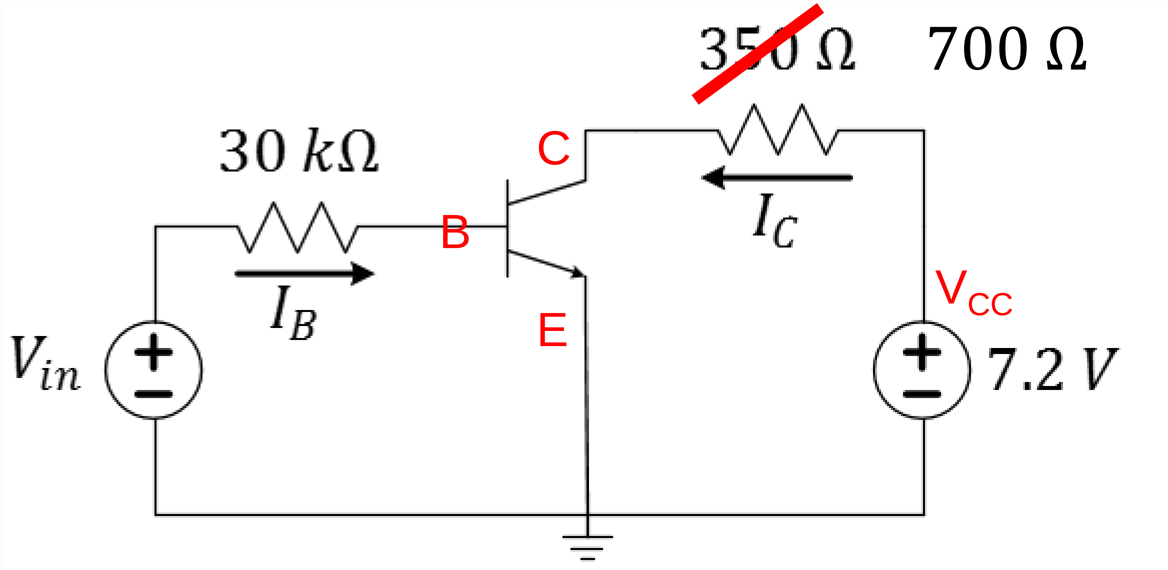
BJT datasheet parameters:

- $\beta = 100$
- $V_{BE,on} = 0.7\ V$
- $V_{CE,sat} = 0.2\ V$

L20Q11: How does your answer change if, instead, $350\ \Omega \rightarrow 700\ \Omega$?

Q11:

A. $V_{in@sat}$ goes up
B. $V_{in@sat}$ goes down
C. $V_{in@sat}$ stays the same



BJT datasheet parameters:

- $\beta = 100$
- $V_{BE,on} = 0.7\ V$
- $V_{CE,sat} = 0.2\ V$

L20Q11: How does your answer change if, instead, $350\ \Omega \rightarrow 700\ \Omega$?

($V_{in} - V_{BE,sat}$ has to be half)

$$I_{C,sat} = (7.2 - 0.2)/700 = 10mA$$

$$I_{B,sat} = I_{C,sat}/\beta = 100\mu A$$

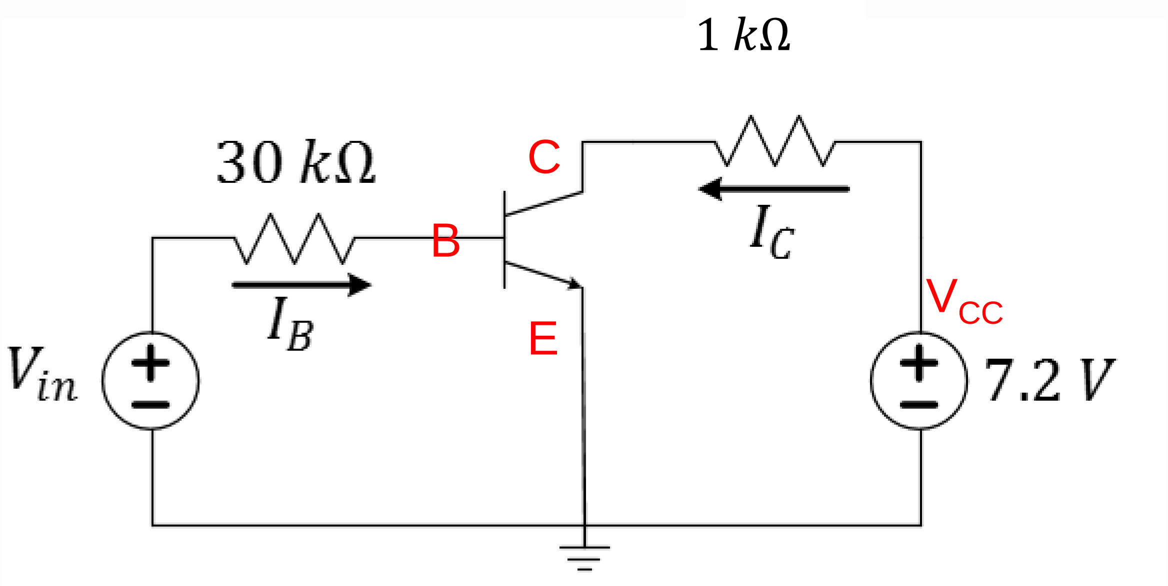
$$V_{in} = 30k \times 100\mu + 0.7 = 3.7V$$

Q11:

A. $V_{in@sat}$ goes up
B. $V_{in@sat}$ goes down
C. $V_{in@sat}$ stays the same

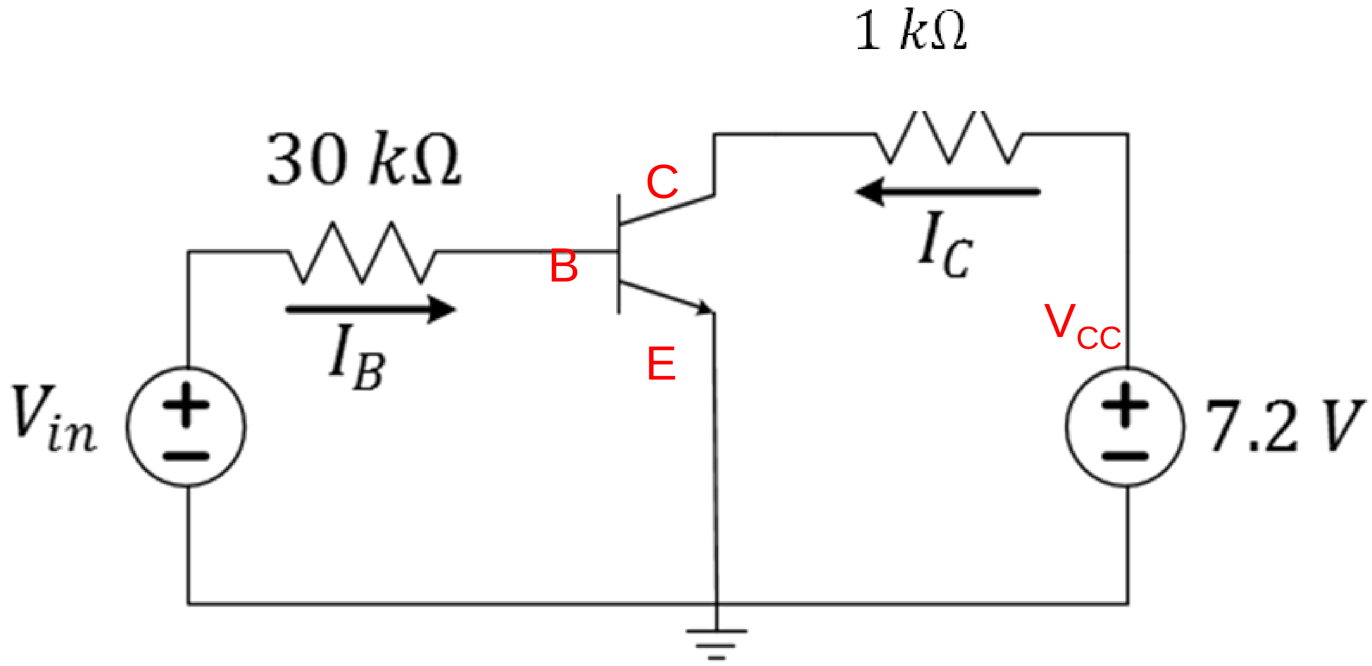
BJT circuit analysis: working back to V_{in}

BJT Datasheet: $\beta = 100, V_{BEon} = 0.7V, V_{CE,sat} = 0.2V$



L20Q12: Find V_{in} such that $V_{CE} = 3\ V$

L20Q12: Find V_{in} such that $V_{CE} = 3\ V$



BJT Datasheet:

- $\beta = 100$,
- $V_{BEon} = 0.7\ V$
- $V_{CE,sat} = 0.2\ V$

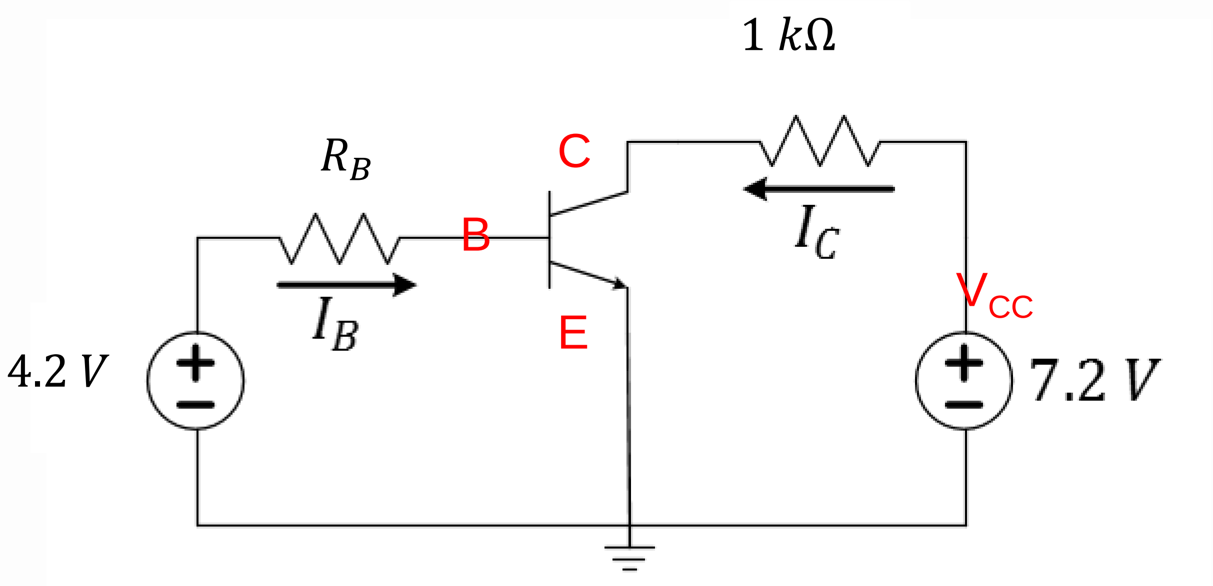
$V_{CE} > V_{BE,on}$, working in active regime

$$I_C = (7.2 - 3)/1k = 4.2mA$$

$$I_B = I_C/\beta = 42\mu A$$

$$V_{in} = 30k \times 42\mu + 0.7 = 1.96V$$

BJT circuit analysis

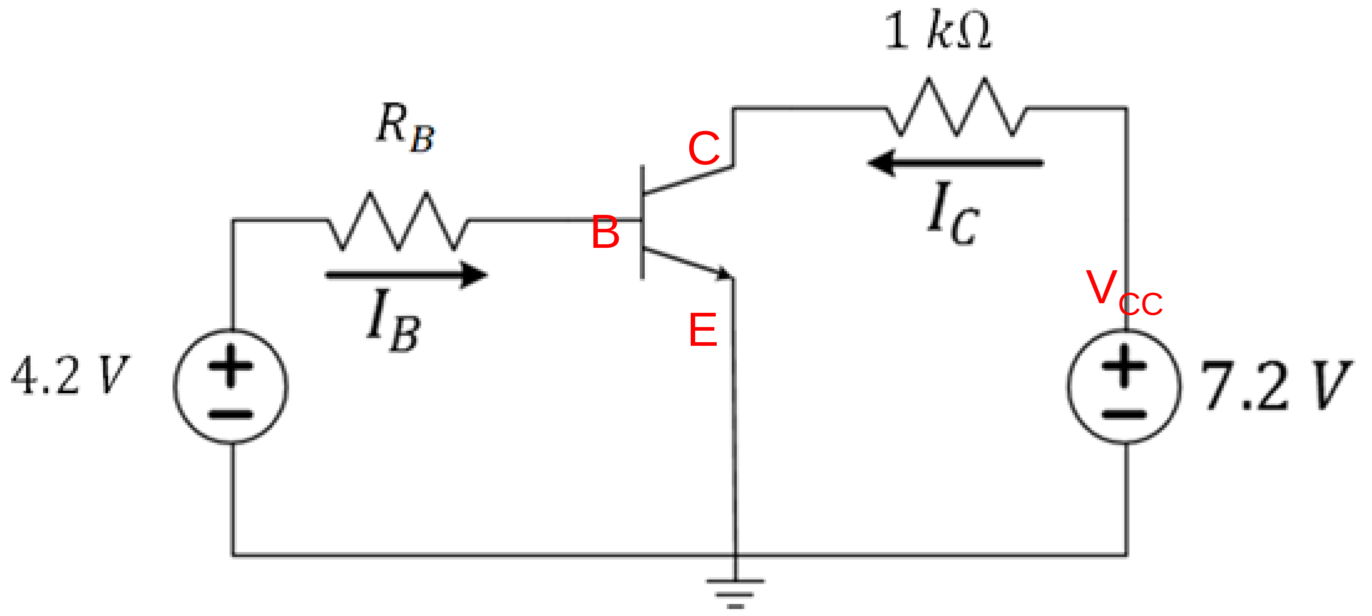


BJT Datasheet:

- $\beta = 100,$
- $V_{BEon} = 0.7\ V$
- $V_{CE,sat} = 0.2\ V$

L20Q13: Choose R_B such that the BJT is driven to the edge of saturation.

L20Q13: Choose R_B such that the BJT is driven to the edge of saturation.



BJT Datasheet:

- $\beta = 100,$
- $V_{BEon} = 0.7\ V$
- $V_{CE,sat} = 0.2\ V$

$$I_{C,sat} = (7.2 - 0.2)/1k = 7mA$$

$$I_B = I_{C,sat}/\beta = 70\mu A$$

$$R_B = \frac{V_{in} - V_{BEon}}{I_B} = \frac{4.2 - 0.7}{70\mu} = 50k\Omega$$

L20 Learning Objectives

a. Find β and $V_{CE,sat}$ for a given BJT IV characteristic

b. Find V_{CC} and R_C from the IV characteristic of the load line

c. Compute $I_{C,sat}$ from $V_{CC}, V_{CE,sat}$, and R_C

d. Identify the BJT CE operating point given IV characteristics

e. Solve numerically for unknown parameters among $\{V_{in}, R_B, I_B, \beta, V_{BE,on}, V_{CE,sat}, I_C, R_C, V_{CC}, I_{C,sat}\}$ when given some or all of the other values

f. Determine settings to drive transistor into a desired regime