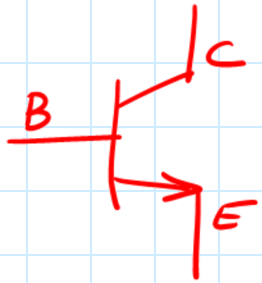
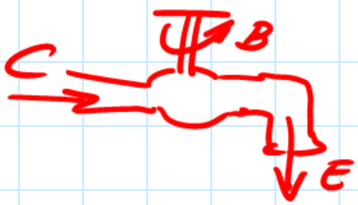
1.5 The bipolar transistor. Foundations



BJT: **B**ipolar **J**unction **T**ransistor

- A Bipolar Junction Transistor is a three-terminal device that, in most logic circuits, acts like a current-controlled switch.

Analogy with a tap:



- If we put a small current into one of the terminals, called the base, then the switch is ON:

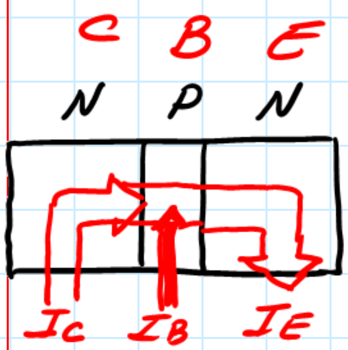
  Current may flow between the other two terminals, called the emitter and the collector.

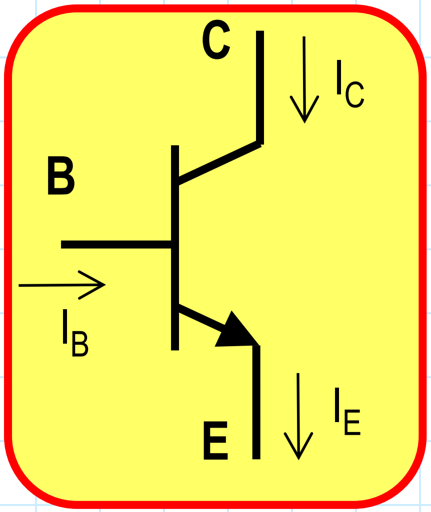
- If no current is put into the base, then the switch is OFF:

  No current flows between the emitter and the collector.

1.5 The bipolar transistor. Foundations

N-P-N TRANSISTOR





B: Base

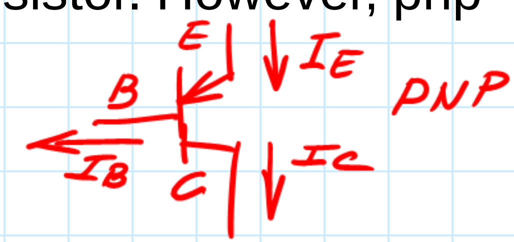
C: Collector

E: Emitter

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

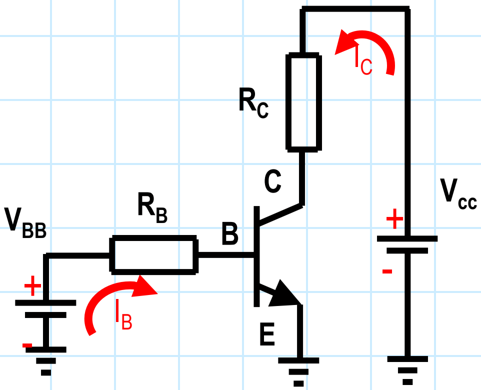
• Notice that the symbol contains an arrow in the direction of positive current flow (base-to-emitter junction, like in a diode)

• It is also possible to manufacture a PNP transistor. However, pnp transistors are seldom used in digital circuits.

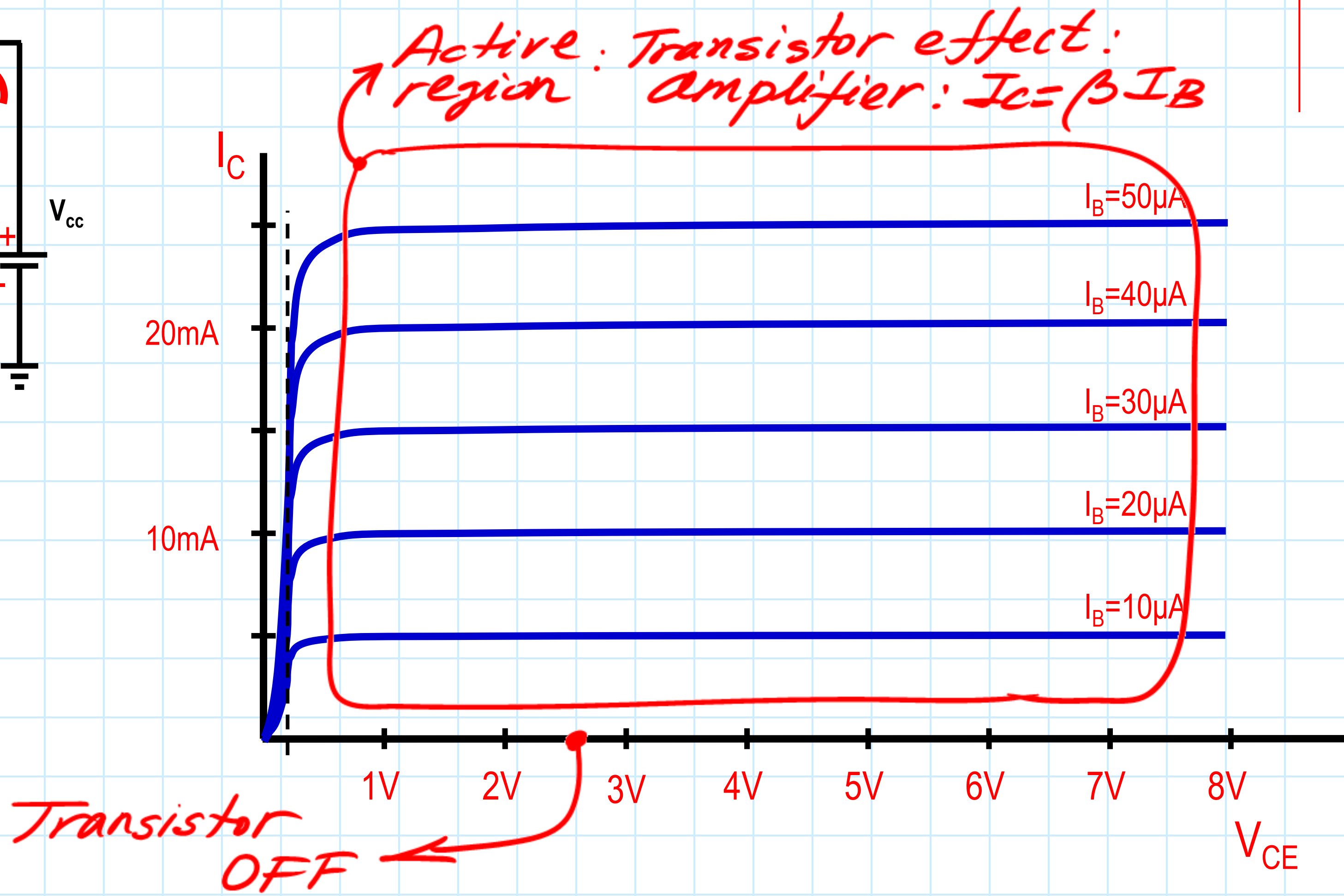


1.6 Output Characteristic Curves

Current I_C as a function of voltage V_{CE} and current I_B



Data:
β=500
(gain of the transistor)
R_B=100kΩ
R_C=0.4kΩ
V_{CC}=8V



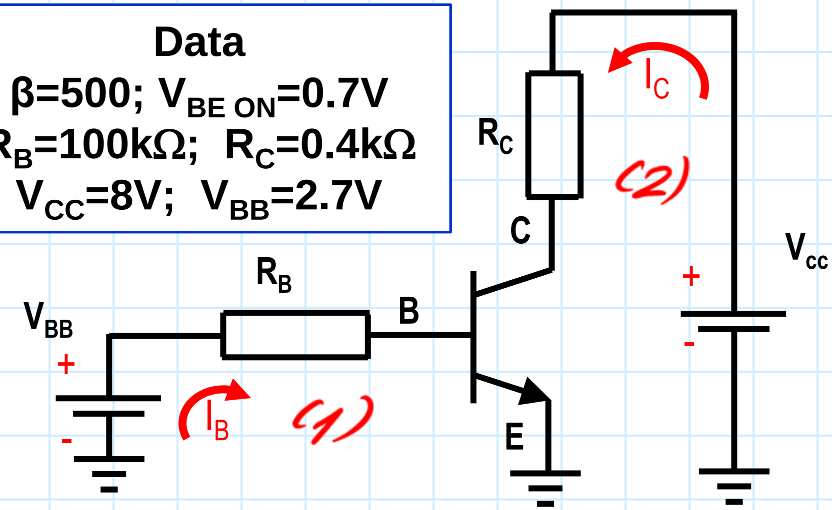
1.6 Static Load Line

(2): output loop
(1): Input loop

Static Load Line: $\boxed{V_{CE}=V_{CC}-R_C \times I_C}$ (1)

$I_B = (V_{BB}-0.7) / R_B = 20\mu A$ (2)

Data
$\beta=500$; $V_{BE\ ON}=0.7V$
$R_B=100k\Omega$; $R_C=0.4k\Omega$
$V_{CC}=8V$; $V_{BB}=2.7V$

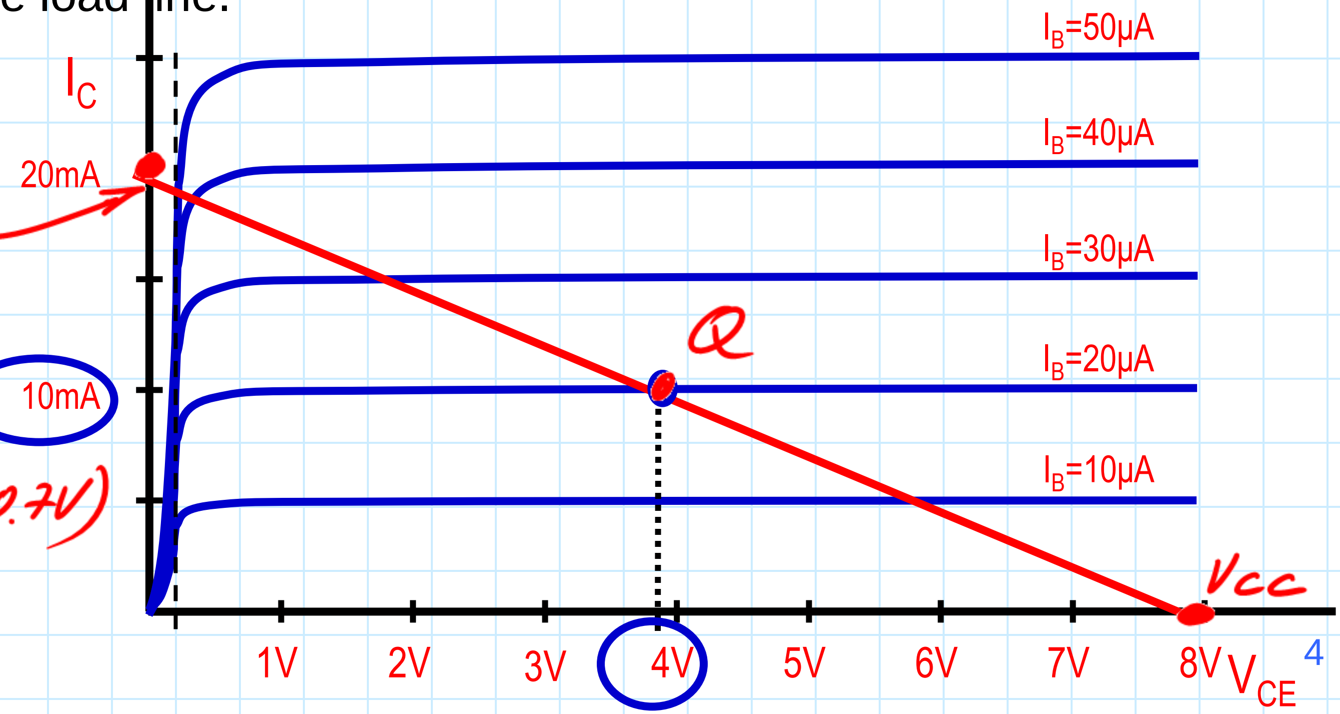


The quiescent point is determined by the intersection of the transistor output characteristic curve associated with $I_B=20\mu A$ and the load line.

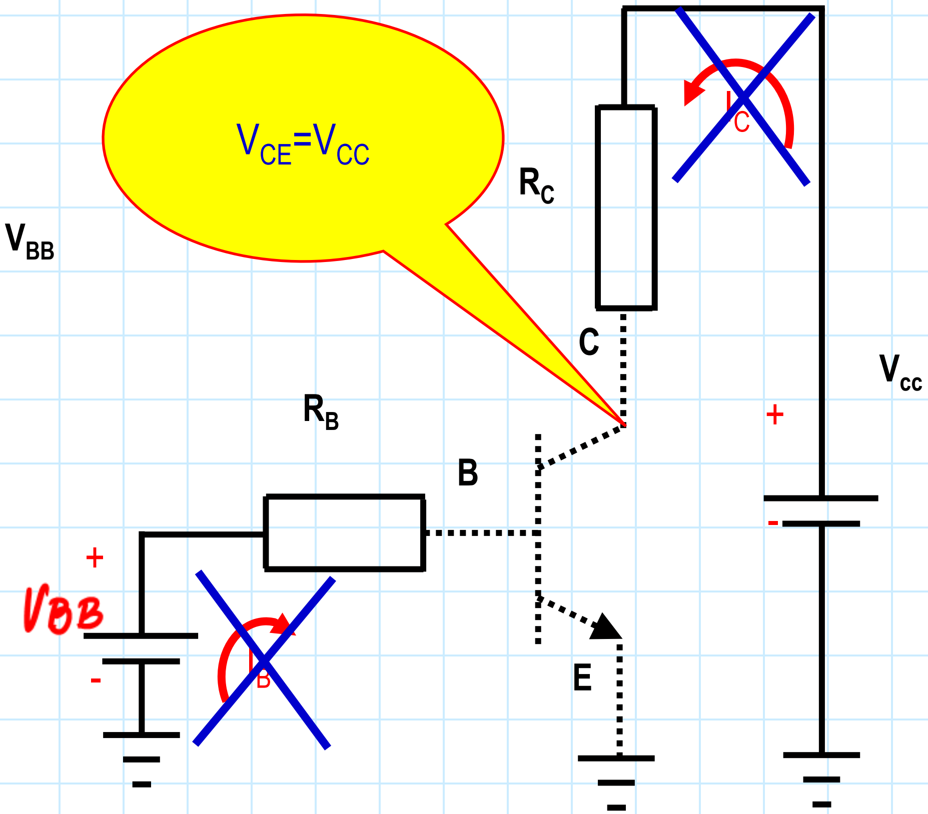
From (1):
$V_{CE}=0 \Rightarrow I_C = \frac{V_{CC}}{R_C}$

$I_C=0 \Rightarrow V_{CE}=V_{CC}$

$V_{BE(ON)}$: V_{BE} for transistor ON (Si: 0.7V)



1.7 Regions of operation. Cut-off



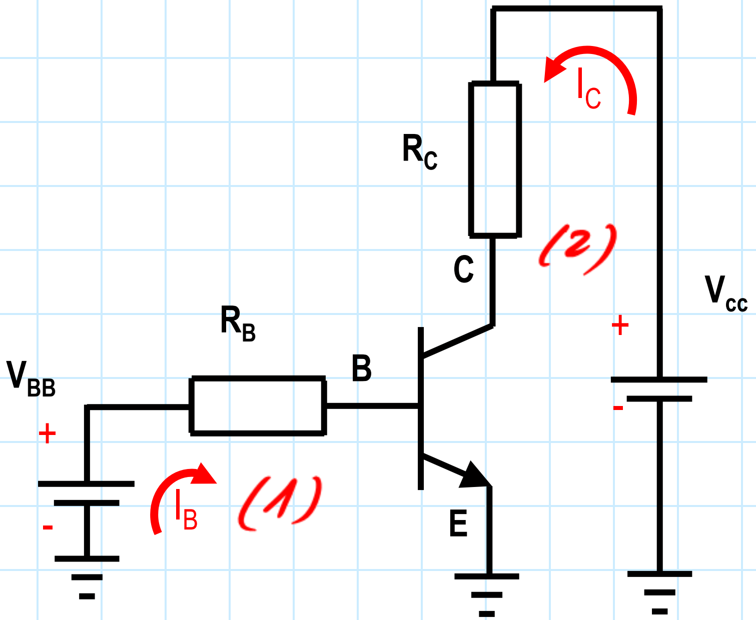
$$\boxed{I_B=0,\ I_C=0,\ I_E=0}$$

$V_{BB} = V_{BE} < V_{BE(ON)}$

The switch is OFF

$V_{CE} = V_{CC}$

1.7 Operating regions. Active



$V_{BB} > V_{BE(ON)} = 0.7V$

$\Rightarrow$ $V_{BE} = V_{BE(ON)}$ and we have $I_B > 0$

$$\boxed{I_B > 0 \quad \rightarrow \quad I_C = \beta\, I_B}$$

I_C current is proportional to I_B (linear zone)

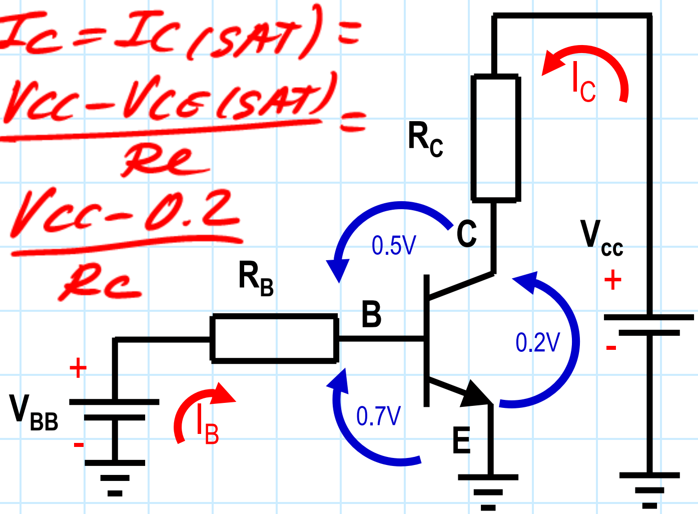
$I_B \uparrow \Rightarrow \begin{cases} I_C \uparrow \\ V_{CE} \downarrow \end{cases}$

(1) $I_B = \dfrac{V_{BB} - V_{BE(ON)}}{R_B} = \dfrac{V_{BB} - 0.7}{R_B}$

(2) $V_{CE} = V_{CC} - R_C I_C = V_{CC} - \beta I_B R_C$

1.7 Regions of operation. Saturation

$I_C = I_{C(SAT)} = \frac{V_{CC} - V_{CE(SAT)}}{R_C} = \frac{V_{CC} - 0.2}{R_C}$



The switch is fully ON

In active if $I_B \uparrow \Rightarrow I_C \uparrow$; $V_{CE} \downarrow$, but V_{CE} has a lower limit: when $V_{CE} = V_{CE(SAT)} = 0.2V \Rightarrow$ Transist. saturated, and I_C doesn't increment more

- I_C can not increase more, the transistor is said to be SATURATED

$\Rightarrow$ Si

$I_C < \beta . I_B$; $V_{CE} \approx 0.2V$; being $I_B \geq I_{BmínSAT}$

- Saturation occurs because the output circuit (V_{CC} and R_C) limits I_C to a maximum value.

BJT summary (NPN)

OFF

$V_{BE} \le V_{BE(ON)}$

$$\left\{\begin{array}{l} V_{BE} \le V_{BE(ON)} \\ I_B = 0;\ I_C = 0;\ V_{CE} = V_{CC} \end{array}\right\} \text{CUT OFF}$$

ON

$V_{BE} > V_{BE(ON)}$

$$\left\{\begin{array}{l} V_{BE} = V_{BE(ON)} \\ I_C = \beta I_B \\ V_{CE} = V_{CC} - R_C I_C \\ I_B \uparrow \Rightarrow I_C \uparrow;\ V_{CE} \downarrow \end{array}\right\} \text{ACTIVE (Linear)}$$

$$\left\{\begin{array}{l} V_{BE} = V_{BE(ON)} \\ I_C < \beta I_B \\ V_{CE} = V_{CE(SAT)} \\ I_C = I_{C(SAT)} = (V_{CC} - V_{CE(SAT)})/R_C \end{array}\right\} \text{SATURATION}$$

Si $V_{BE(ON)} = 0.7V$; $V_{CE(SAT)} = 0.2V$