Transistors.

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Lecture 06

Transistors

- invented in 1947
- amplify current
- lower power consumption
- cheap for mass production
- robust to vibration
- long working time (decades) when properly used
- replaced vacuum tube
- building block of modern electronics

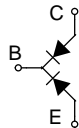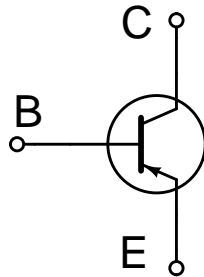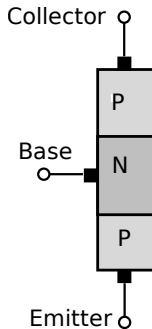Some areas where vacuum tube are still good

- ultra high voltage applications (more then 1000 V)
- radiation prone locations
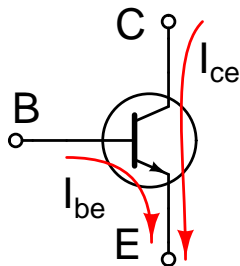
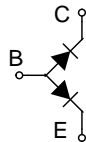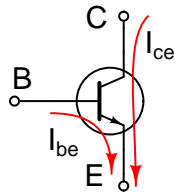# Bipolar junction Transistor (BJT)

NPN-transistor
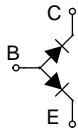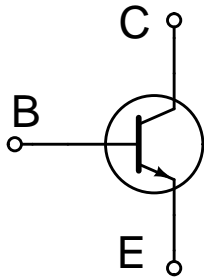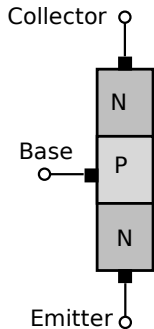
PNP-transistor

- Base-emitter current (I_{be})
- Collector-emitter current (I_{ce})
- Base-emitter voltage difference ($V_{be} = V_b - V_e$)
- Collector-emitter voltage difference ($V_{ce} = V_c - V_e$)

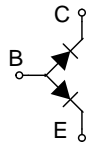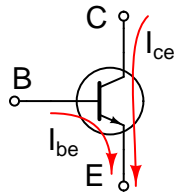# Simple NPN-transistor rules

To support shown currents direction

Simple NPN-transistor rules
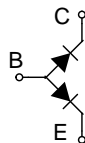
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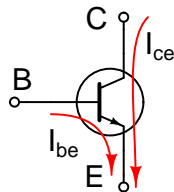 - if $V_{cb} < 0$ transistor goes to saturation and cannot be described by the following simple rule.
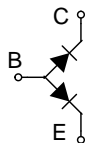
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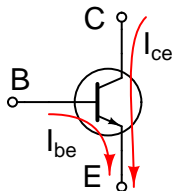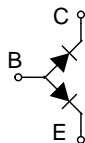# Simple NPN-transistor rules

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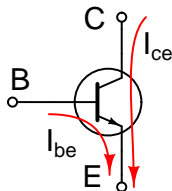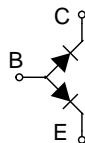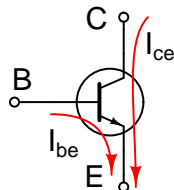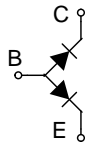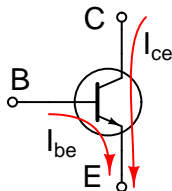- $I_{ce} = \beta I_{be}$ thus a BJT is a current amplifier

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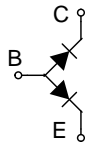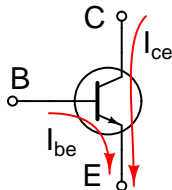 - if $V_{cb} < 0$ transistor goes to saturation and cannot be described by the following simple rule.

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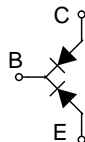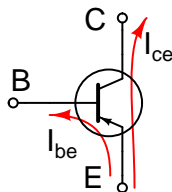
- $I_{ce} = \beta I_{be}$ thus a BJT is a current amplifier
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- $I_e = I_{be} + I_{ce} = (\beta + 1)I_{be} \approx \beta I_{be}$

Simple PNP-transistor rules

Apply the same rules as before for NPN BJT
but multiply currents and voltages by -1.
Hints

- the arrow indicates the direction in which current is supposed to flow.
- the arrow always connects the base and emitter.

Design considerations for β
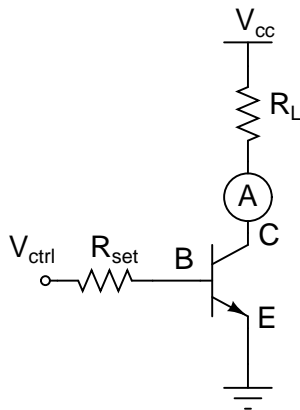
Remember β is not a constant!
It depends on many parameters

- temperature
- collector current
- varies from device to device even in the same batch

Good design should not depend on β value.

Constant current source

Current through the load resistor does not depend on the load resistance.
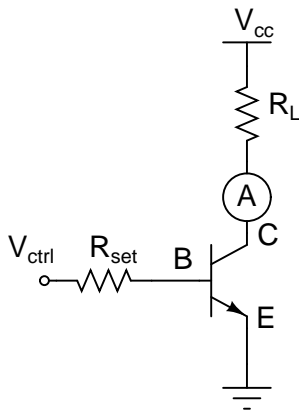
$$I_L = I_c = \beta I_{be} = \beta \frac{V_{ctrl} - .6V}{R_{set}}$$

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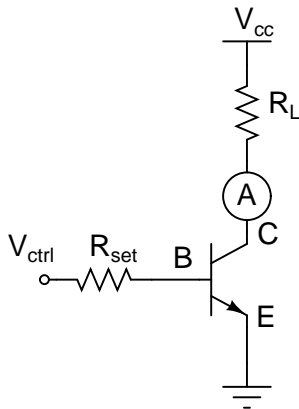
$$V_c = V_{cc} - R_L I_L$$

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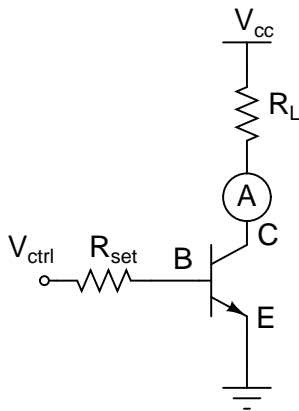Current through the load resistor does not depend on the load resistance.

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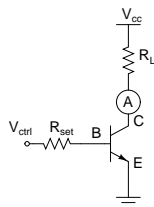
$$V_c = V_{cc} - R_L I_L$$

remember that V_c must be $> V_b$ thus current cannot be bigger then the saturation current

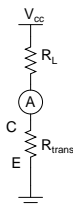$$I_{sat} = max(I_L) \leq \frac{V_{cc} - V_b}{R_L} \approx \frac{V_{cc}}{R_L}$$

From V_{cc} point of view, left schematic is equivalent to the right one.

$$R_{trans} = \frac{V_c}{I_L} = \frac{V_{cc} - I_L R_L}{I_L}$$

Transistor

Tran(sform)-(re)**sistor**
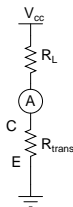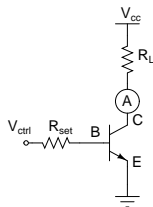
Constant current source. Power dissipation.

Transistor power dissipation

$$P_{trans} = P_{be} + P_{ce} = V_{be}I_{be} + V_{ce}I_{ce}$$

Since
$$V_{be} \leq V_{ce} , I_{be} = I_{ce}/\beta \ll I_{ce}, \text{ and } I_{ce} = I_L$$

$$P_{trans} \approx V_{ce}I_{ce} = R_{trans}I_L^2$$

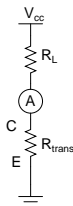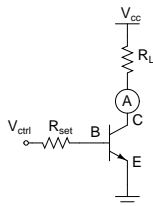# Constant current source. Power dissipation.

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Maximum power dissipation in transistor

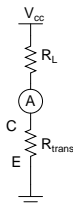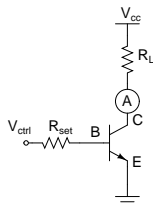# Constant current source. Power dissipation.

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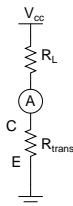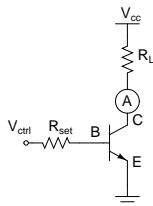$$P_{trans} = P_{be} + P_{ce} = V_{be}I_{be} + V_{ce}I_{ce}$$

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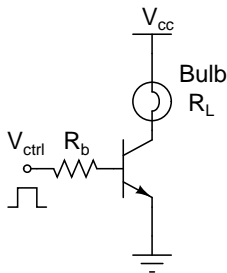$$max(P_{trans}) = \frac{V_{cc}^2}{4R_L}, \text{ when } I_L = \frac{V_{cc}}{2R_L}$$

Voltage controlled switch

When properly designed outcome does not depend on reasonable variations of β

Recall that typically $\beta = 100 \ldots 200$

We will assume the worst case scenario $\beta = 10$

Notice that R_L limits collector current
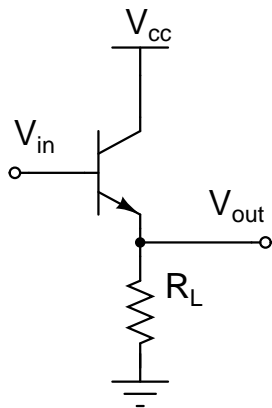
$$I_L = \frac{V_{cc}}{R_L}$$

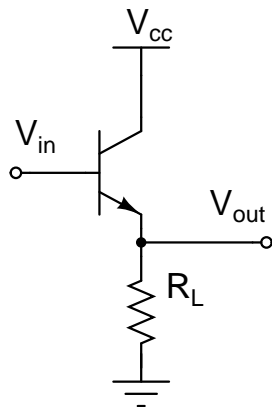$$I_{be} = \frac{V_{ctrl} - .6\,V}{R_b} = \frac{I_L}{\beta}$$

$$R_b \leq \frac{V_{ctrl} - .6\,V}{V_{cc}} \beta R_L$$

$$V_{out} = V_{in} - 0.6V$$

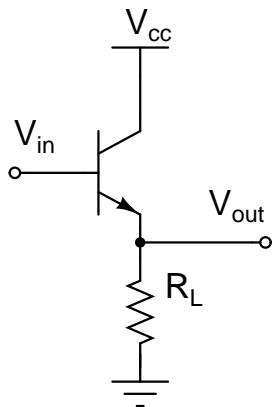$$V_{out} = V_{in} - 0.6V$$

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Gain. What gain?
We achieved the input impedance increase.

$$R_{input} = \frac{V_{in}}{I_{be}} \approx R_L(\beta + 1)$$

As result our V_{in} source is not overloaded and our load receive all required current (as long as the collector power supply can support it).