Transistor (transconductance resistor) is a three terminal device used to switch or amplifier signals.

More realistic model:

\[ I = \beta i \]

\[ I \approx (\beta + 1)i \approx \beta i \]
Rules for NPN transistor
1. Collector is more positive than Emitter.
2. Base-emitter and base-collector are effectively diodes.
3. $I_{\text{collector}} = \beta I_{\text{beta}}$. Beta can be as high as 60-100.
4. Constraints: $I_{\text{base}}$, $I_{\text{collector}}$ and $V_{\text{ce}}$ should not be too high. Typically $I_{\text{collector}} < 0.1\sim1$ A and $V_{\text{ce}} < 15\sim40$V.

Model of a transistor:

Applications:
1. Switch

```
<table>
<thead>
<tr>
<th>10V</th>
<th>1kΩ</th>
<th>β=100</th>
</tr>
</thead>
</table>
|       |      | switch on: $I = 940mA$
|       |      | Why?   |
|       |      | switch off: $I = 0$
```
Emitter follower: emitter follows the input (base), less one diode drop:

\[ V_{\text{in}} = V_E \approx V_{\text{in}} - 0.6V \]

Impedance change: (look at purple circle)

\[ Z_{\text{in}} = \frac{\Delta V_{\text{in}}}{\Delta I_{\text{in}}} = \frac{\Delta V_B}{\Delta i_B} \]

Now remember:

\[ V_B = V_E + 0.6 \]
\[ i_E = (\beta + 1) i_B \]

\[ \Rightarrow Z_{\text{in}} = \frac{\Delta V_B}{\Delta i_B} = \frac{\Delta V_E (\beta + 1)}{\Delta i_E} = (\beta + 1) R \]

Input impedance improved by \((\beta + 1)!!\)

Reminder: the higher the input impedance the better.
Output impedance: \( \text{look at the orange circle} \)

\[
Z_{\text{out}} = \frac{\Delta V_{\text{out}}}{\Delta i_e} \\
= \frac{\Delta V_b}{(\beta+1) \Delta i_b} \\
= \frac{r}{(\beta+1)}
\]

Output impedance reduced by \((\beta+1)\).

A single transistor makes both input/output device happier by a factor of \(\beta+1\).

Extension:

Darlington Pair:

\[
\beta_{\text{eff}} = (1+\beta)(1+\beta')
\]

Transistor as a current source

\[
V_c \\
R \\
\text{Load} \\
V_b \\
R \\
\Delta
\]

Transistor on:

\[
V_c = \beta i_b R + (\beta+1) i_b r \\
\Rightarrow i_c = \beta i_b \approx \frac{V_c}{R+r} \\
V_b > 0.6 + (\beta+1) i_b r \\
> 0.6 + \frac{V_c R}{R+r}
\]

Transistor off:

\[
V < 0.6 + V_c \frac{r}{R+r}
\]
Transistor as an amplifier:

![Transistor Diagram]

Working in the regime $i_c = \beta i_b$, we have

$$V_{out} = V_c - i_c R$$

$$\approx V_c - \frac{\beta i_b R}{r}$$

$$= V_c - \frac{V_{in} - 0.6}{r} R$$

**AC gain**

$$G_{AC} = \frac{\Delta V_{out}}{\Delta V_{in}}$$

$$= - \frac{R}{r}$$