Semiconductors:

A semiconductor, such as Silicon, normally has a high resistnace. Most of the electrons are in covalent bonds and are not free to conduct electricity.

If you add Boron to a Silicon crystal, each Boron atom has 3 (vs 4) electrons in its outer shell. This creates a hole in the crystal which allows current flow. These holes act like positive charged charge carriers (h+).

If you add Phosphorus to a Silicon crystal, each Phosphorus atom has 5 (vs 4) electrons in its outer shell. This creates an extra electron which has no place in the crystal. This extra electron is free to carry current as a negative charge carrier (e-).

Above 0K, the number of electrons and holes are roughly constant:

$$np = n_i^2 = 1.5 \cdot 10^{10} \quad \text{carriers/cc}$$

If you dope with Boron with a density of 10^{14} atoms/cc, the material has mostly p-type charge carriers:

$$p \approx 10^{14} \quad n \approx 1.5 \cdot 10^{6}$$

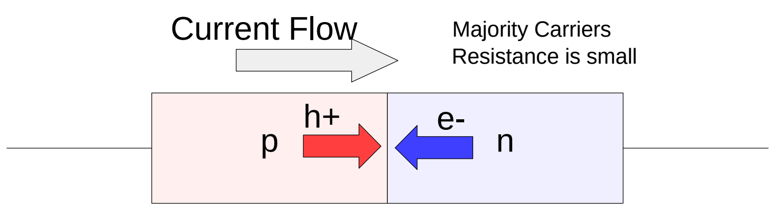
If you dope with Phosphorus with a density of 10^{14} atoms/cc, the material has mostly n-type charge carriers:

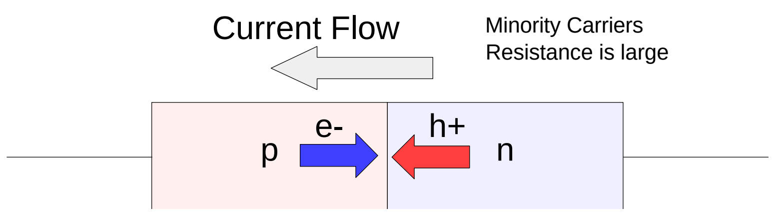
$$n \approx 10^{14} \quad p \approx 1.5 \cdot 10^{6}$$

Diodes:

If you place a p-type semiconductor next to an n-type semiconductor you get a diode.

Diodes only allow current to flow in one direction:



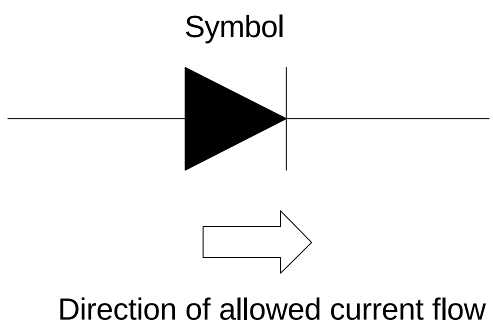


If you try to force current to flow from p to n, you are using majority carriers: you have $\approx 10^{14}$ charge carriers per cc to carry the current.

If you try to force current to flow from n to p, you are using minority carriers: you have $\approx 1.5 \cdot 10^{6}$ charge carriers per cc to carry the current. This is approximately 10^{8} times fewer charge carriers, implying that the resistance is 10^{8} times higher.

VI Characteristics of a Diode:

A diode allows current to flow from p to n but not the other way. The symbol for a diode reminds you which way current can flow:



When a diode turns on, it drops voltage a little. As an approximation, assume this voltage drop is constant. This creates two models for a diode:

$I_d = 0$ if $V_d < 0$ (you try to push current backwards)

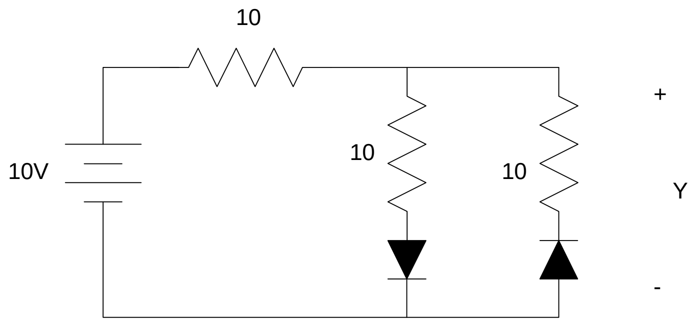
$V_d =$constant if $I_d > 0$.

Vd is approximately:

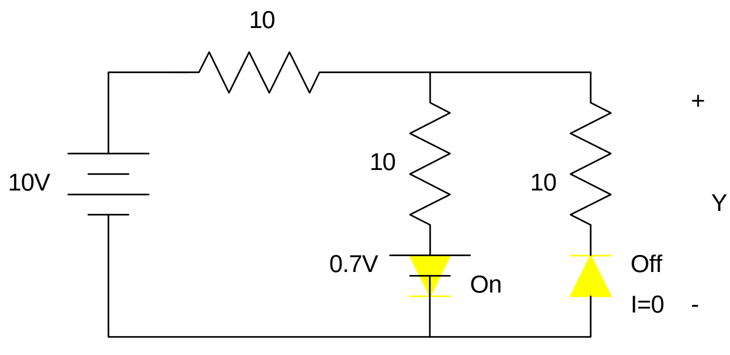
- 0V: ideal diode
- 0.3V ideal Germanium diode
- 0.7V ideal Silicon diode

Diode Example:

Determine I for the following circuit. Assume ideal Silicon diodes:



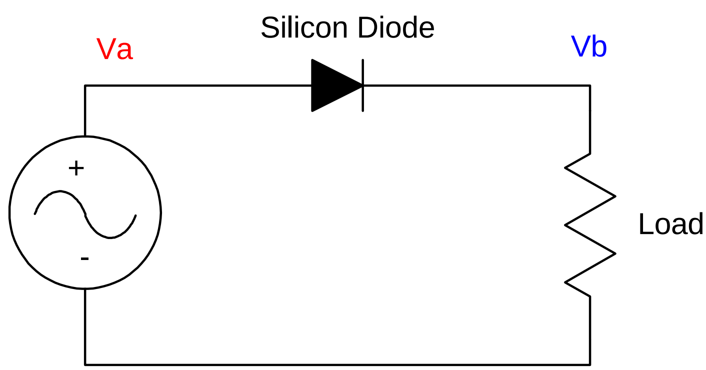
'Guess' which diode is on and which is off. Replace each diode with its appropriate model.

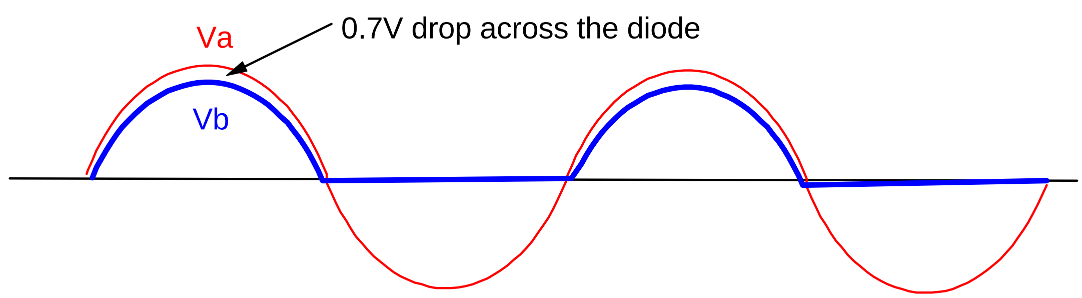


Solve: By superposition: $Y = \left(\frac{1}{2}\right)10 + \left(\frac{1}{2}\right)0.7 = 5.35V$

Diodes and AC - DC Converters

Diodes are useful in converting AC signals to DC signals. The following is a 1/2 wave rectifier. The load only sees the input when it is positive (above 0.7V in this case).



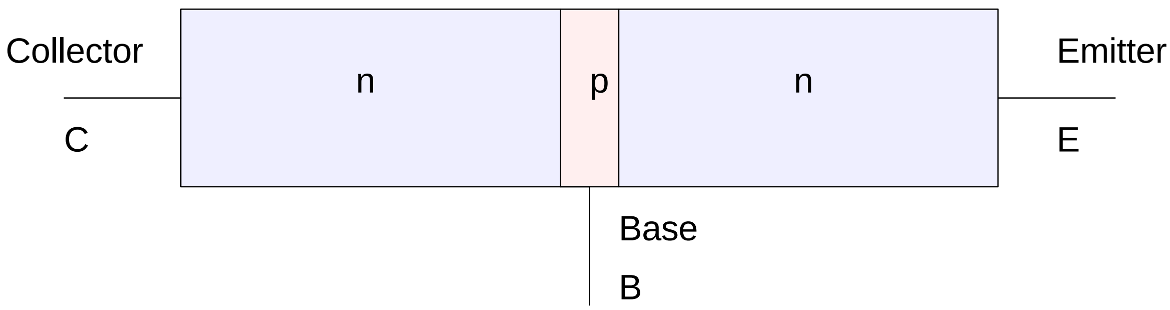


Transistors:

A transistor is a 3-terminal semiconductor device:

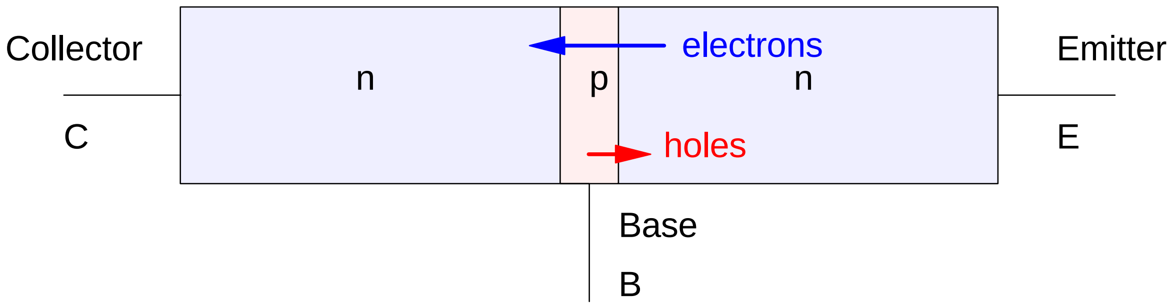
- NPN
- PNP

Let's look at an NPN:



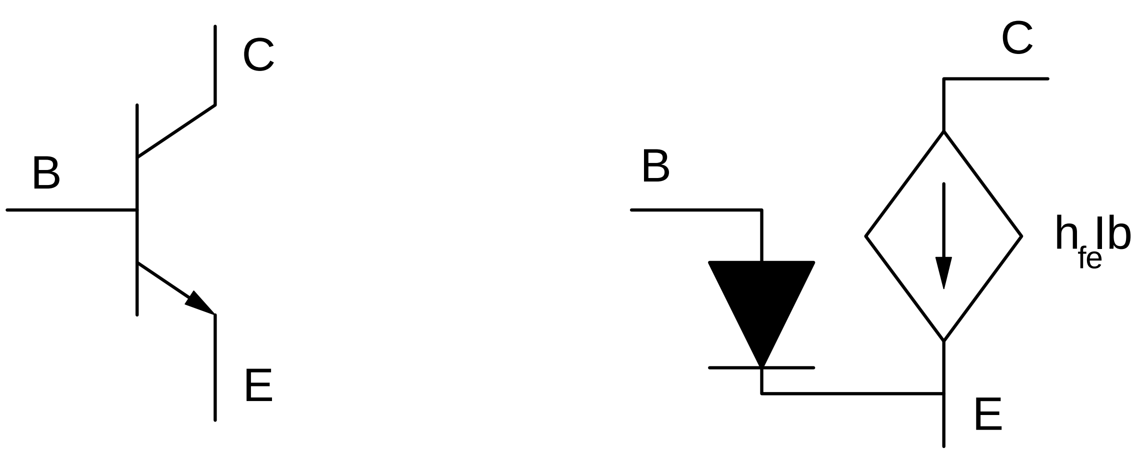
Current cannot flow from the collector to the emitter since there is a reverse-biased pn junction inbetween.

A transistor acts as a current limitor. It is designed so that when current is applied base-to-emitter, a large amount of current can flow from the emitter to the collector.



This creates the model for a transistor:

- Base to Emitter is a diode (a pn junction)
- Emitter to Collector is a current-controlled current limitor.



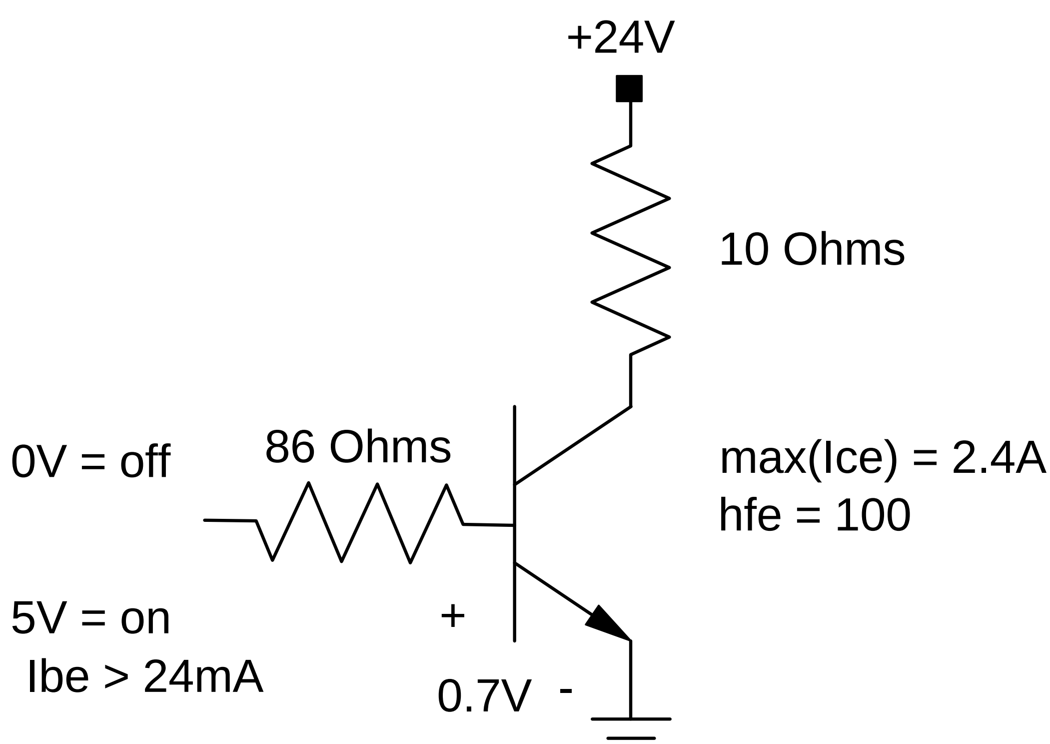
Transistor as a Switch:

A transistor can be used as a switch:

- If Ib = 0, Ice = 0. The switch is open.
- If Ib > max(Ice), Ice is held at its maximum value. The switch is closed.

Example: Turn on and off a 10 Ohm load at 24V using a 5V processor output.

Solution: Design a circuit which drives 0mA at 0V and 50mA at +5V. This limits the current to 0mA (off) and 5A (on).

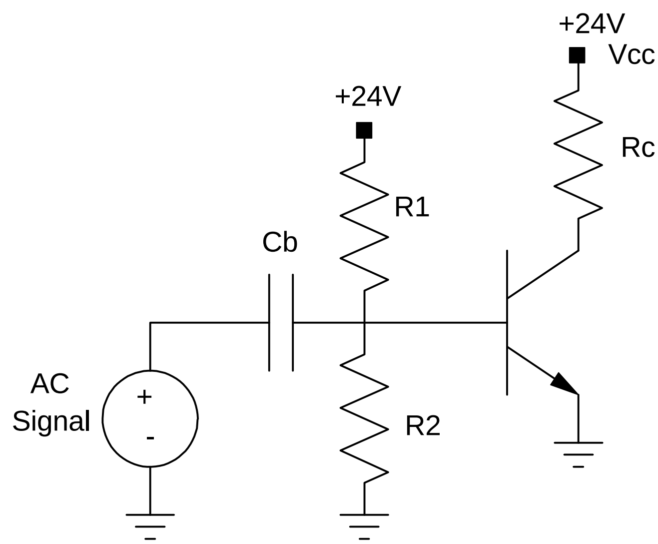


Transistor as an Amplifier:

Bias the transistor so that it is about 1/2 of Vcc.

As you vary the base current, the current Ice varies (with a gain of hfe).

As Ice varies, Vc varies and is amplified:



R1 and R2 are selected so that Vc = 12V

They set the base current, Ib, at DC

The input signal adds to Ib, which is amlified by the transistor which is converted to voltage by Rc