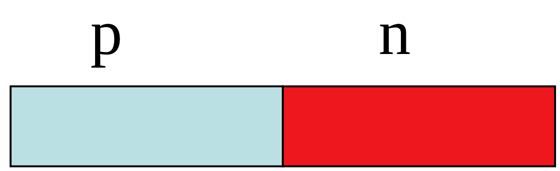
Doped Semiconductors

- Silicon and germanium act as semiconductors because of the ~1 eV gap between their valence and conduction bands
- Doping with arsenic adds extra electrons that can very easily move into conduction band (n-type)
- Doping with gallium creates “holes” (p-type)
- Type and concentration of doping can be verified with Hall effect

pn Junction



Reverse bias creates a "depletion layer". The size of the depletion layer can be measured by measuring the capacitance. A reverse-biased diode is a voltage-controlled capacitor—useful in tuners.

Zener diode uses reverse-bias to strip electrons from atoms.

Other Diode Applications

- Tunnel diodes are heavily doped and conduct with very small bias current. They have a region where I-V slope is negative and are very fast
- Silicon solar cells use energy from a photon to excite electron from valence to conduction band; some electrons move into n-type region to make current
- Surface-barrier detectors are reverse-biased. Ionizing particle creates electron-hole pairs in depletion region

Other Diode Applications

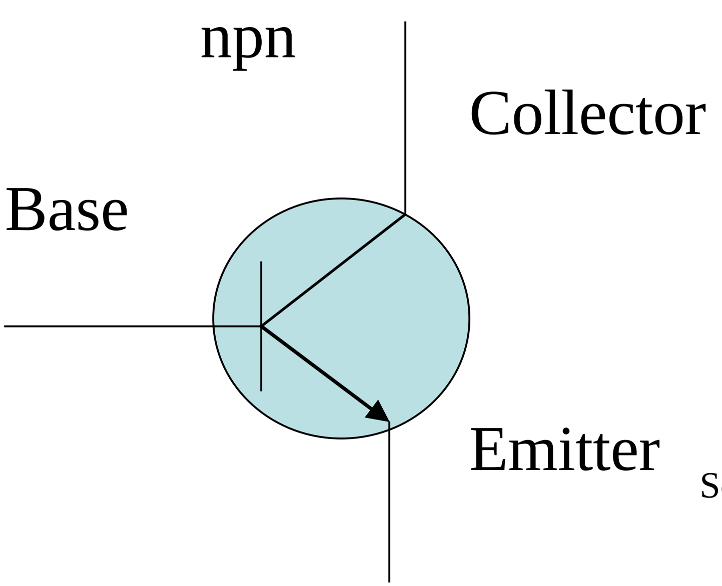
- Light emitting diodes are forward-biased and emit light as electron-hole pairs recombine. Need larger band gap to get higher energy photons. Most are made of gallium arsenide or gallium arsenide phosphide.

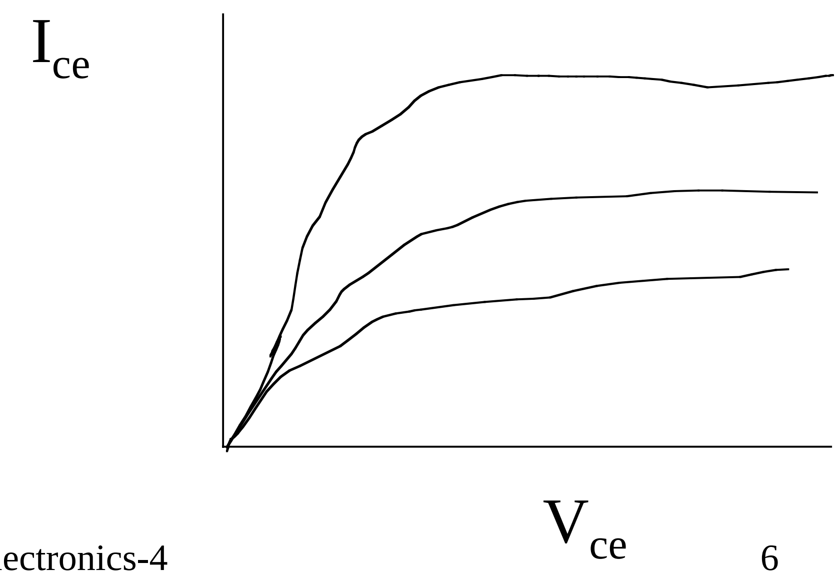
Bipolar Junction Transistors

- Transistors are two-junction, three-element devices—either npn or pnp.
- Three regions are called emitter, base and collector.
- npn: Heavily doped emitter region has many extra electrons. Thin base is forward-biased, so current flows easily.
- Because base is thin, most electrons do not recombine with holes in base and instead pass into collector, which is reverse-biased with respect to base.

Bipolar Junction Transistors

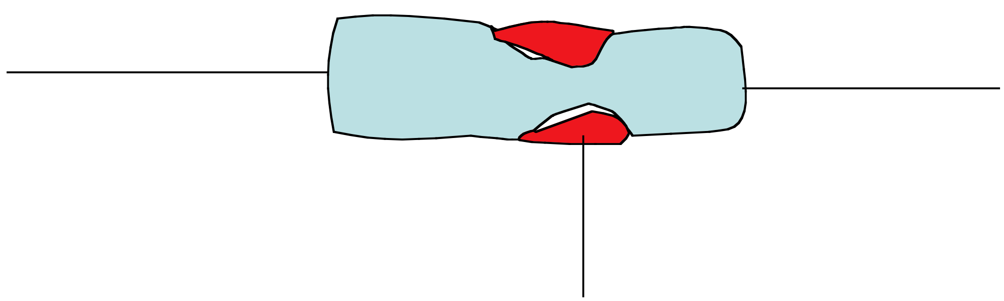
- Small changes in emitter-base current I_b result in large changes in emitter-collector current I_c.
- $I_c = \beta I_b$, where β is called the *current gain*



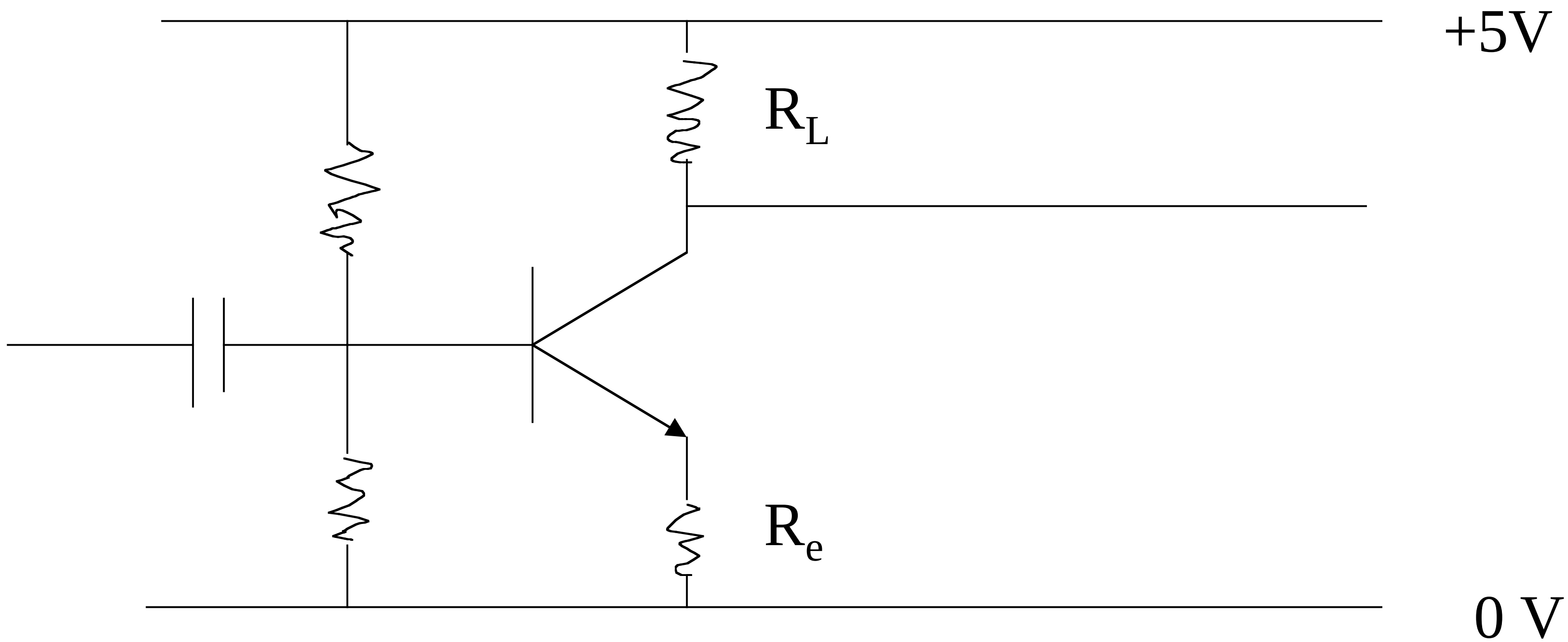


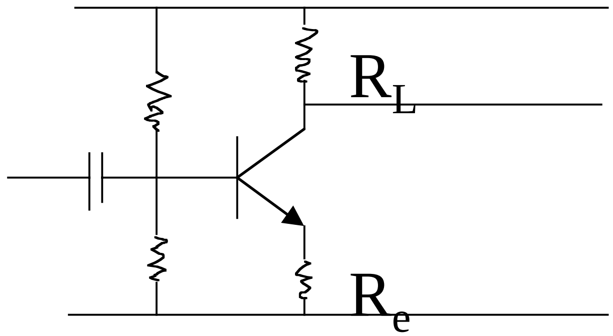
Field Effect Transistors

- Have a large region of one doping type with a central "choke" point surrounded by other doping type
- Size of depletion region controlled by reverse-bias voltage at choke point



BJT Circuit





Amplifier

$$I_c = \beta I_b$$

$$I_b = \frac{v_s}{R_e + R_{be}}$$

$$I_c = \frac{v_L}{R_L}$$

$$\frac{v_L}{v_s} = \beta \frac{R_L}{R_e + R_{be}}$$

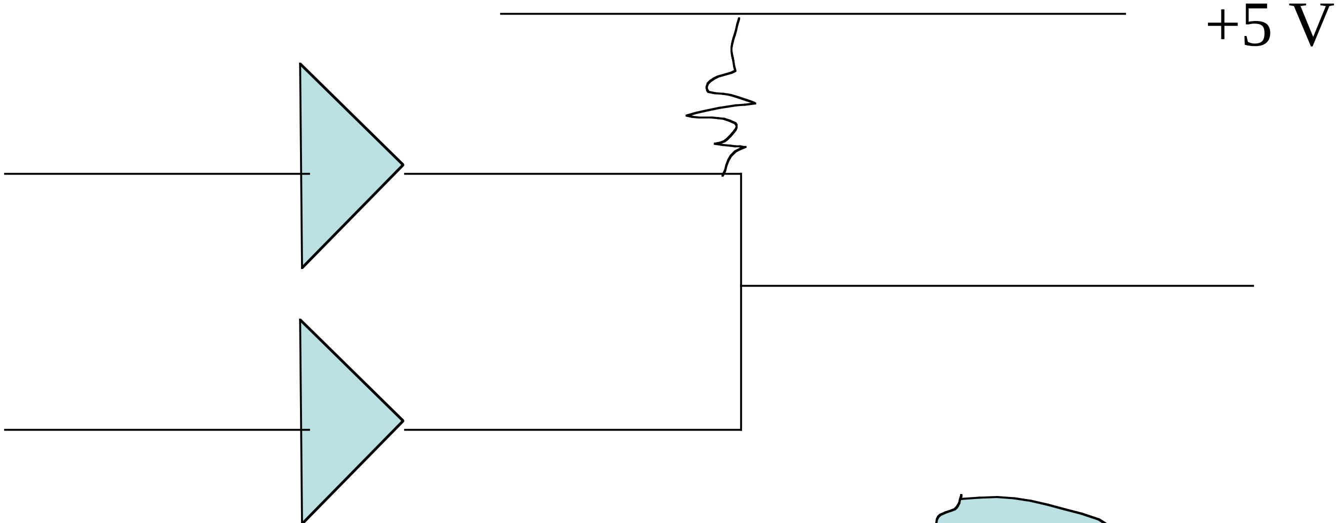
Use resistors to set gain of amplifier

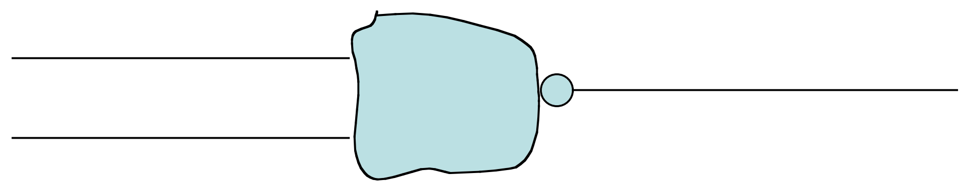
This is an npn stage. Can cascade to a pnp stage.

Note that output is inverted

Gates

One amplifier makes
A NOT gate





NAND gate

Gate provides amplification

RS Flip-Flop