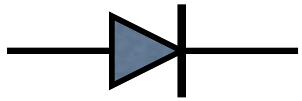
Key points from yesterday

- How is a diode constructed?

  Put an n-type semiconductor next to a p-type semiconductor - see yesterday's slides.

- What does a diode do? What's its circuit symbol?

  A diode lets only one direction of current through - turns AC into DC.



- What's the difference between a half-wave rectifier and a full-wave rectifier? What's their purpose? What would a graph of voltage vs time look like for each one? What would those circuits themselves look like?

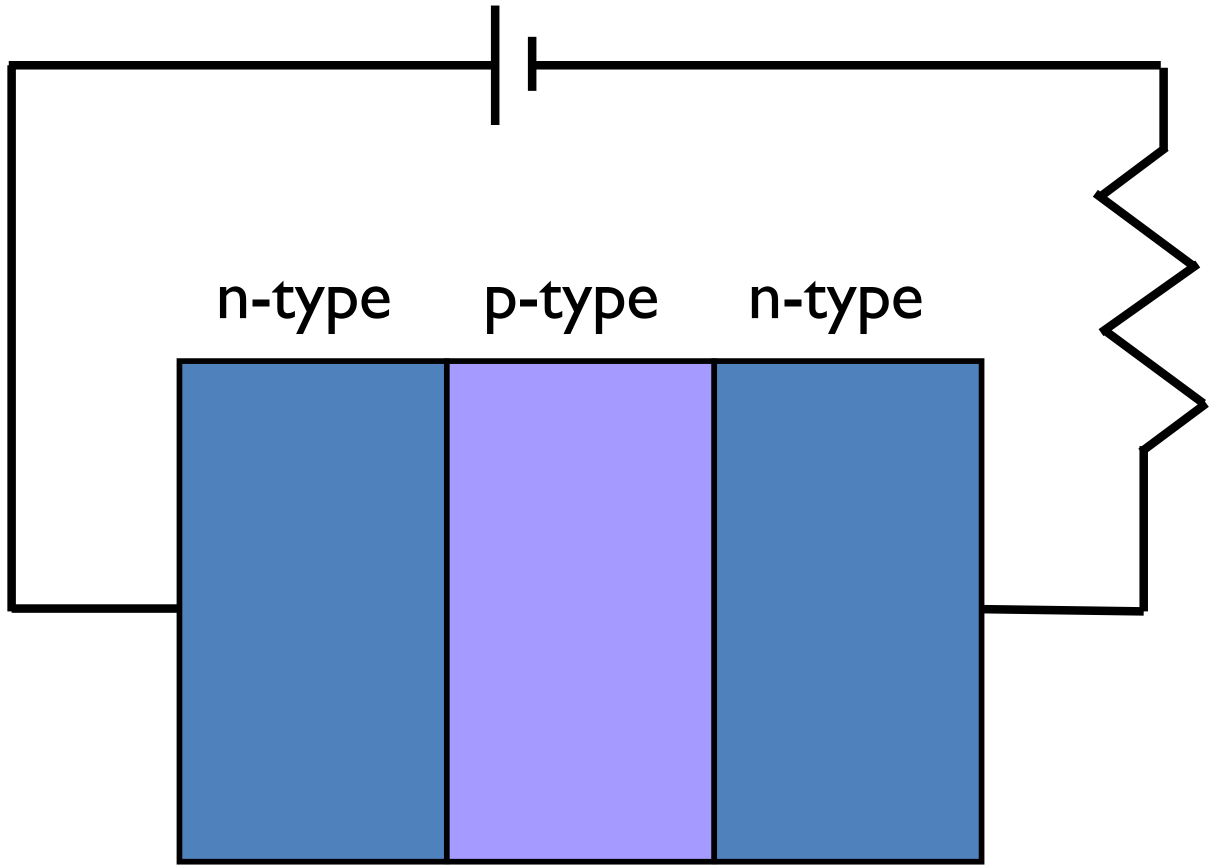
- Half wave only lets half the AC signal through - it's a single diode. This wastes some energy, as the voltage graph looks like bumps with 0 voltage sections in between.

  Full wave lets the whole signal through as bumps of same voltage polarity - this is accomplished with a **diode bridge**. (Can you draw it?)

- How do we smooth out the full-wave signal?

  With a capacitor in parallel across the resistor of the diode bridge!

What's going to happen here?



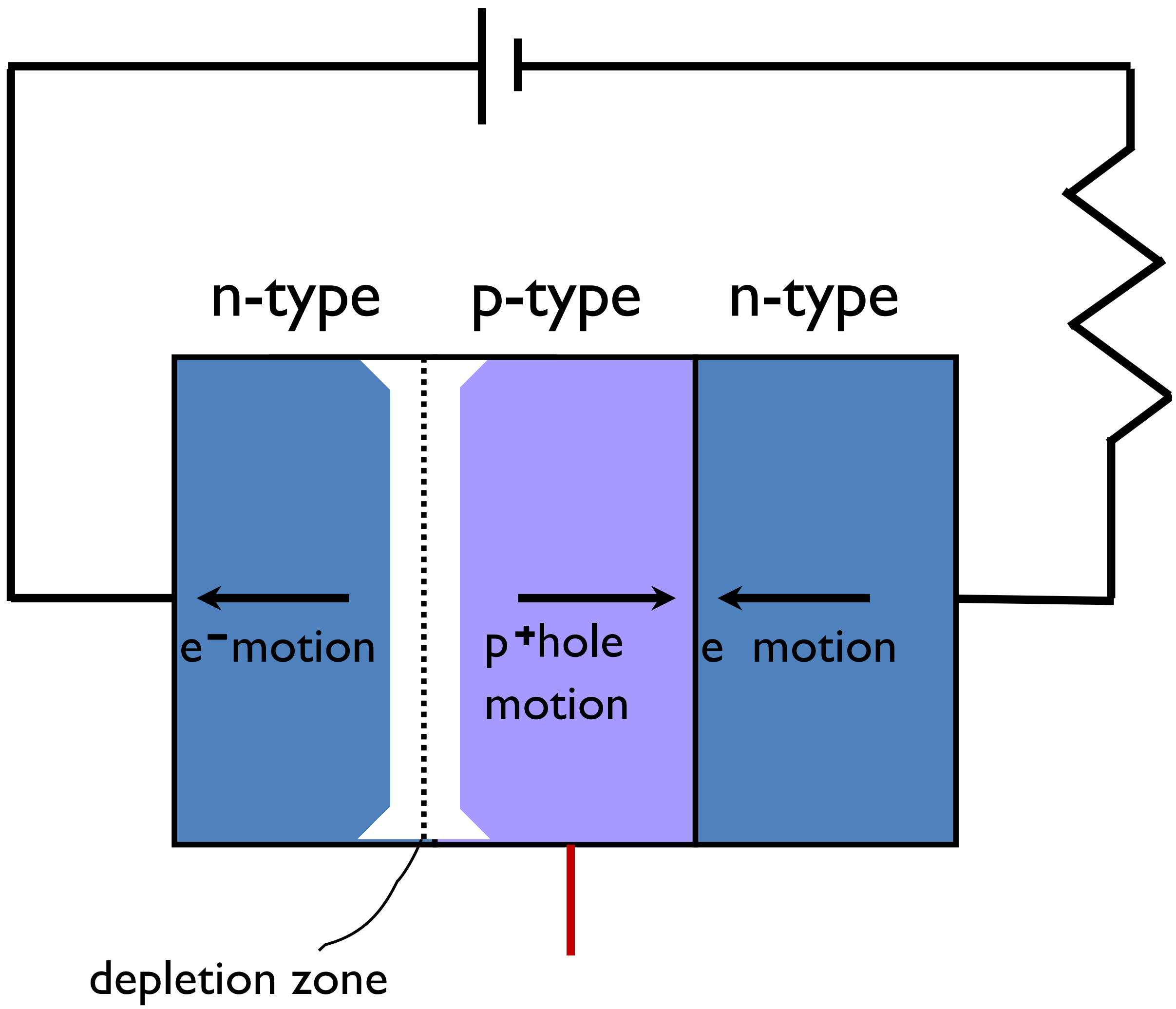
Note: all the parts in this are drastically enlarged to show what's going on. These semiconductor sheets are VERY thin in reality.

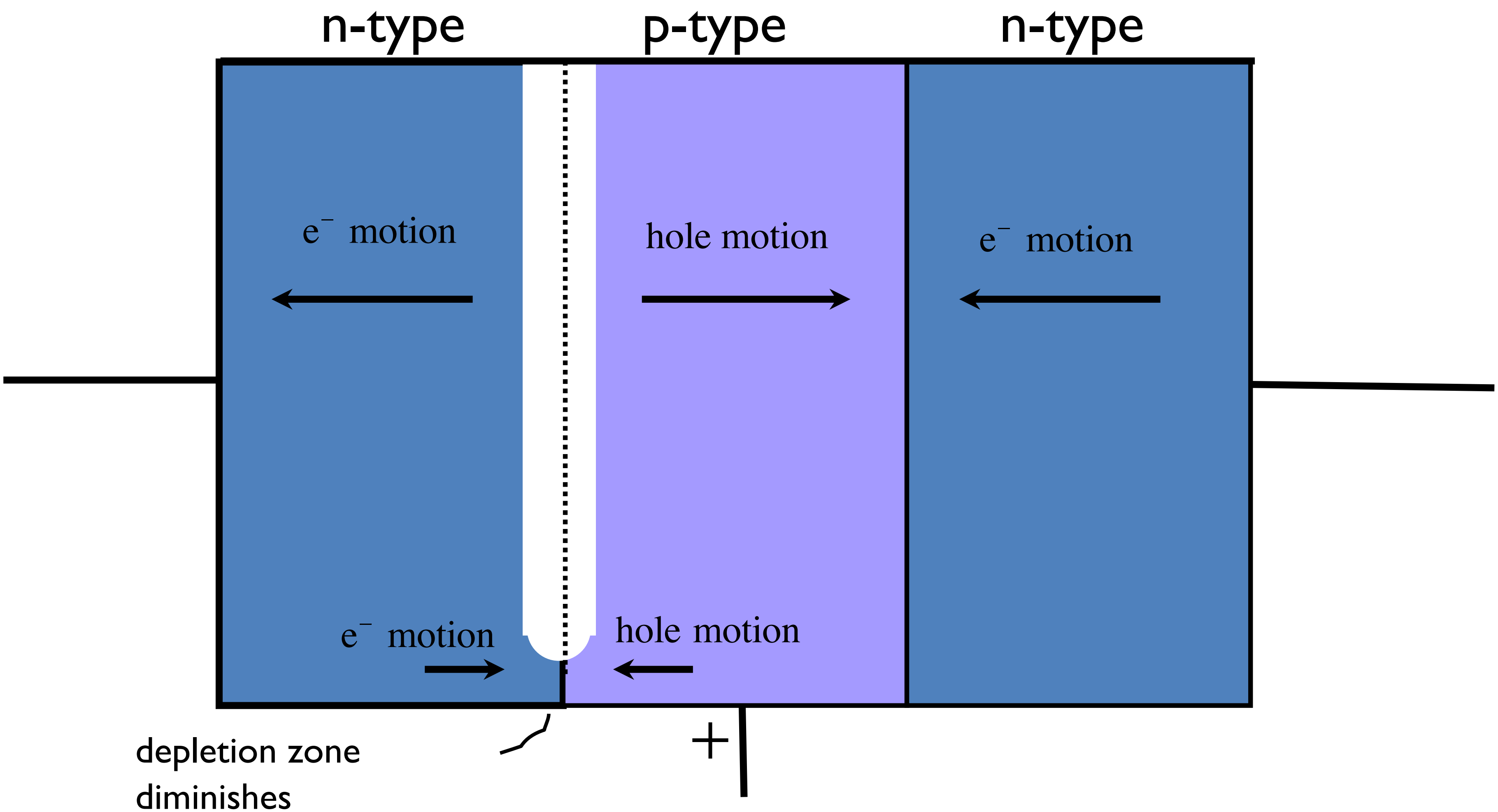
Transistors

- This circuit is a **transistor**. Let's see what happens:

A depletion zone is going to form along the left p-n junction, and no current will pass through the load resistor.

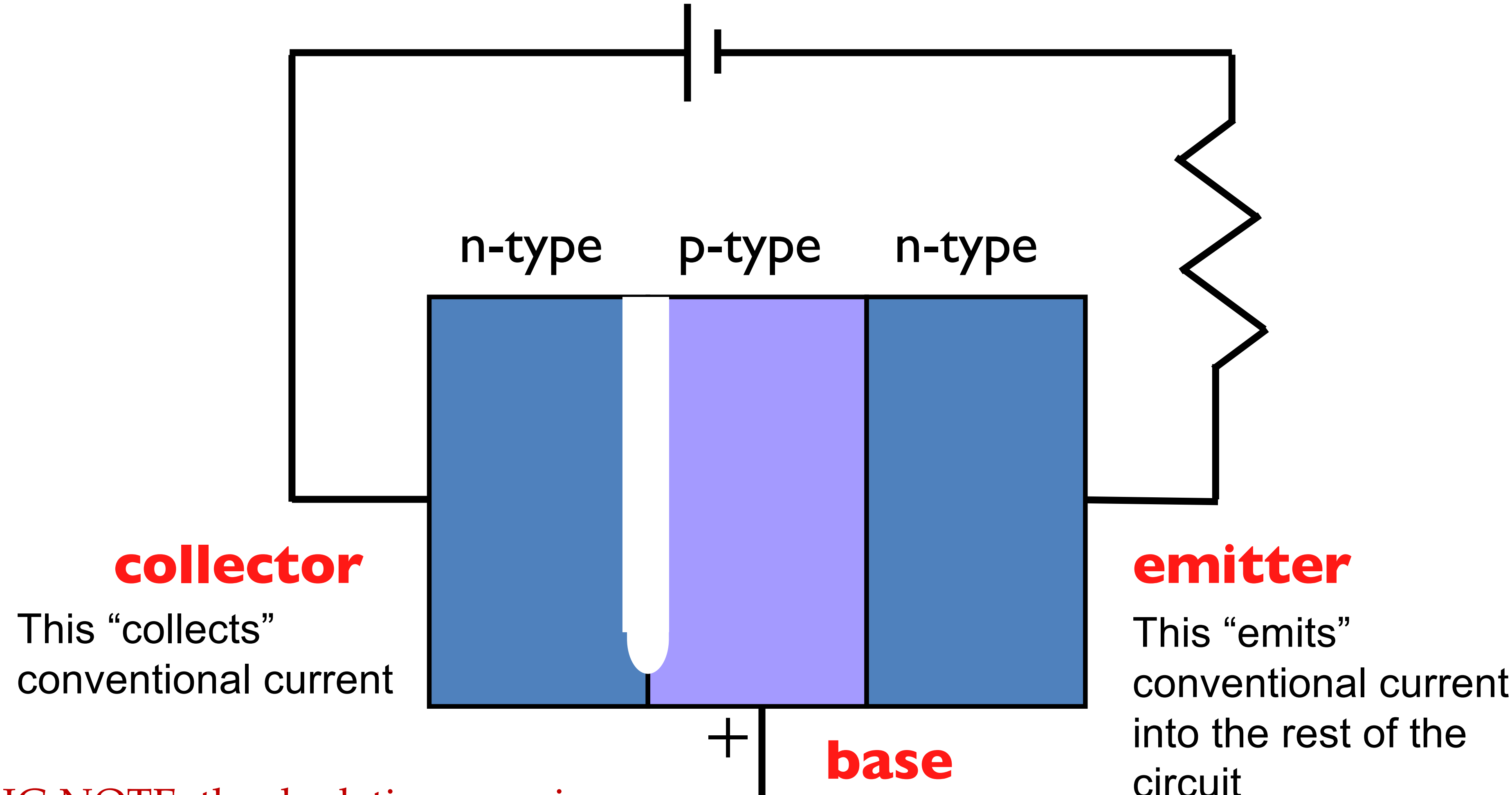
But what if we were clever? What if we made the connector to the central section electrically positive? What then?





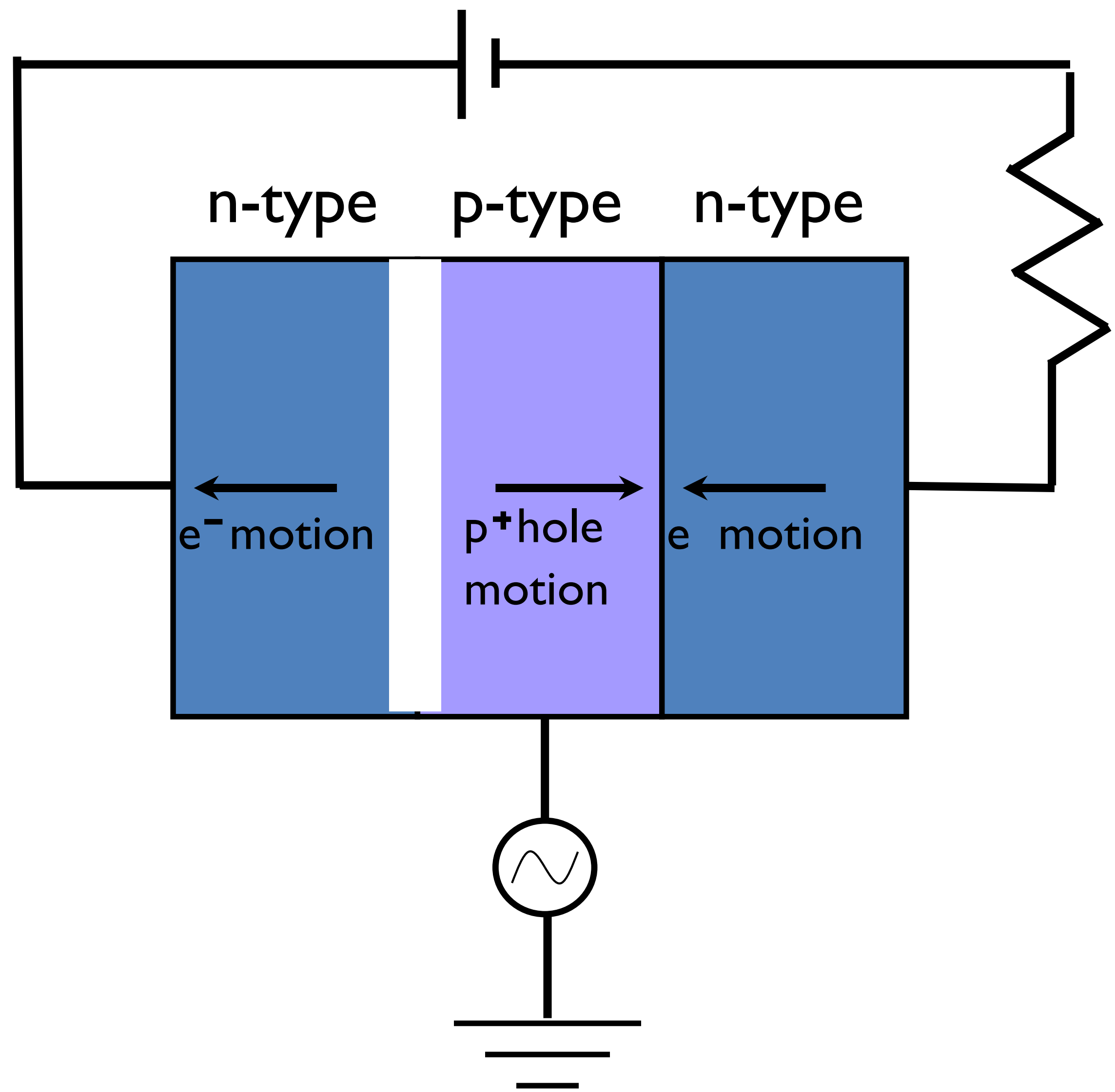
Electrons at the bottom of the left n-type semiconductor will be attracted rightward toward the positive central lead, and similar holes in the p-type semiconductor will be repulsed leftward away from the positive central lead, and the depletion zone at the bottom of the p-n junction will diminish effectively allowing “current” to flow through the circuit and, as a consequence, the load resistor.

This device is called an **"npn" transistor**. The left lead in this case is called "the collector," the right lead "the emitter" and the middle lead "the base."

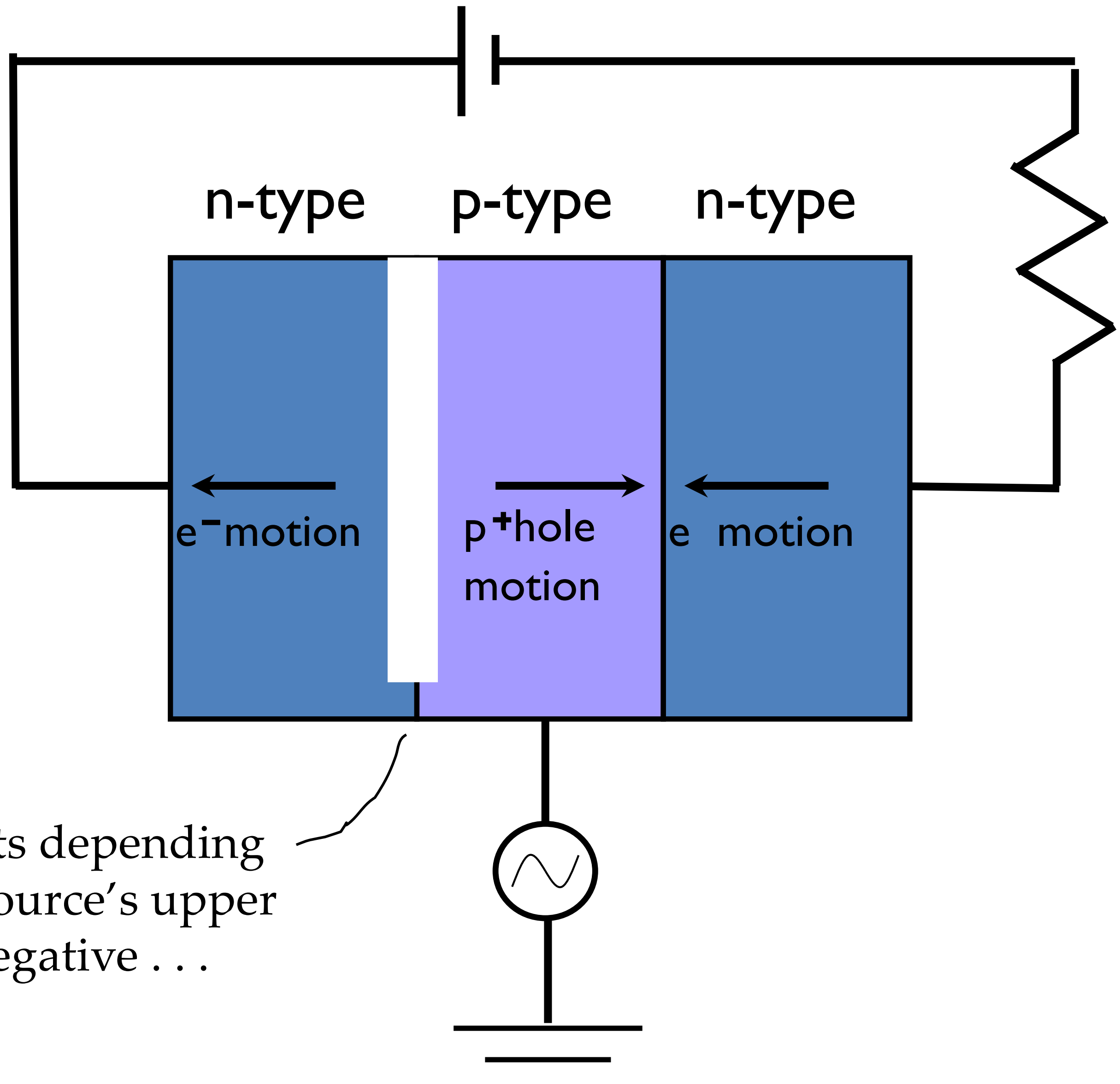


BIG NOTE: the depletion zone is ALWAYS at the collector/base junction for an npn transistor!

So back to the original circuit, with modification. Let's attach an AC source to the base and see what happens.

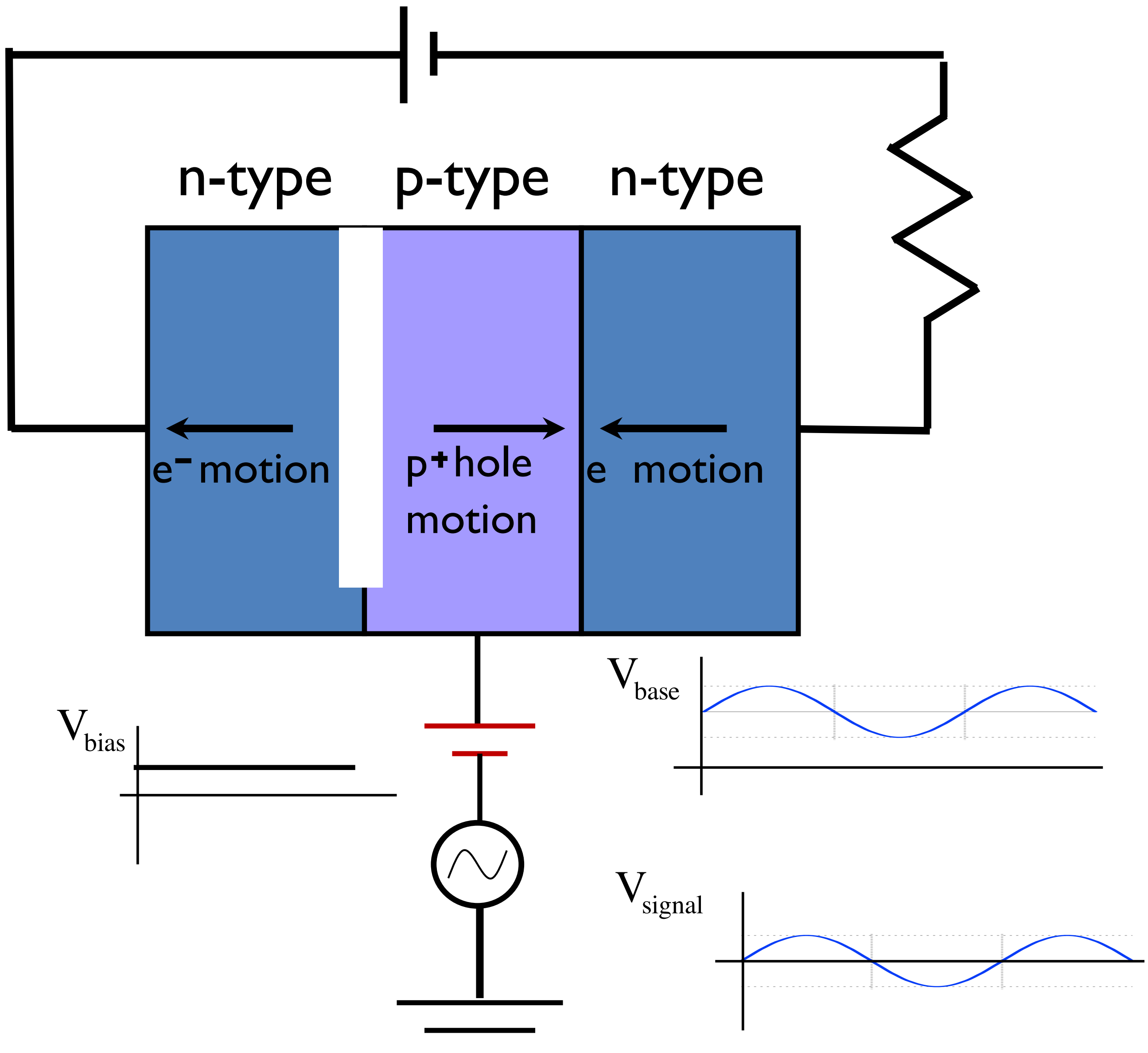


With this configuration, you would get current flow through the load resistor when the polarity of the AC source made the upper terminal and the base electrically positive, but you'd lose the effect when that terminal went negative. So how to fix that problem?

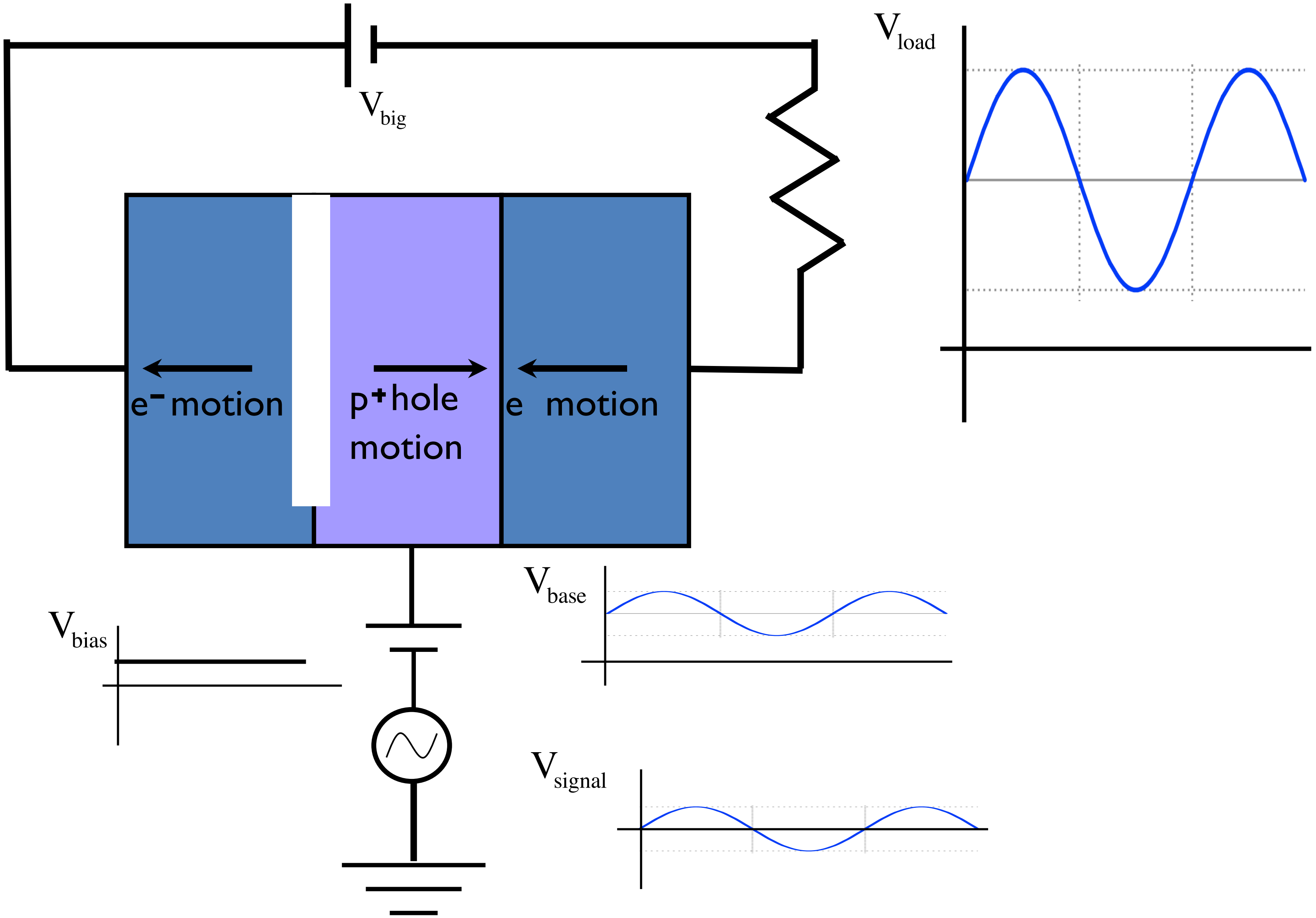


Depletion zone exists depending upon whether AC source's upper lead is positive or negative . . .

By putting in a bias voltage to keep the base terminal always positive, though, we can get current to flow in the upper circuit non-stop. The voltages produced by each element is shown below.



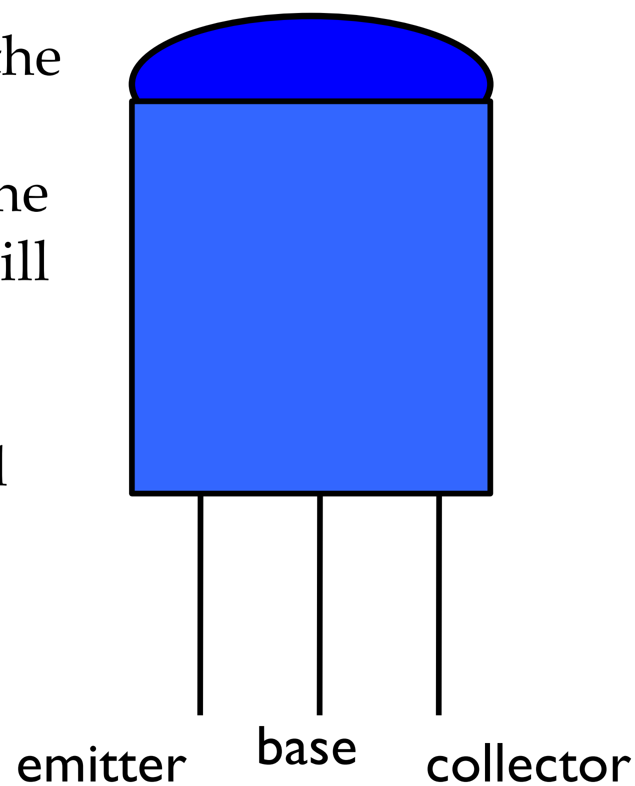
What's useful is that as the positiveness varies at the base, the current through the load resistor varies in exactly the same way, but (assuming V_{big} is, indeed, big) in a bigger way. In other words, what the transistor does is **AMPLIFY the signal**.



Transistor types

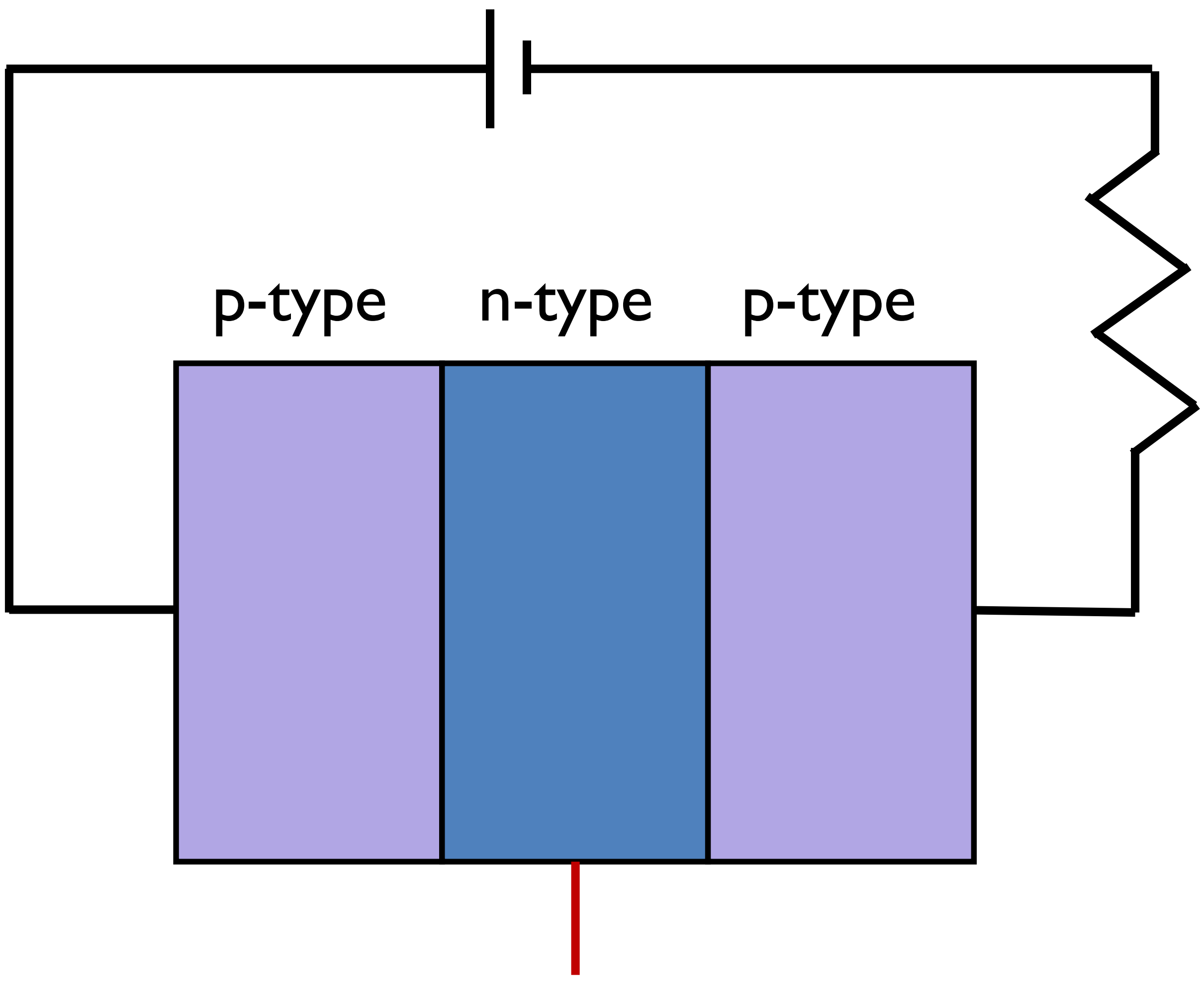
There are two kinds of transistor, npn transistors and pnp transistors. Each has its particular characteristic, but each has the potential to do the same thing, amplify. Know the symbol for transistors, know what the terminals are called, know the main difference(s) between the two types of transistor, and knowing generally how they do what they do (i.e., about the depletion zone, etc.) is what you will be tested on come the next test.

BIG NOTE: When using a pnp or npn transistor in the lab (like, when you are wiring your robot), you will need to know which terminal is the emitter, which the collector and which the base. The BASE is easy, it will always be the MIDDLE terminal. As for the others: when looking at the flat side of a 3904 transistor (an npn) OR a 3906 transistor (a pnp), the EMITTER will always be on the LEFT SIDE.



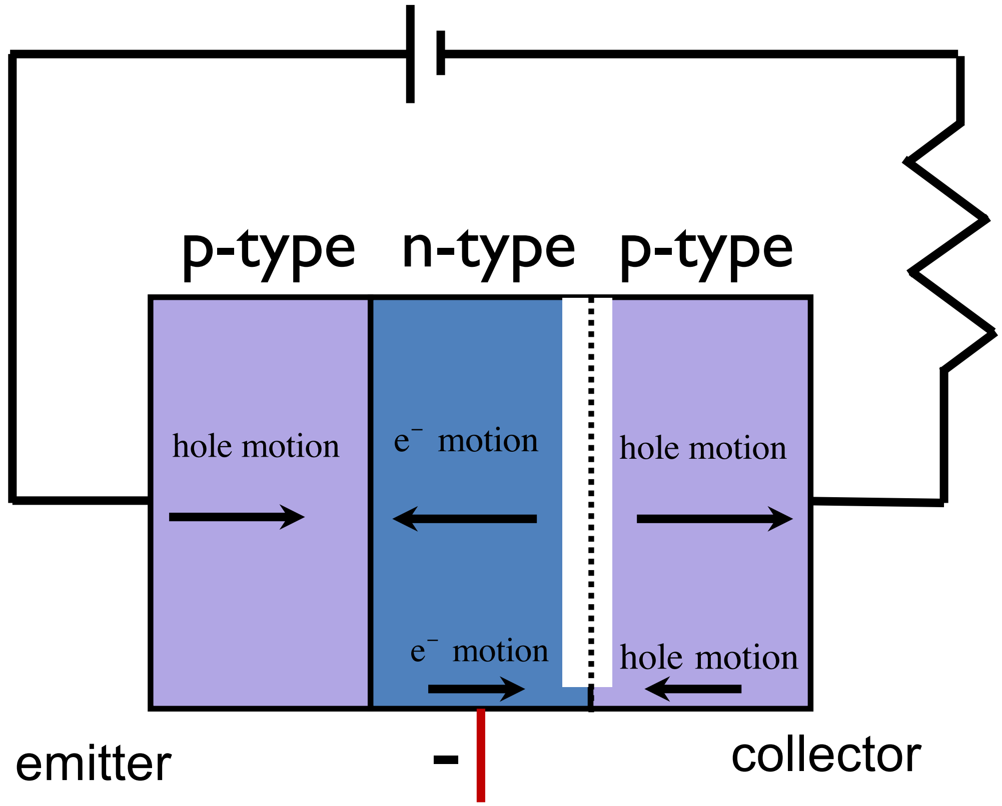
pnp transistor

Ok, your turn. What will happen in a pnp transistor?



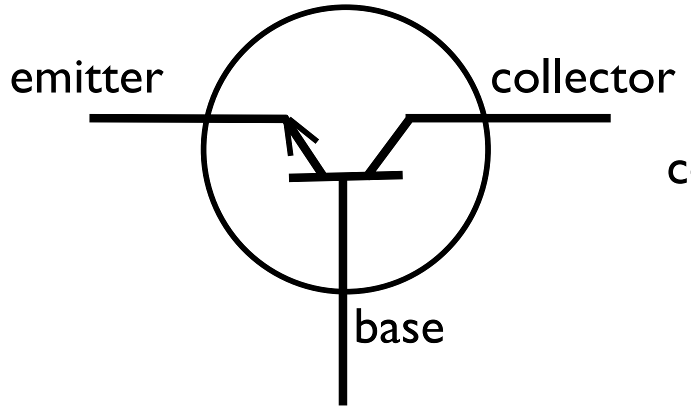
pnp transistor

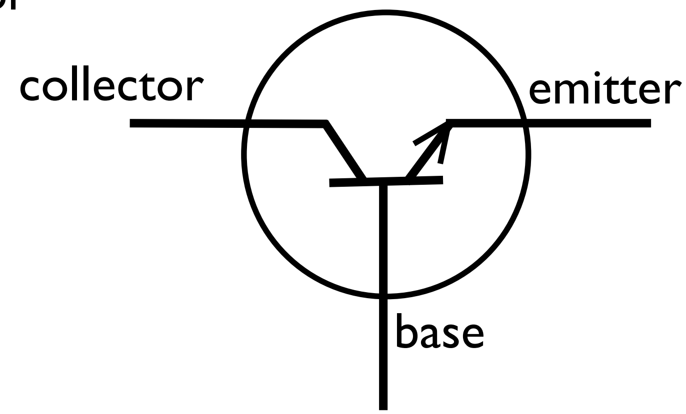
1. A depletion zone will form on the collector/base junction and we'll get no motion unless we bias the base properly.
2. By biasing the base **negatively**, we can get current to flow.
3. This means that for a pnp transistor, the **collector** is the side from which convention current will flow OUT, and the **emitter** is the side where current will flow IN -- this is the OPPOSITE of an npn transistor!



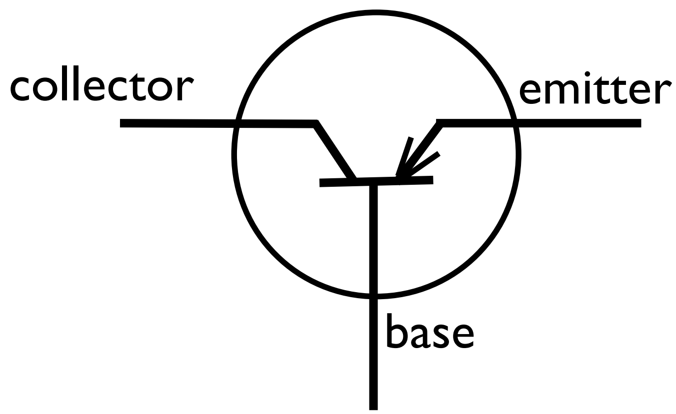
Transistor notation

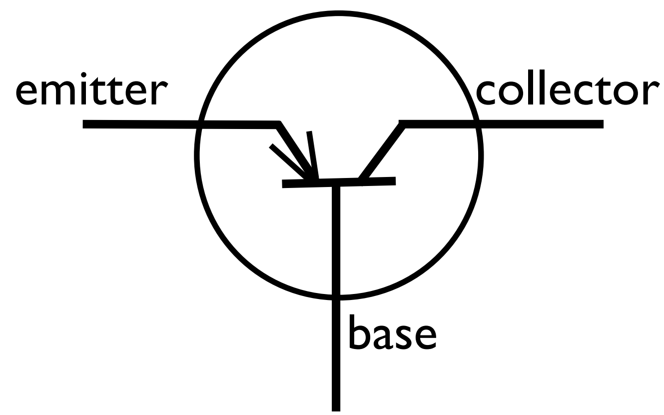
ways to symbolize an npn transistors





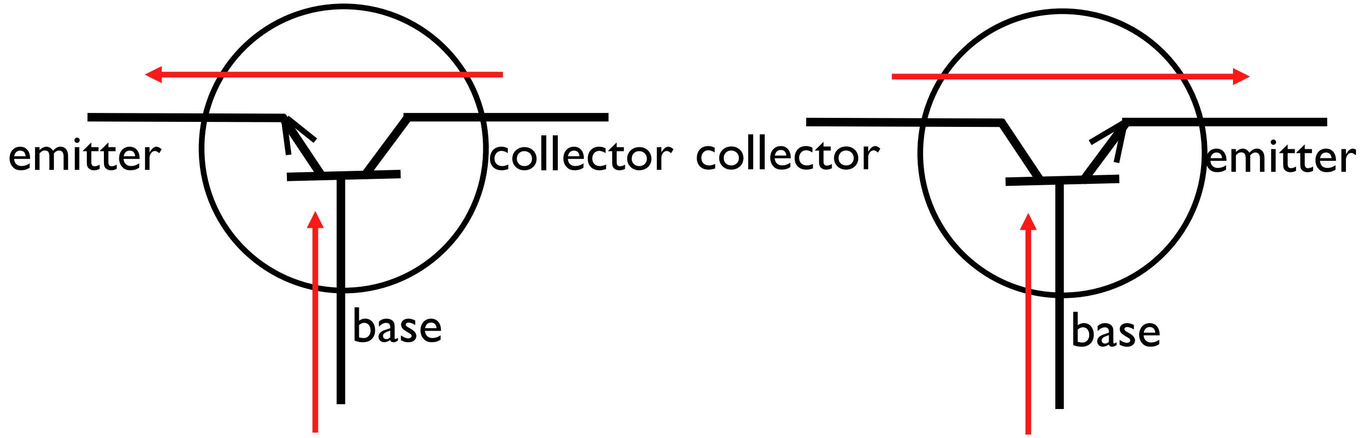
ways to symbolize an pnp transistors



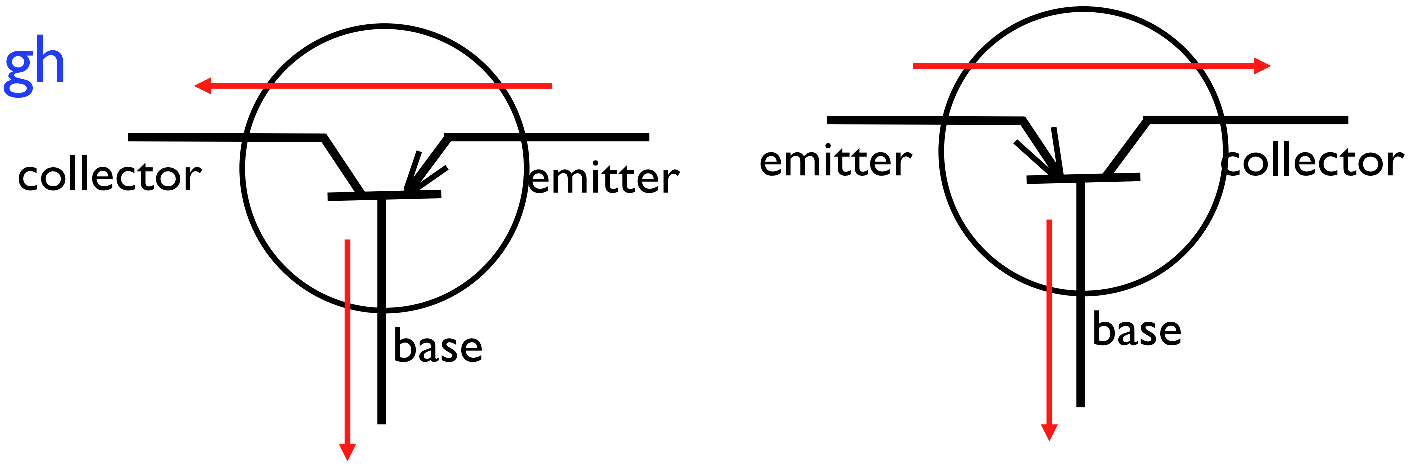


Transistor notation + current

current flows through
npn transistor



current flows through
pnp transistor



Generalizations

- 1. The arrow always points:
  ___AWAY FROM___ the center for an npn transistor
  ___TOWARD___ the center for a pnp transistor

- 2. The arrow always depicts the direction current will flow along the collector/emitter pathway

- 3. The arrow in a schematic is always presented on the ___EMITTER___ side.

- 4. The depletion zone is always found on the ___COLLECTOR___/base junction.

Generalizations

- For an npn transistor, the base voltage must be __+__ relative to the emitter for the depletion zone to diminish and allow current to flow. In this case, the base current will flow INTO the transistor.
- For a pnp transistor, the base voltage must be __-__ relative to the emitter for the depletion zone to diminish and allow current to flow. In this case, base current will flow OUT of the transistor.
- More important than the polarity of the base, relative to the emitter, is the relationship between the various currents in the transistor.

Current relationships in a transistor

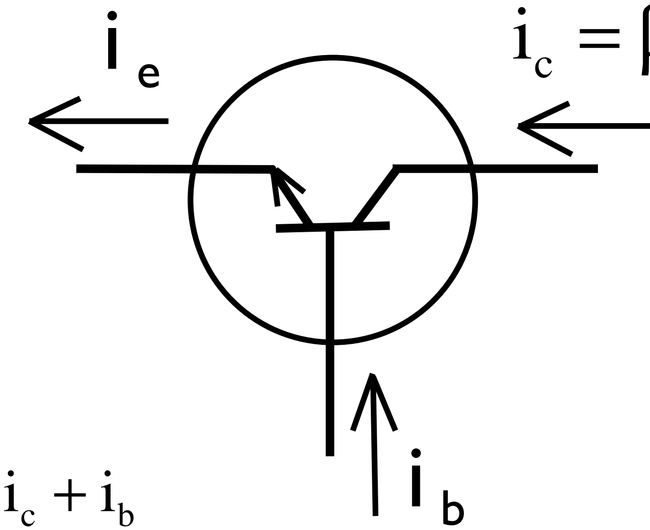
For an npn transistor, when the depletion zone is compromised and current flows into the collector, the base current is related linearly to the collector current.

a.) This relationship can be written as:

β is a constant called the "gain" of the transistor

$$i_c = \beta\ i_b$$

b.) This means that when the depletion zone is thinned and current flows into the collector and out of the emitter, the total current out of the emitter will be the current through the collector added to the current into and through the base.



$$i_c = \beta\ i_b$$

$$\begin{aligned} i_e &= i_c + i_b \\ &= \beta\ i_b + i_b \\ &= i_b (1+\beta) \end{aligned}$$

Transistors in action

- What is pointed out in textbooks is that the base current, hence the collector current (remember, the two are related linearly), will not become large enough to generate an appreciable emitter current until the base/emitter voltage is around 0.6 volts for a Silicon npn transistor.
  - Put a little differently, the transistor will not turn "on" until the base/emitter voltage is 0.6 volts.
- Computers use millions and millions of 7 nanometer transistors (that is, transistors whose length is $7\mathrm{x}10^{-9}$ meters long) on integrated circuits as on/off switches while they gate Boolean logic in the execution of the logical operations that let them do what they do.
- You will be using transistors in our upcoming projects - so you need to know how they work!