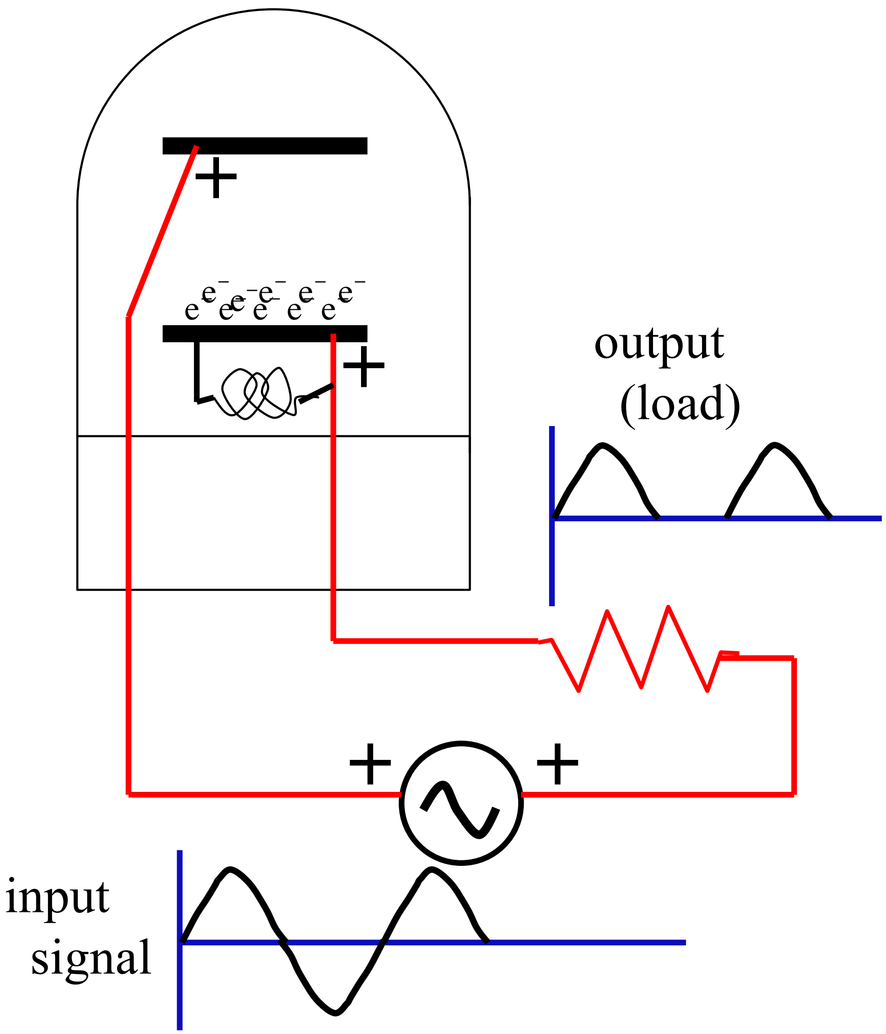
Vacuum tubes

A vacuum tube used to be used to turn AC into DC. Such devices were called **rectifiers**:



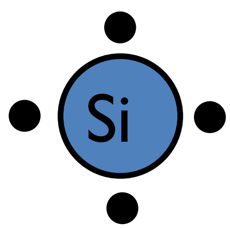
This is called a "**half-wave rectifier**"

It is sloppy DC as a lot of power is wasted, but the current moves in one direction only, and that's the definition of DC.

Vacuum tubes were the common way to turn AC into DC before semiconductor became widespread. They're still used in microwave ovens and power amps (like the kind musicians use), and used to be the basis of early TVs.

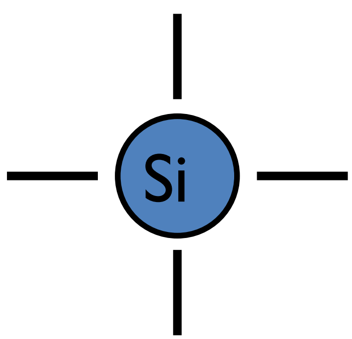
Semiconducting devices

The basis of most semiconducting devices is the **silicon** atom. What makes silicon so useful here?



A silicon atom has **four** valence electrons - which means it can form up to 4 bonds!

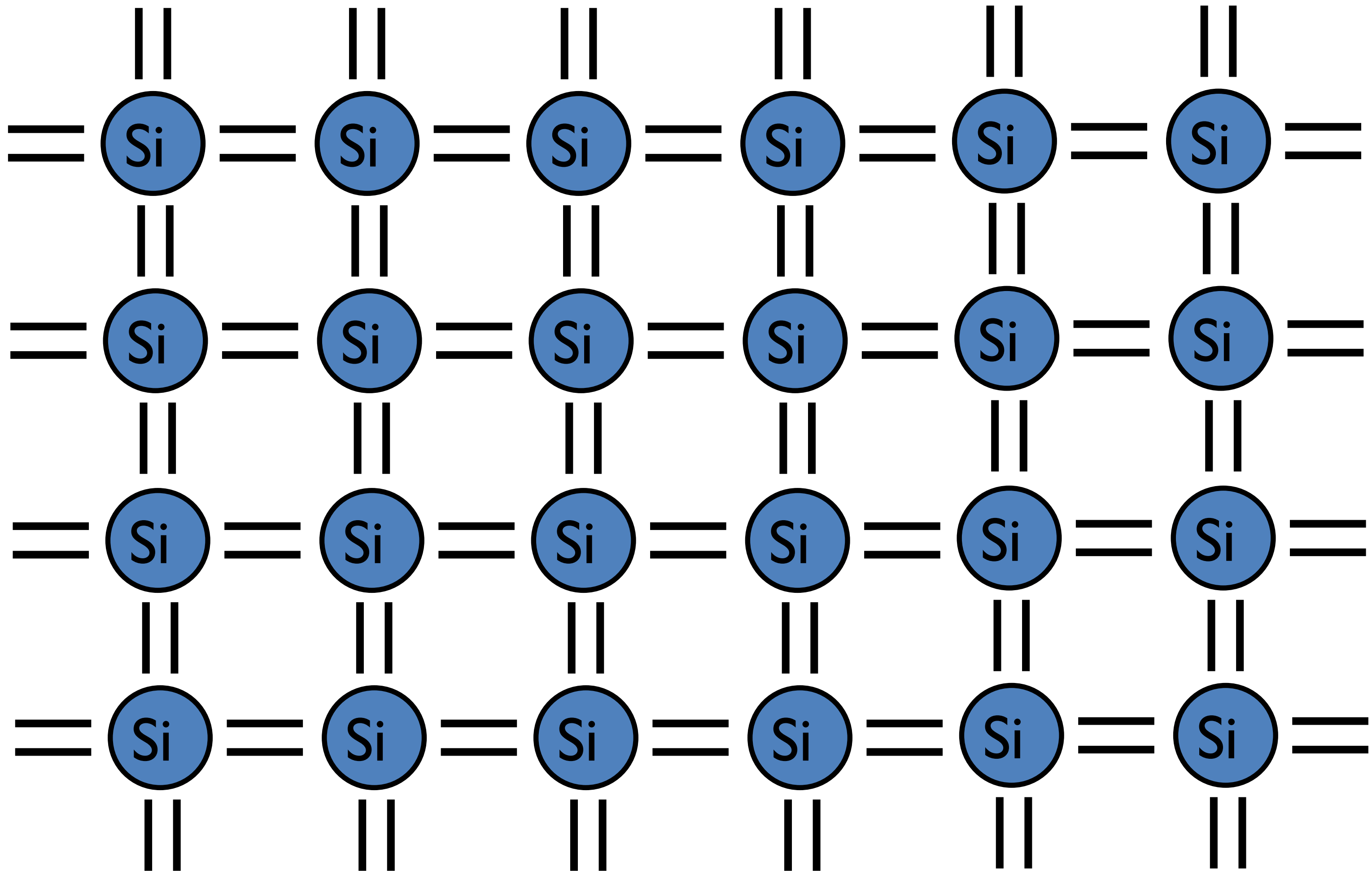
In chemistry, we drew Lewis-electron-dot diagrams to represent this.



For our purposes, we'll show them as lines to represent the bonds.

Silicon atoms

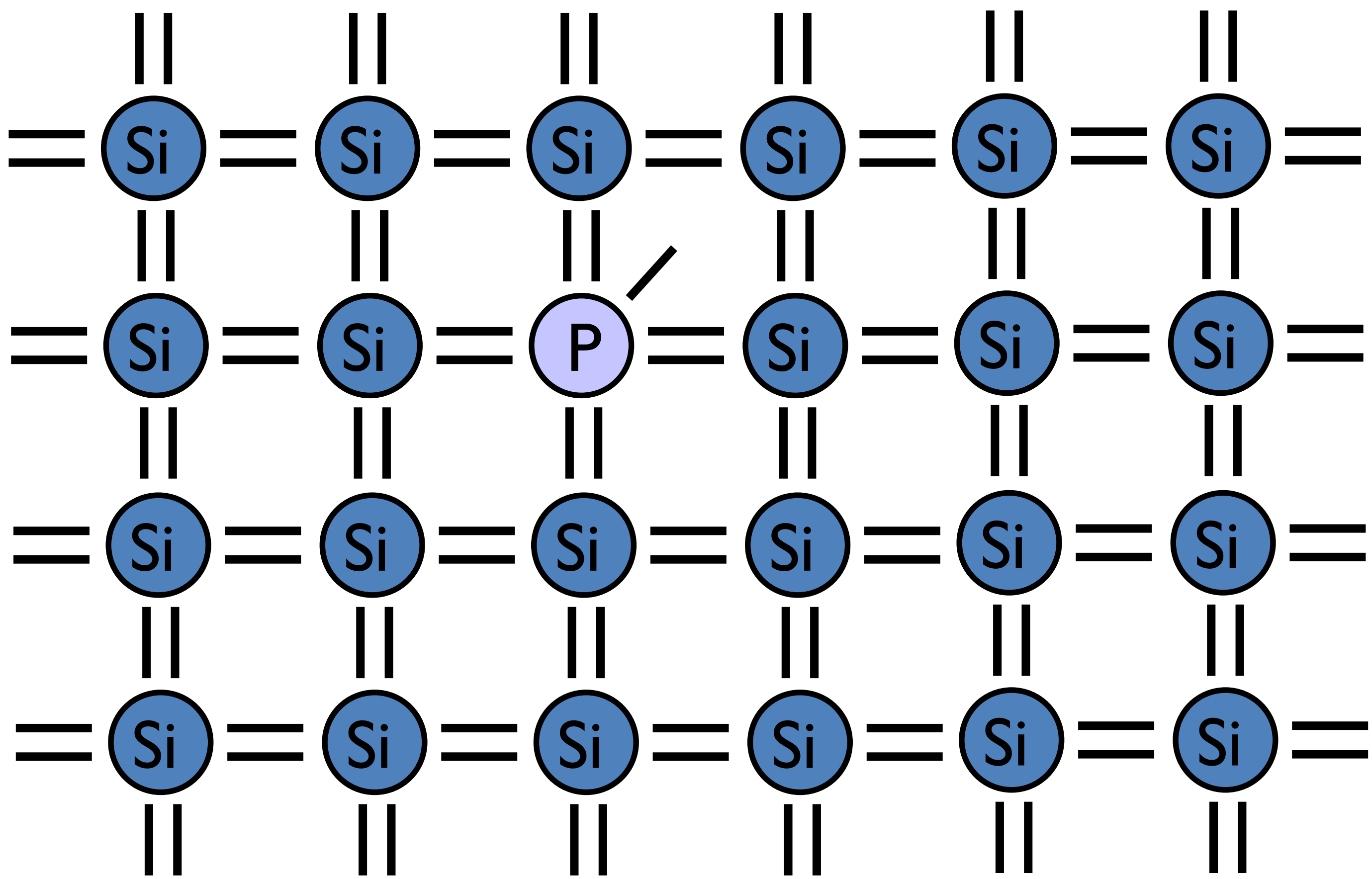
- Silicon wants to complete its valence shell, so it can do so by sharing 4 other electrons with 4 other silicon atoms. This creates a **lattice**, shown below:



Impurities in the lattice

What would happen if we placed an impurity like phosphorus, with five valence electrons, somewhere in the lattice?

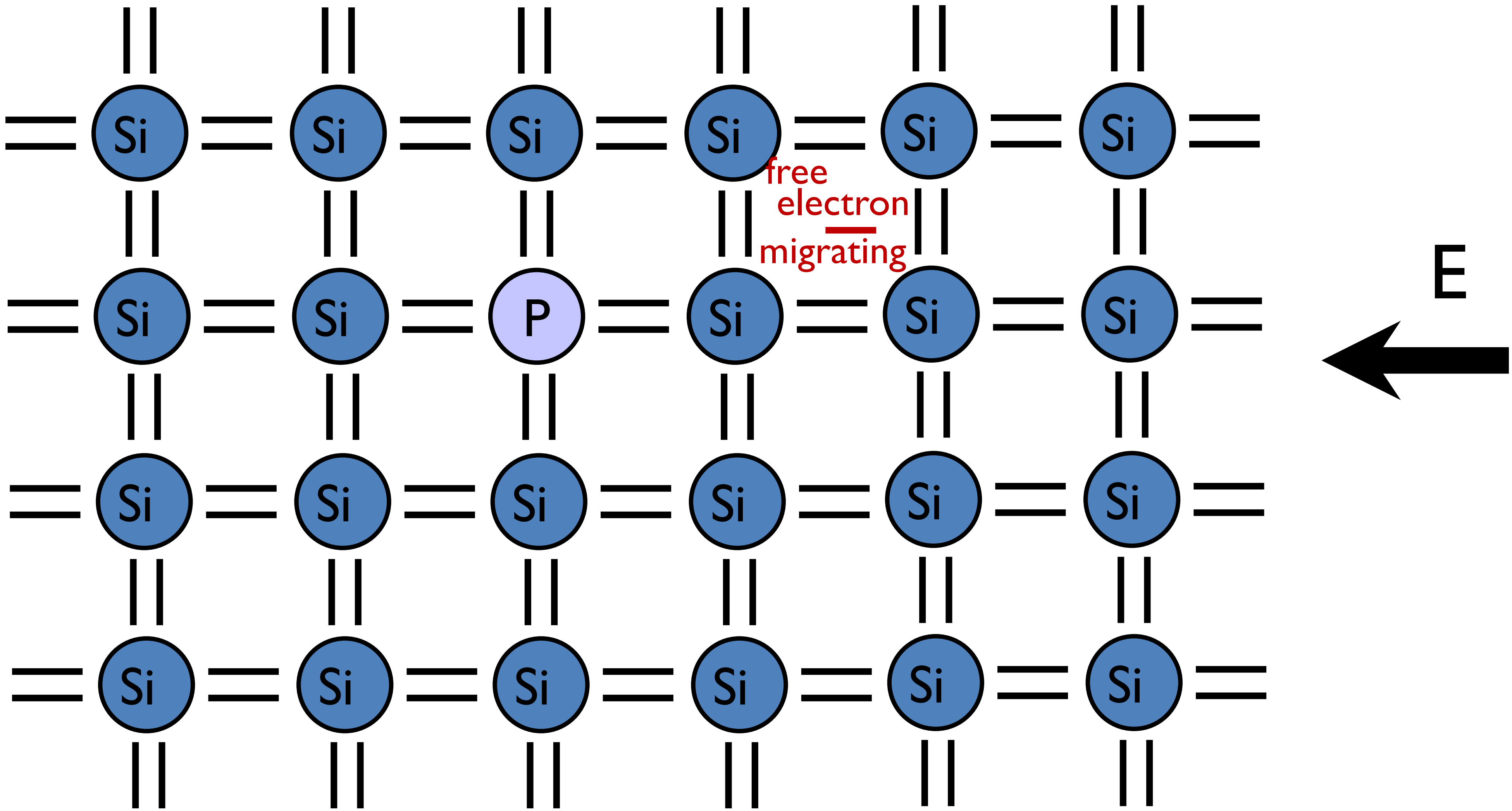
- (This is called "doping.")



Impurities in the lattice

- With that impurity present, we would end up with a lattice in which there was one electron very loosely bound to the atom it came with. And if we put this structure in an electric field, what then?
- In an electric field, that extra electron could be made to break loose so that it might migrate freely throughout the structure, much like a valence electron does in a METALLICALLY BONDED structure.
- In other words, we could end up with an *insulating* material that had *metallic* (conductive) characteristics. Such materials are called SEMI-CONDUCTORS.

Semiconductor illustrated



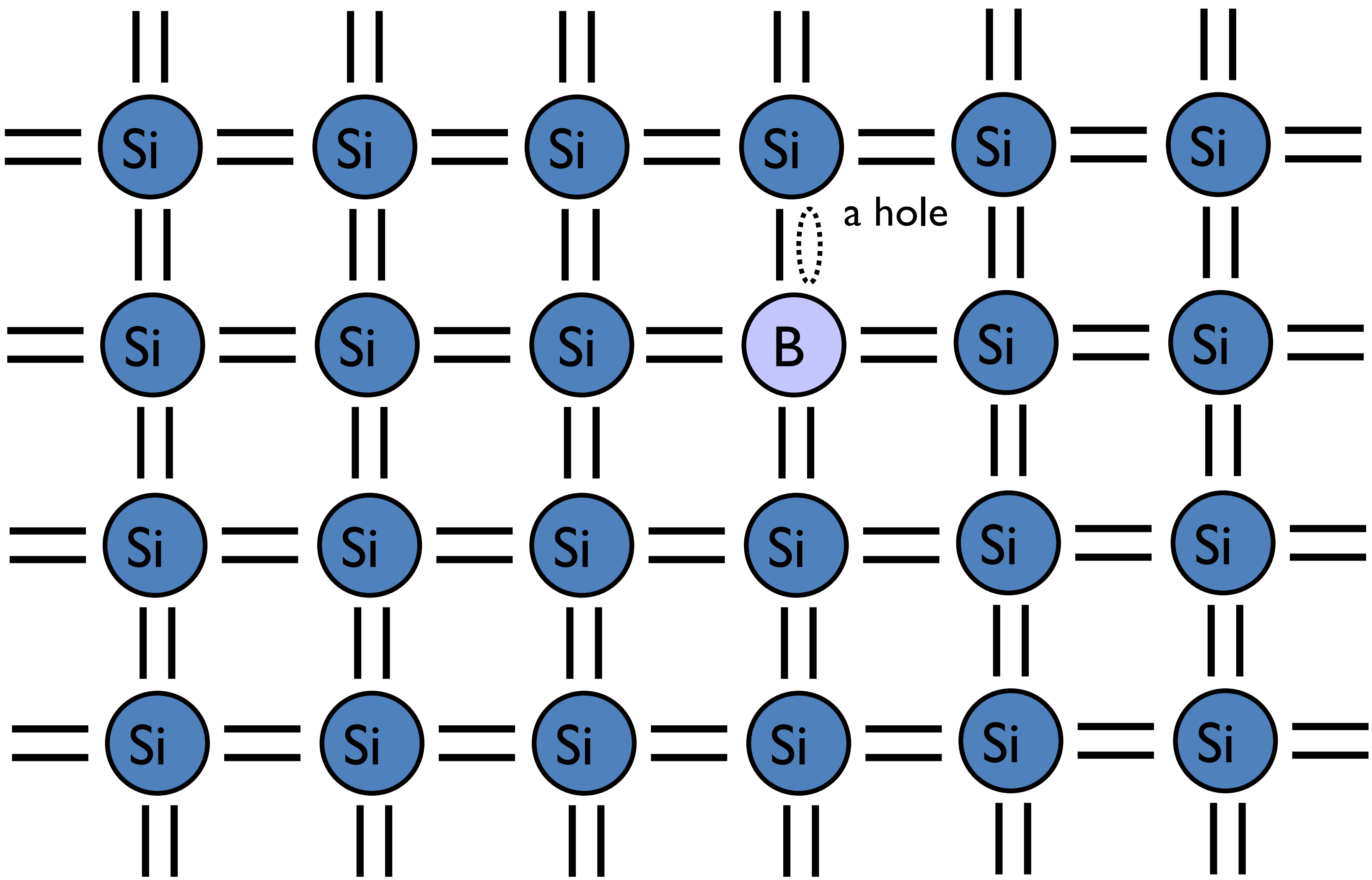
Types of semiconductors

- If a free electron is migrating (as we just saw), the material is termed an "**n-type**" semiconductor -- it has "electron conduction"

- If the impurity had been, say, a boron atom with its <u>three</u> valence electrons, the situation would have been a little different. In that case, there would have been a "hole" in the lattice where an electron should go (as far as the silicon is concerned) but in which there is no electron.

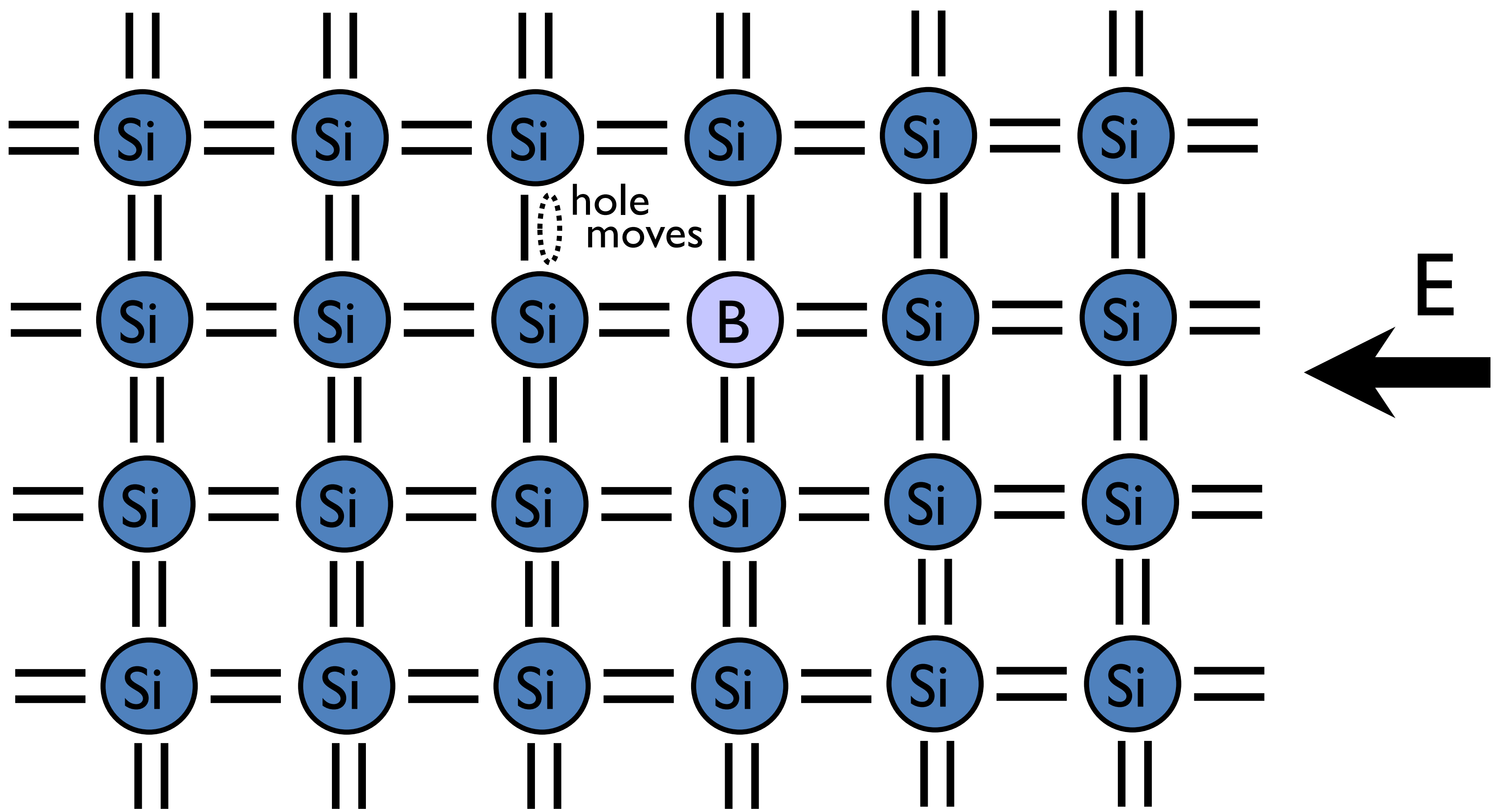
- This situation is shown on the next slide:

Lattice with a hole...



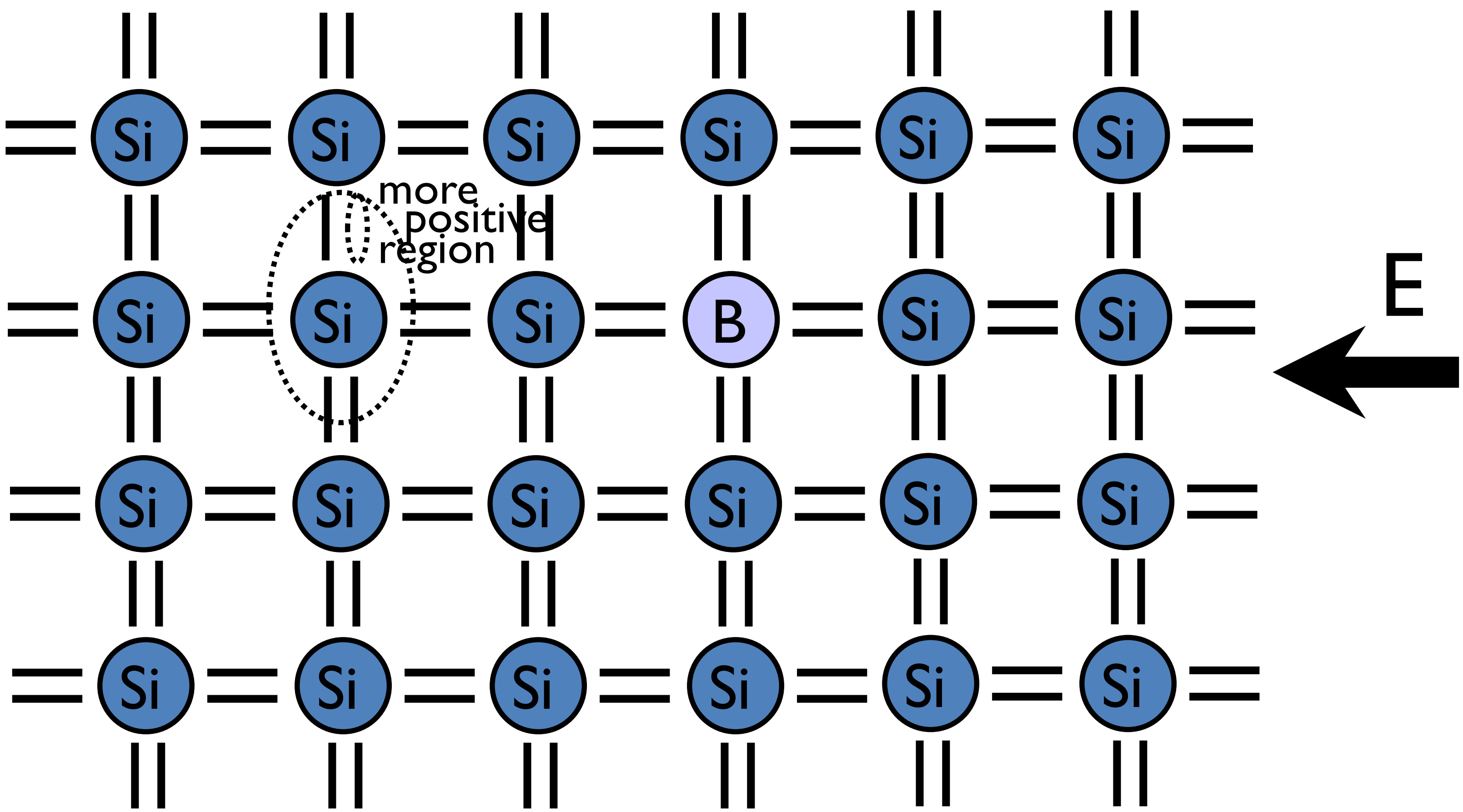
Lattice with a hole

- If we applied an electric field that that situation, a valence electron to the left would migrate to the right to fill the hole leaving a hole behind, and the **hole** would migrate through the lattice



Lattice with a hole

- When a silicon atom hosts a hole, it will be more electrically positive that normal (there is one less electron in the valence shell).



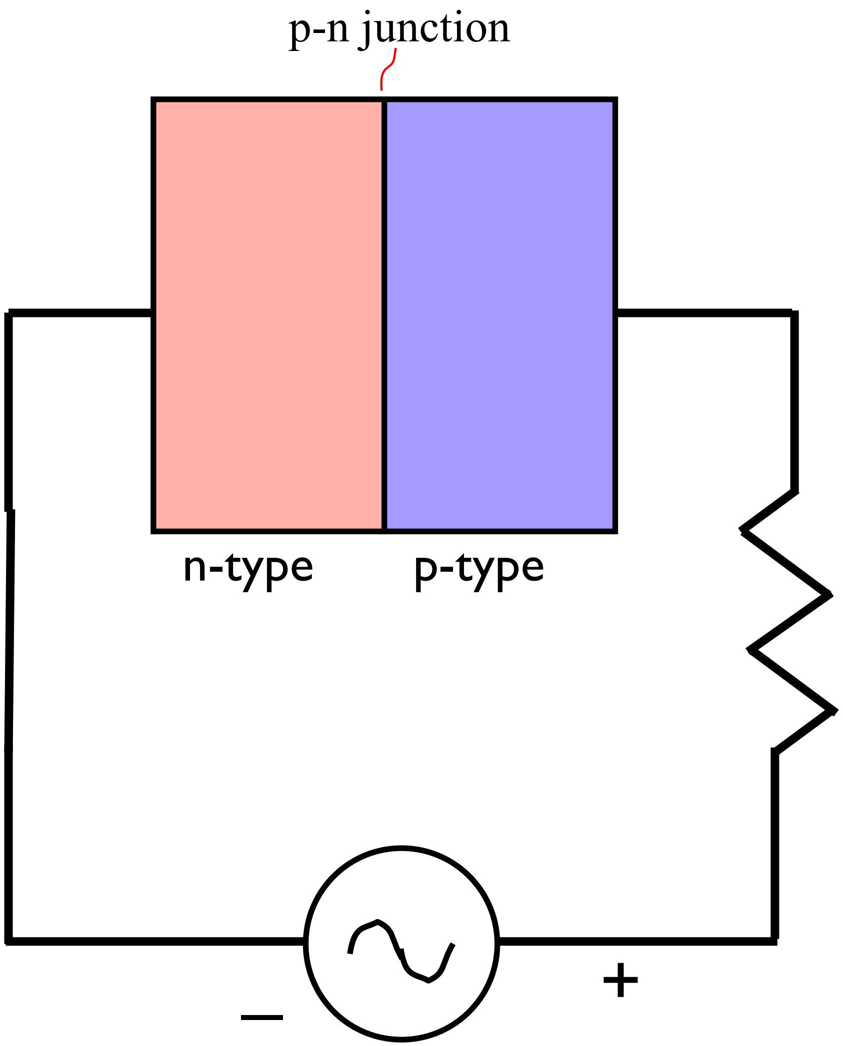
Types of semiconductors

- With a hole in the lattice, we effectively have a **positive** "charge" moving through the structure.
- These are termed **"p-type**" semiconductors, and they undergo "hole conduction"
  - Remember that n-type semiconductors undergo electron conduction

- When asked what the difference is between n-type and p-type semiconductors, say, on a test, you should be able to identify:
  - What kind of conduction they undergo using the terms above
  - How they are "doped" (that is, what's different about the oddball atom in the lattice causing the impurity)

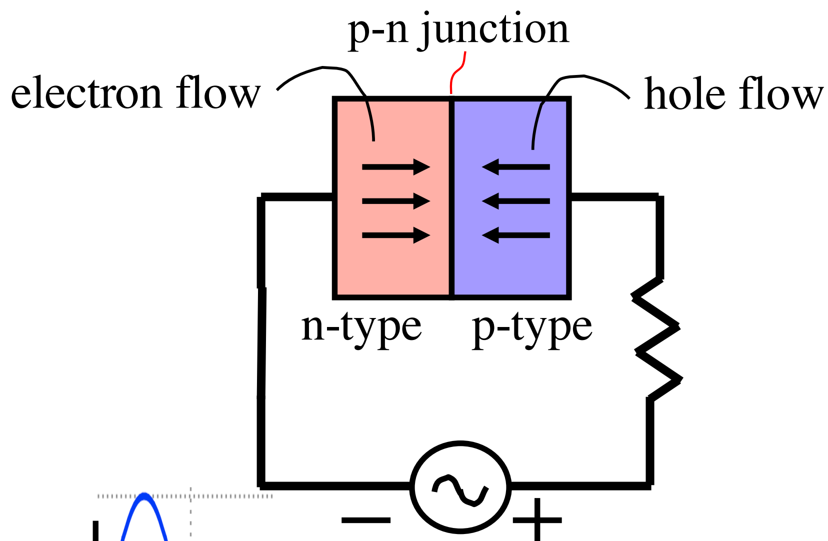
So what if...?

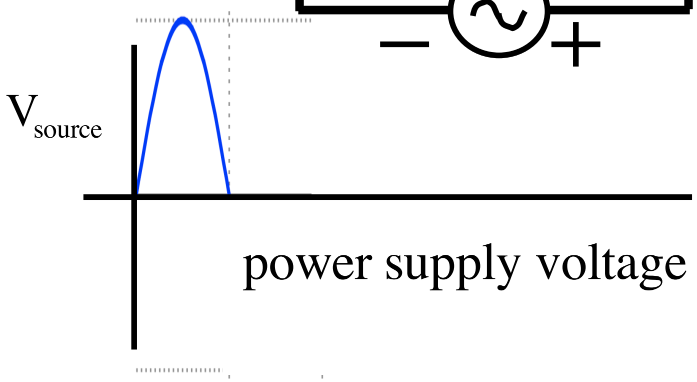
- ...we "glue" a p-type semiconductor onto an n-type semiconductor? To answer, consider the following circuit:

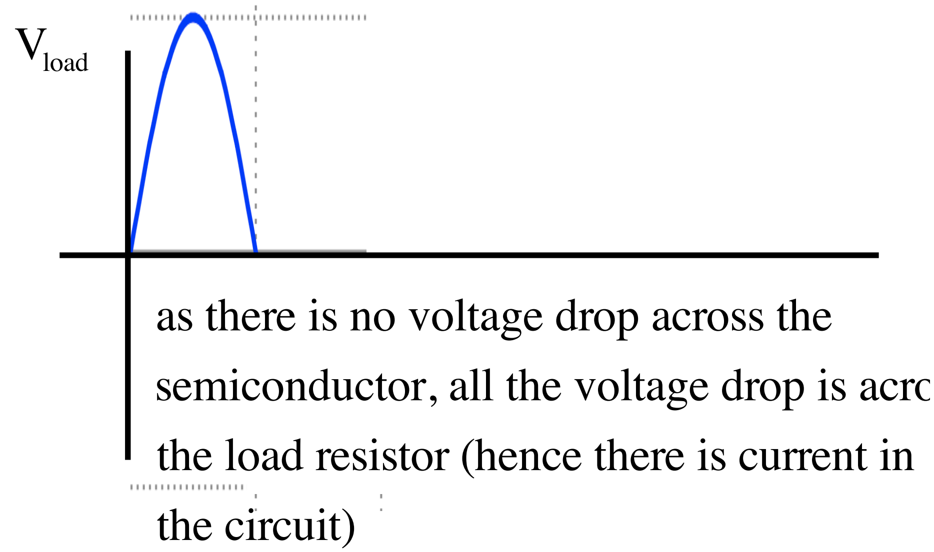


What will happen as current begins to flow at the instant the voltage has the polarity shown?

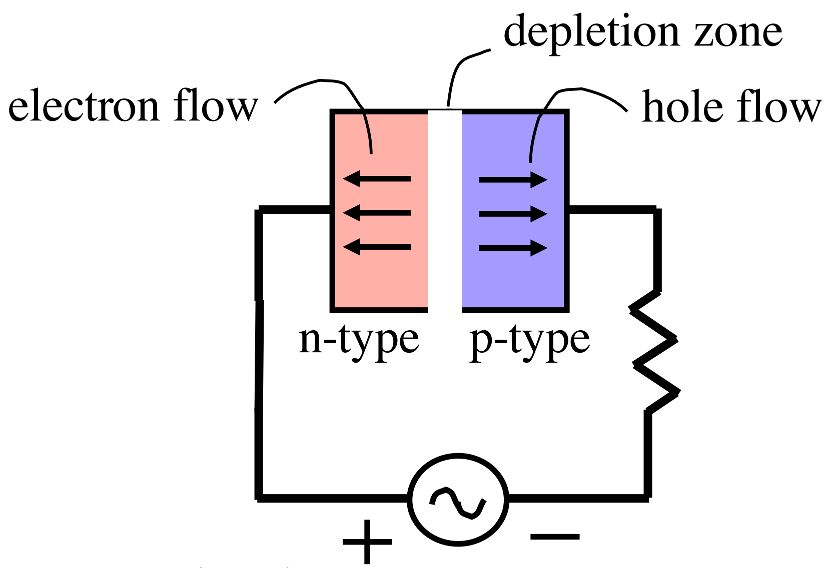
With the polarity shown, the electrons in the n-type semiconductor will move to the right while the holes in the p-type semiconductor will move to the left. Electrons and holes will meet along the boundary between the two semiconductors with the electrons filling in the holes. As it will take little energy to effect this situation, there will be only a tiny potential drop across the semiconductor with almost all of the voltage drop happening across the resistor. As current through a resistor is proportional to the voltage across a resistor, this means there IS a substantial current in the circuit and the output voltage across the load will look as sketched.

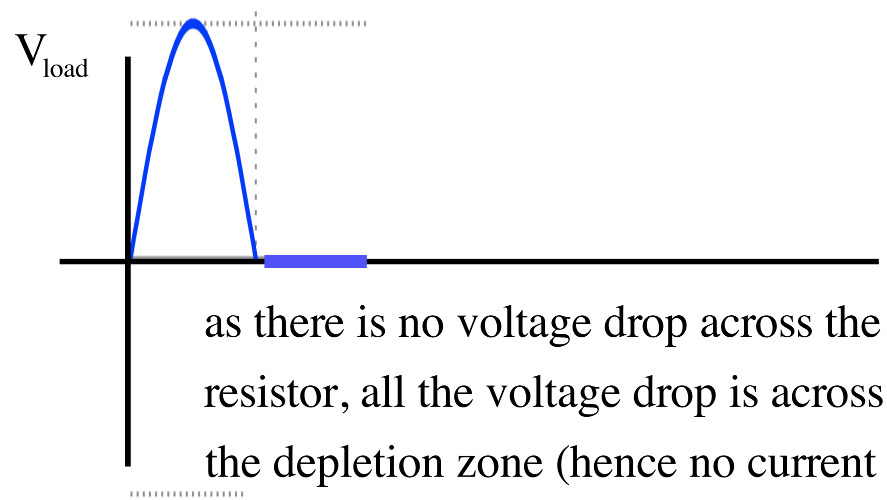




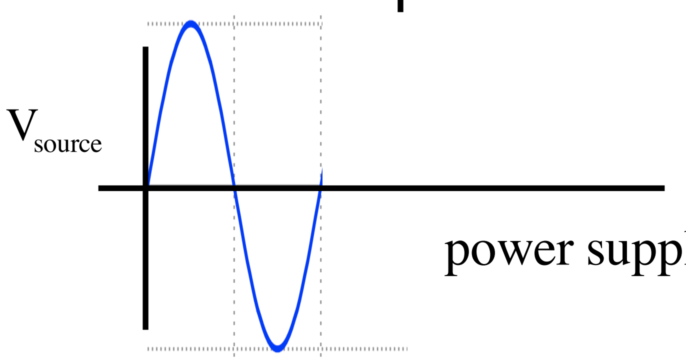


With the polarity change, the electrons in the n-type semiconductor will move to the left while the holes in the p-type semiconductor will move to the right. This will produce a depletion zone at the p-n junction. Acting like a break in the circuit, all the voltage will drop across the junction so that no voltage drop occurs across the resistor. As current through a resistor is proportional to the voltage across a resistor, this means there is NO current in the circuit and the output voltage across the load will look as sketched.





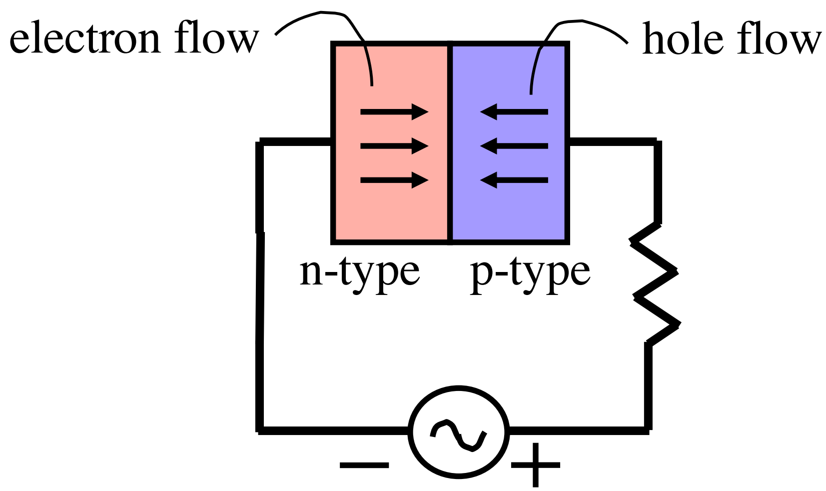
as there is no voltage drop across the resistor, all the voltage drop is across the depletion zone (hence no current in the circuit)

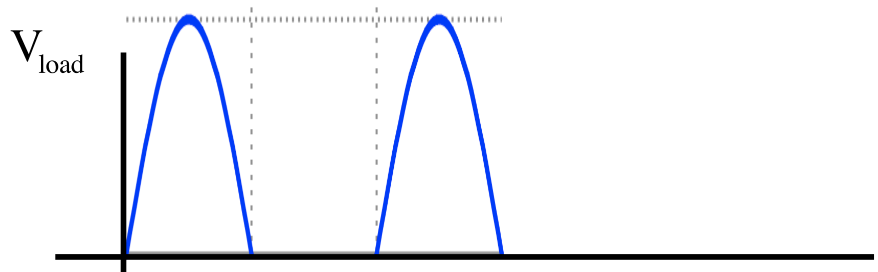


power supply voltage

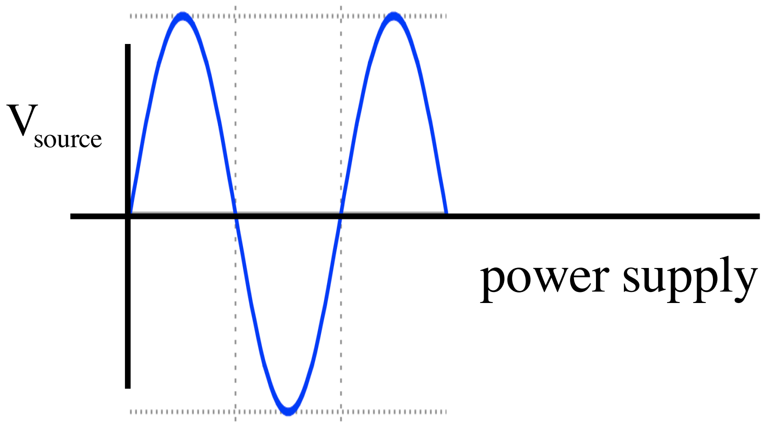
This is called a **reverse bias**.

When the power supply cycles back, the depletion zone goes away, all the voltage drop occurs across the resistor which means we again have current in the circuit. In short, this device is designed to turn AC into DC or, in a DC circuit, restrict the direction current can flow in the circuit.





again, no voltage drop across the semiconductor, all the voltage drop is across the load resistor (hence there is current in the circuit)--what this device does is turn AC into DC . . .

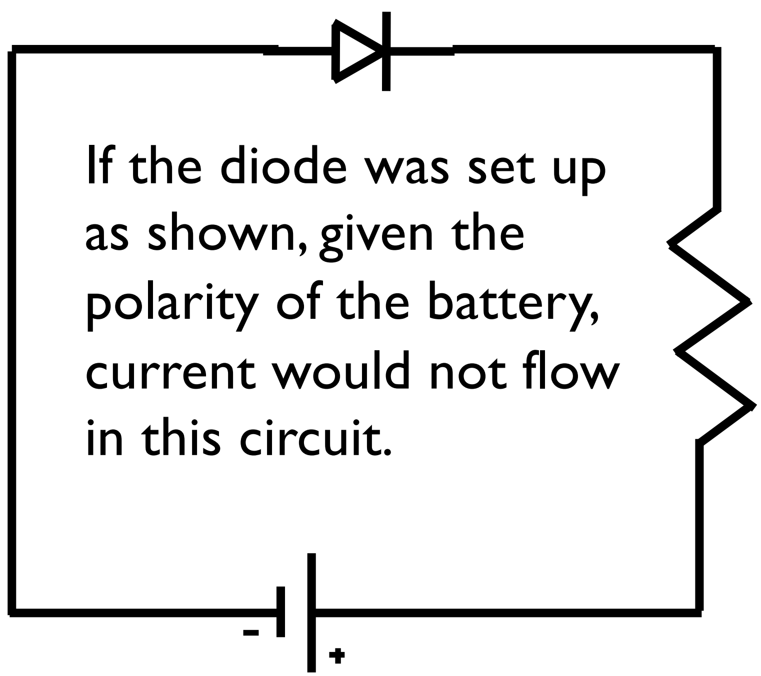


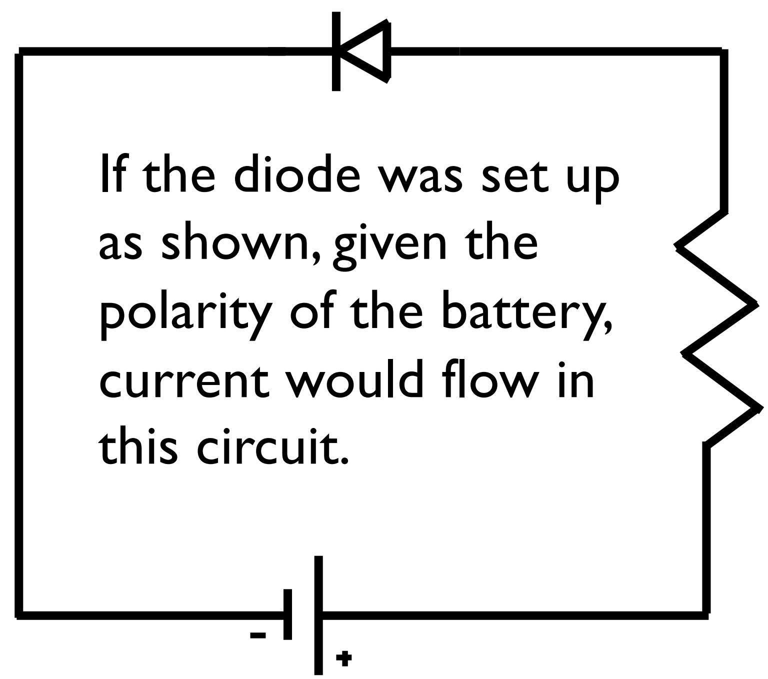
power supply voltage

This is called a **forward bias**.

Diodes

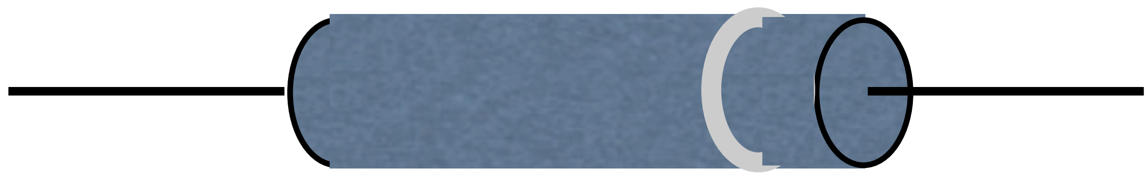
- A device that does what we just explored is called a **diode**. Its symbol is shown below.
- Diodes only allow current to flow in one direction, with the arrow making up the diode's symbol identifying that direction in the circuit.



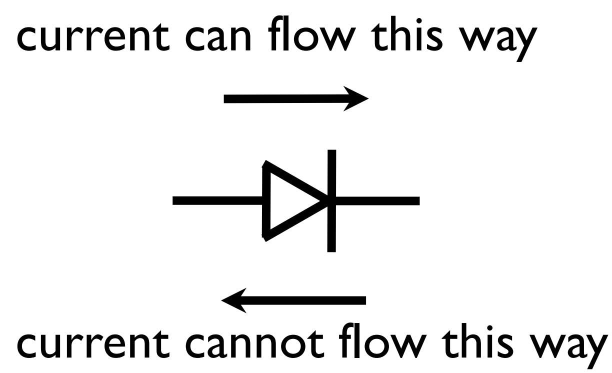


What does this look like?

- Physically, diodes look like resistors but with only one band, usually silver, at one end.

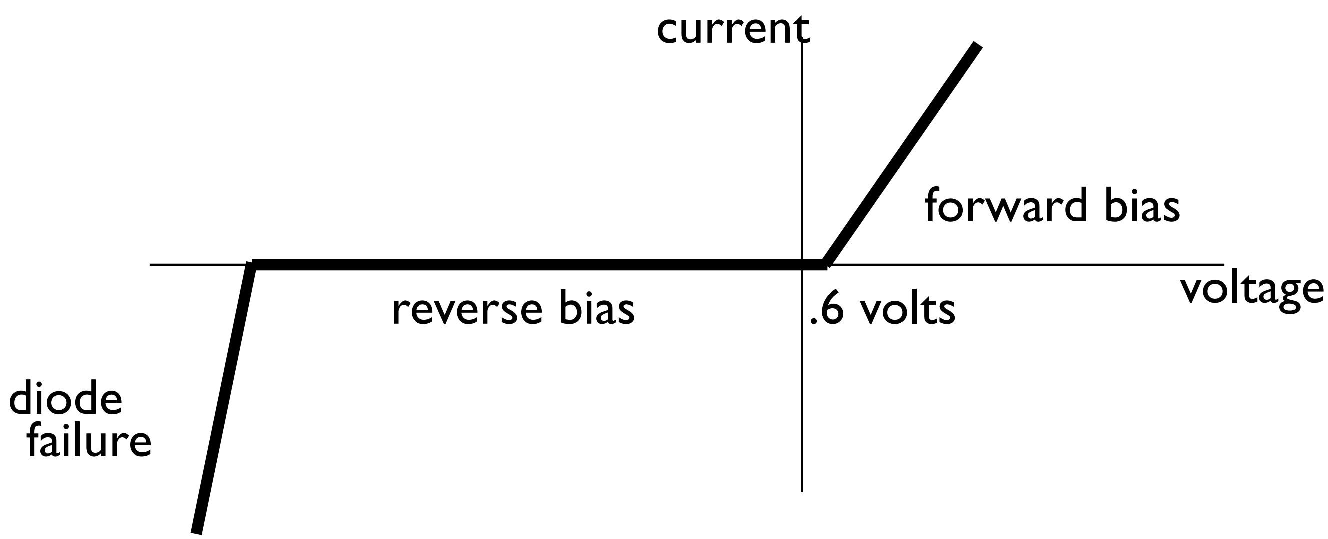


To sum up diode symbols and basic behavior:

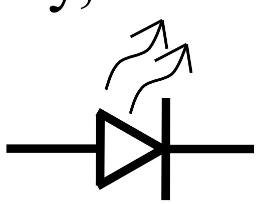


Diode current function

- A current function for a diode looks like this:

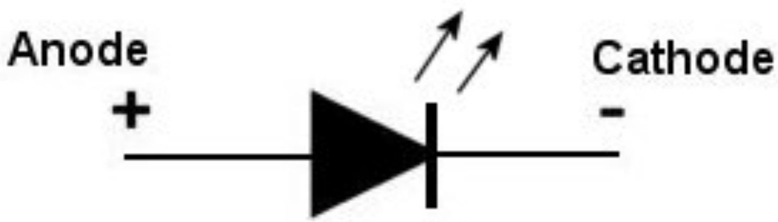


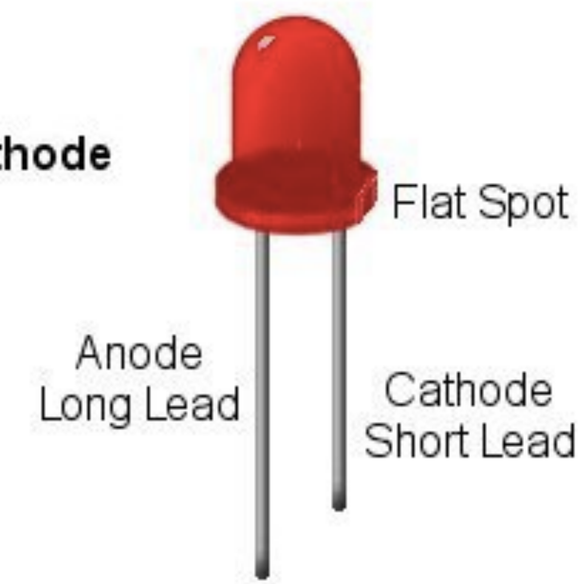
- All diodes give off energy when they are in forward bias. Some do this in the optical range. These are called "light emitting diodes," or LED's. The symbol for an LED is shown to the right where the arrows, usually shown wavy, are meant to denote radiation leaving the device.



LEDs explained a bit more

- Remember that an LED is just a single diode - when current flows in forward bias, energy is given off as heat!
  - Usually, we can't see this because it's in the infrared range
- If the diode is made of certain materials, though, the energy given off will be in the visible light range and it will glow!

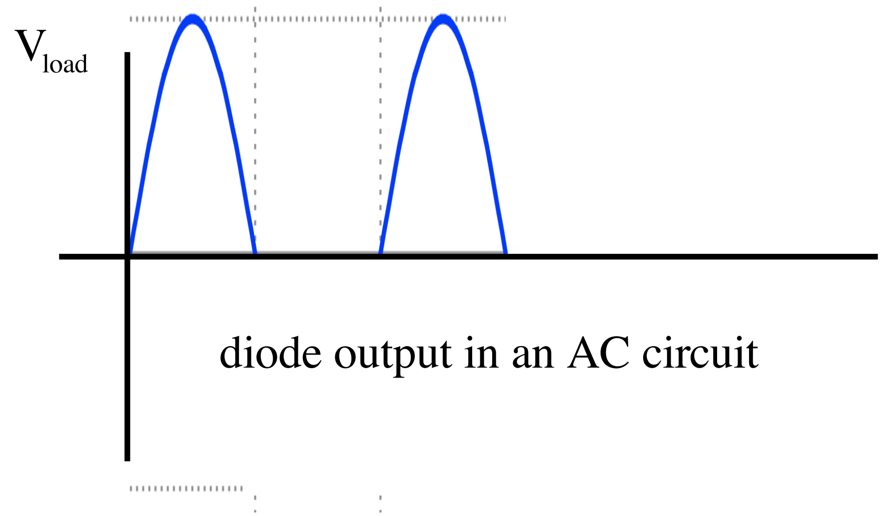




Why use a diode?

- A single diode can convert AC to DC, by means that should be obvious. Less obvious might be the inherent problems here. Can you spot them?

  - It's wasteful! You lose half your power (when V = 0)
  - It's lumpy! You get pulses of current instead of a steady signal.



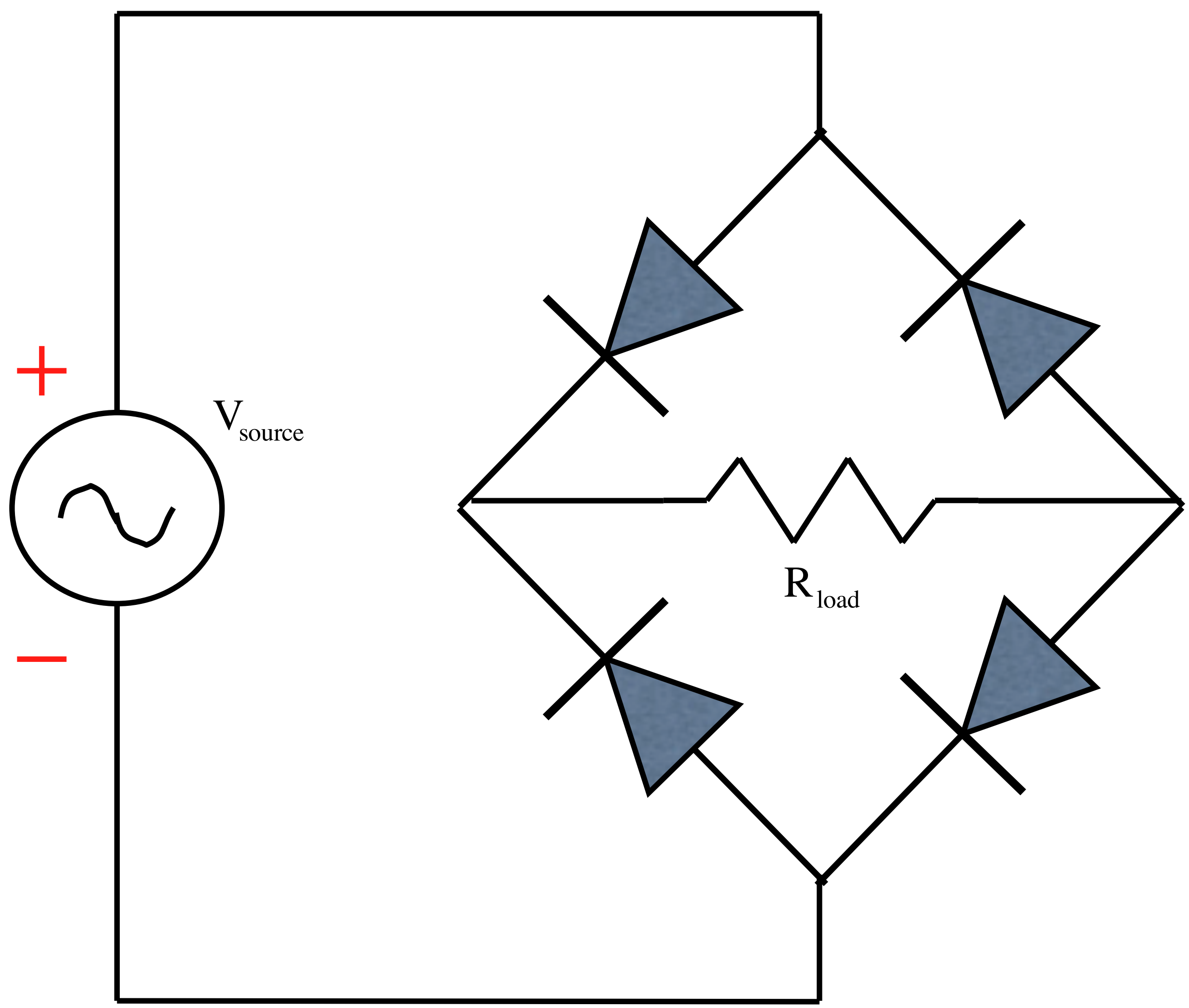
- So how to fix these…?

Diode bridge

Follow the current path when the AC power polarity is as shown.

Note 1: The current at far right node will flow downward instead of upward because current always flows from higher voltage to lower, and flowing upward would violate that stricture.

Note 2: The left side of the load resistor is electrically positive.



Diode bridge

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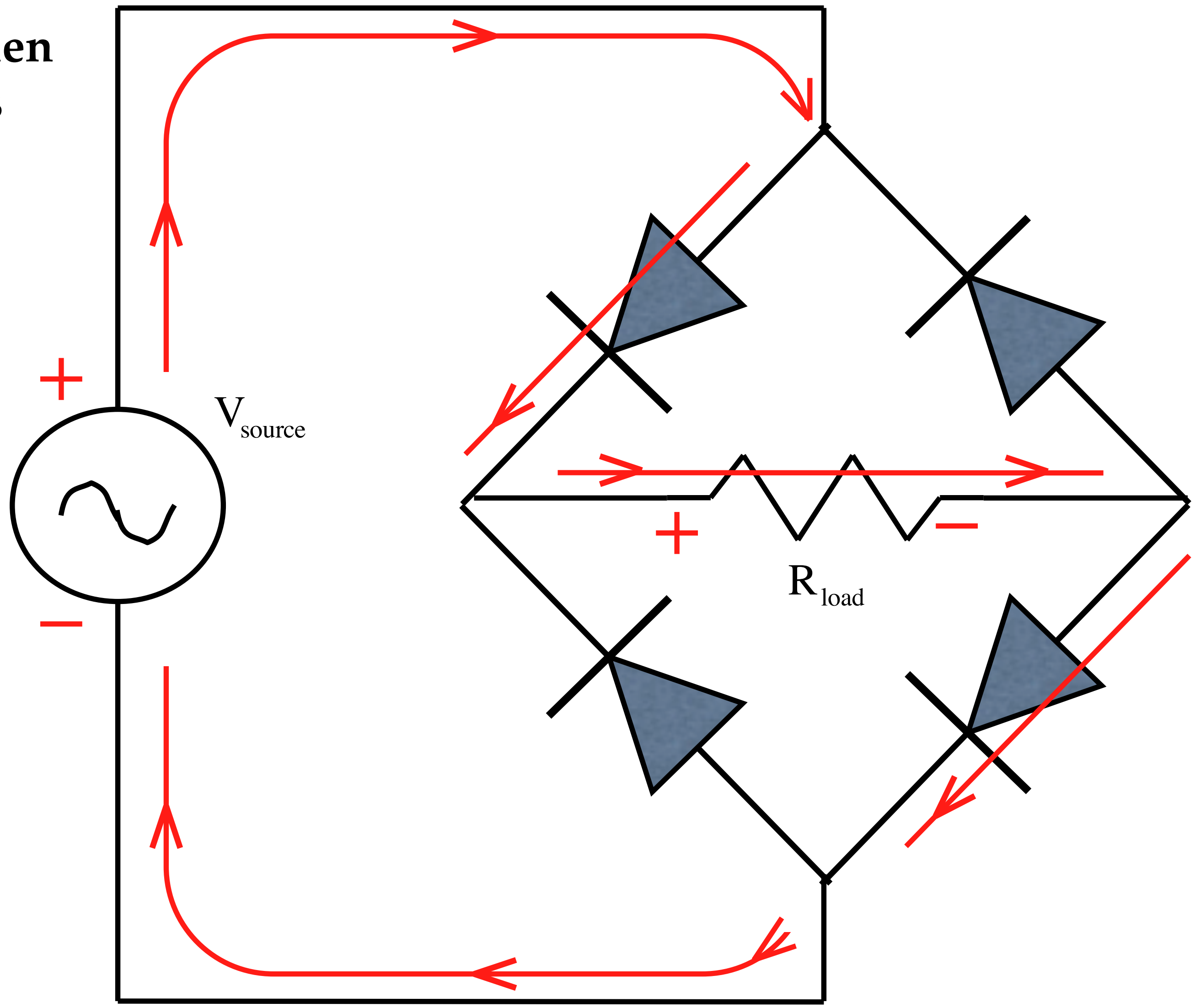
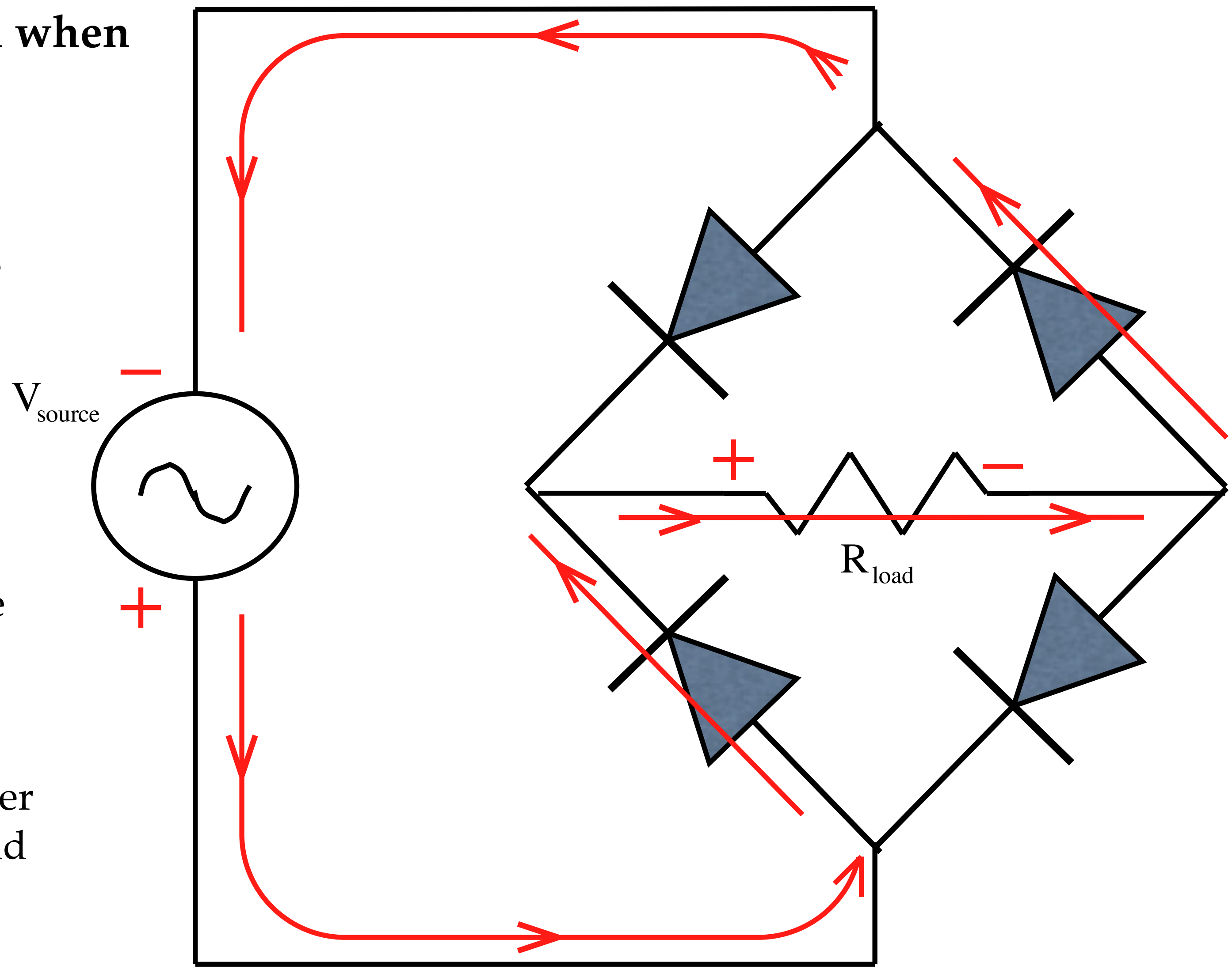


Diode bridge

Follow the current path when the AC power polarity reverses, as shown:

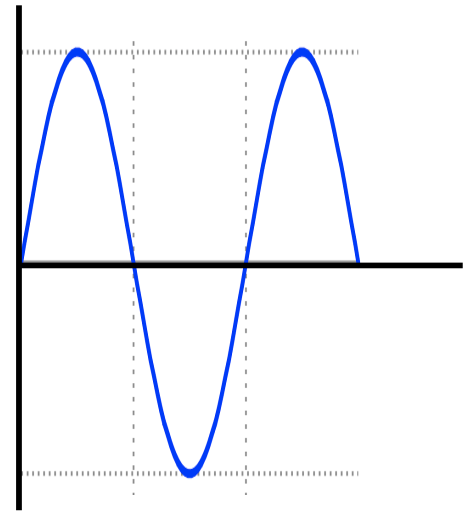
Note 1: The left side of the load resistor is STILL electrically positive.

Note 2: Evidently, with a diode bridge it doesn't matter what polarity there is across the AC source, current through the load resistor ALWAYS flows in the same direction. In other words, we've taken AC and turned it into DC.

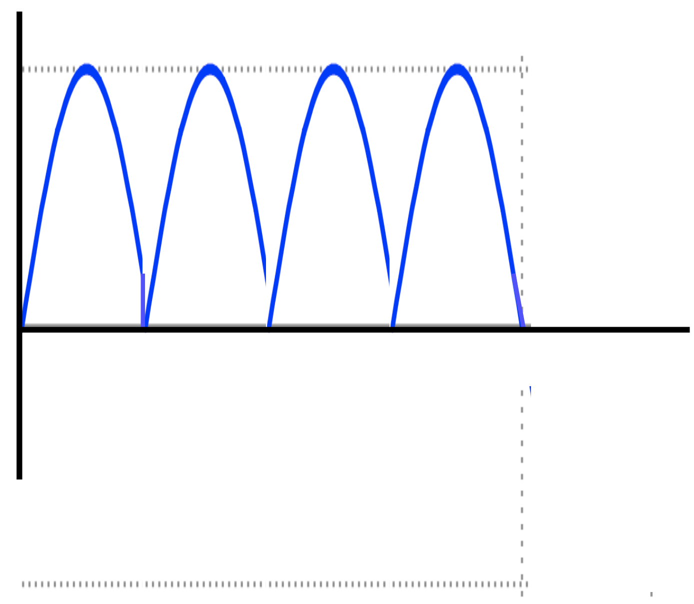


The net result?

From an AC power supply input of:



we get a DC load resistor output that looks like:



Now what?

- So we've fixed the first problem: we aren't losing big amounts of power anymore (no big gaps of 0 voltage). But we still have a lumpy signal. How can we smooth it out?

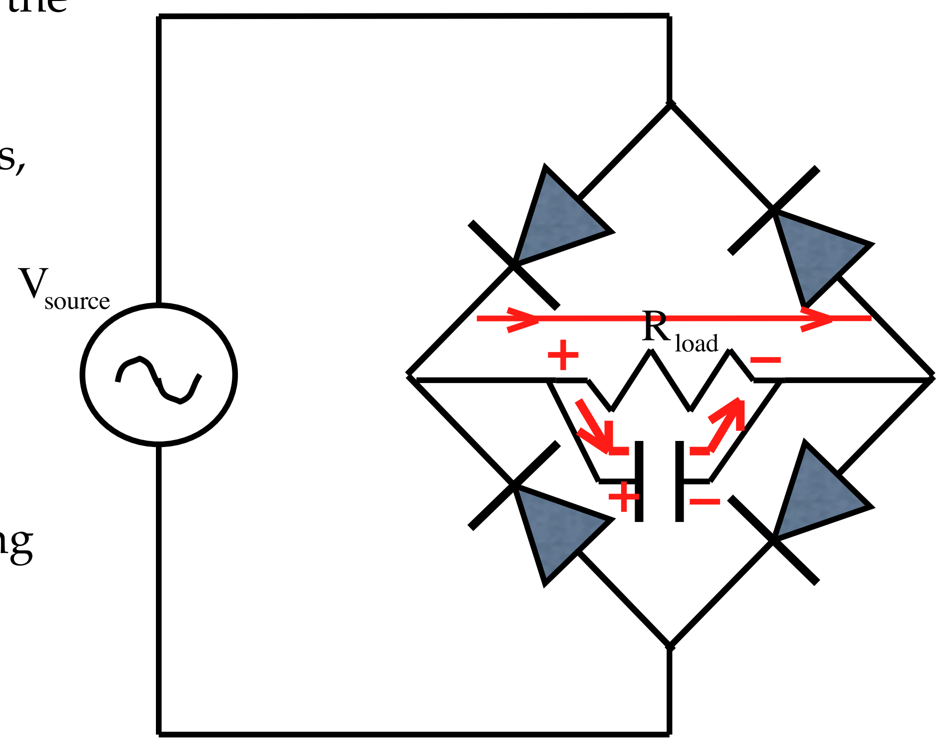
- Hint: start by considering what actually needs to happen in the wires to even out the lines…then think about a circuit element that can do this.

AC→DC

- Put a capacitor across the load resistor!

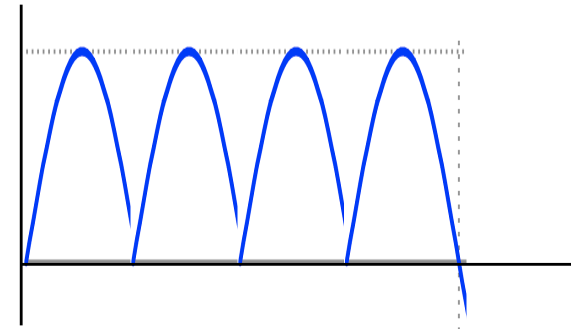
a.) As the voltage across the load resistor increases due to the voltage increase across the AC power supply, the voltage across the capacitor also increases.

b.) As the voltage across the power supply decreases, the voltage across the load resistor also begins to decrease but not as fast as normal. Why? Because the charged capacitor, which is in parallel with the resistor and, hence, must have the same voltage as the resistor, is still charged. It responds to the attempted voltage drop across the resistor by beginning to discharge through the resistor. In doing so, it keeps the resistor's voltage artificially high.

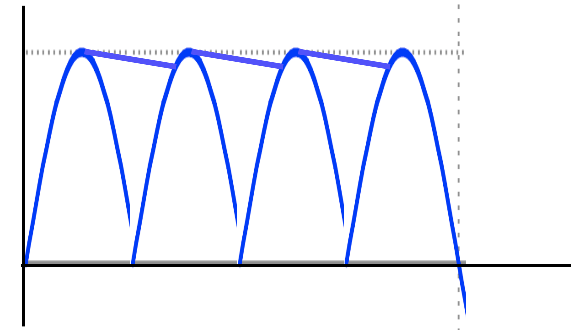


c.) This buoying of voltage across the resistor continues until the duty cycle across the resistor and capacitor begins to again charge up the capacitor and the whole cycle starts over again.

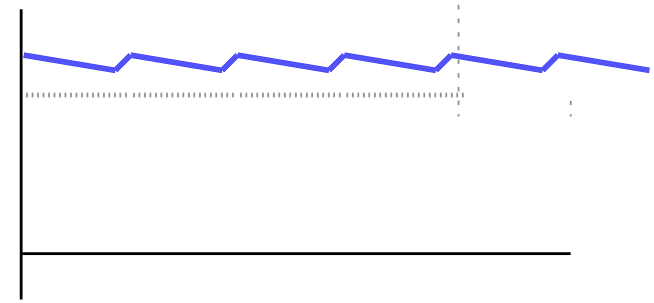
The end result is that our lumpy DC load voltage



gets smoothed out



and ends up looking like:



Called *ripple*, this effect is exaggerated in the sketch. It is usually no more than 2% to 5% of the amplitude of the voltage, so the actual waveform looks to the naked eye like: