Electronics of Audio

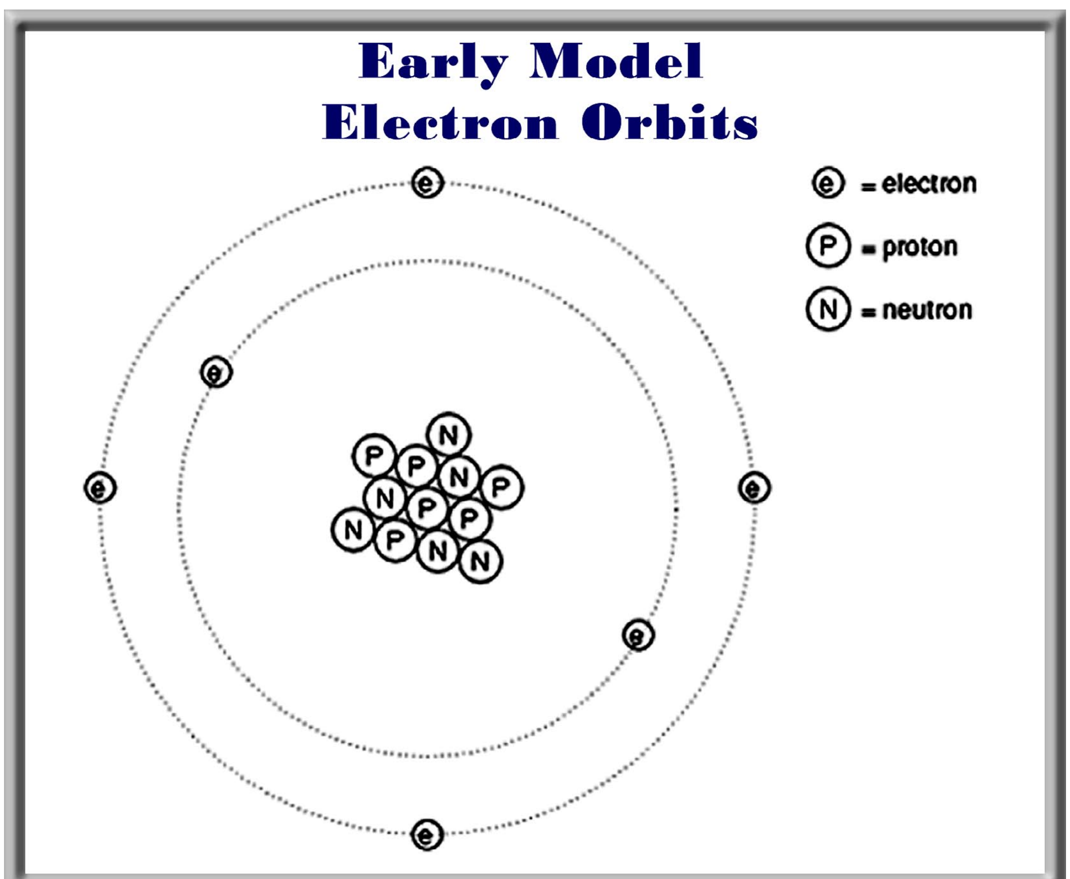
Chapter 6: Semiconductors

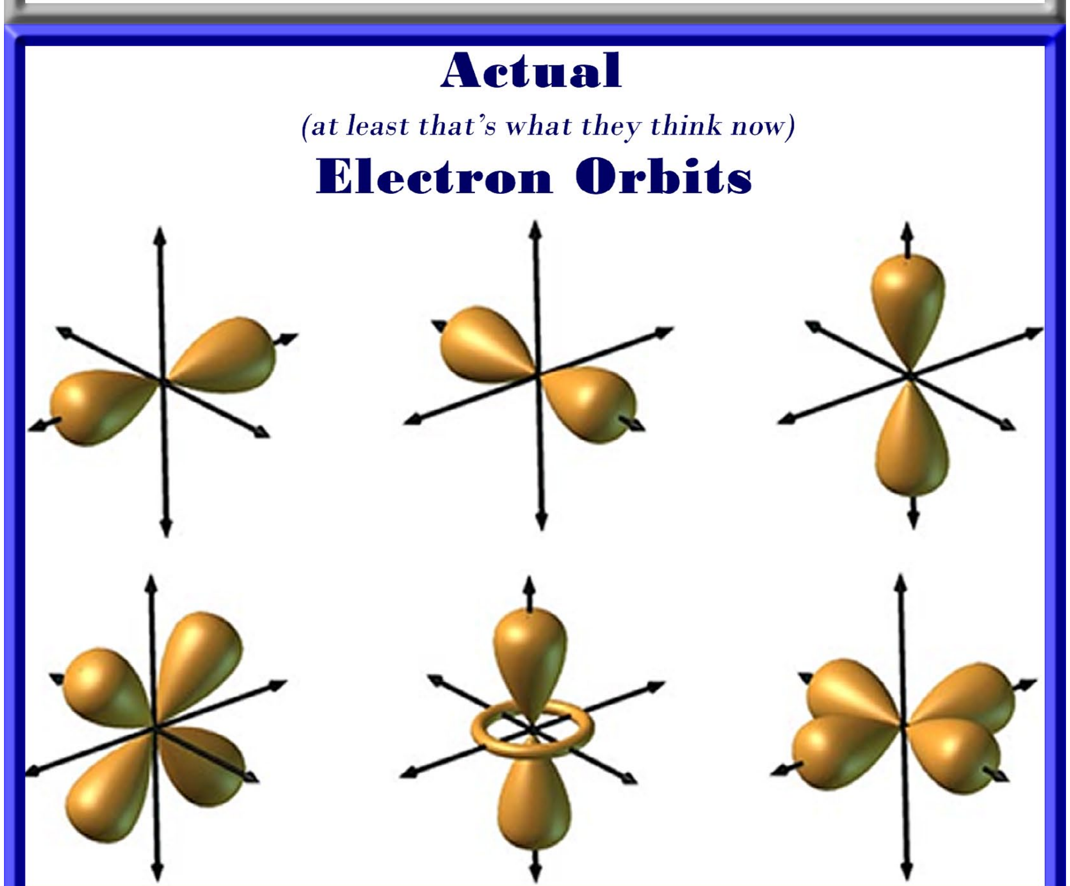
Michael Stucker

6.1 Crystal Structures

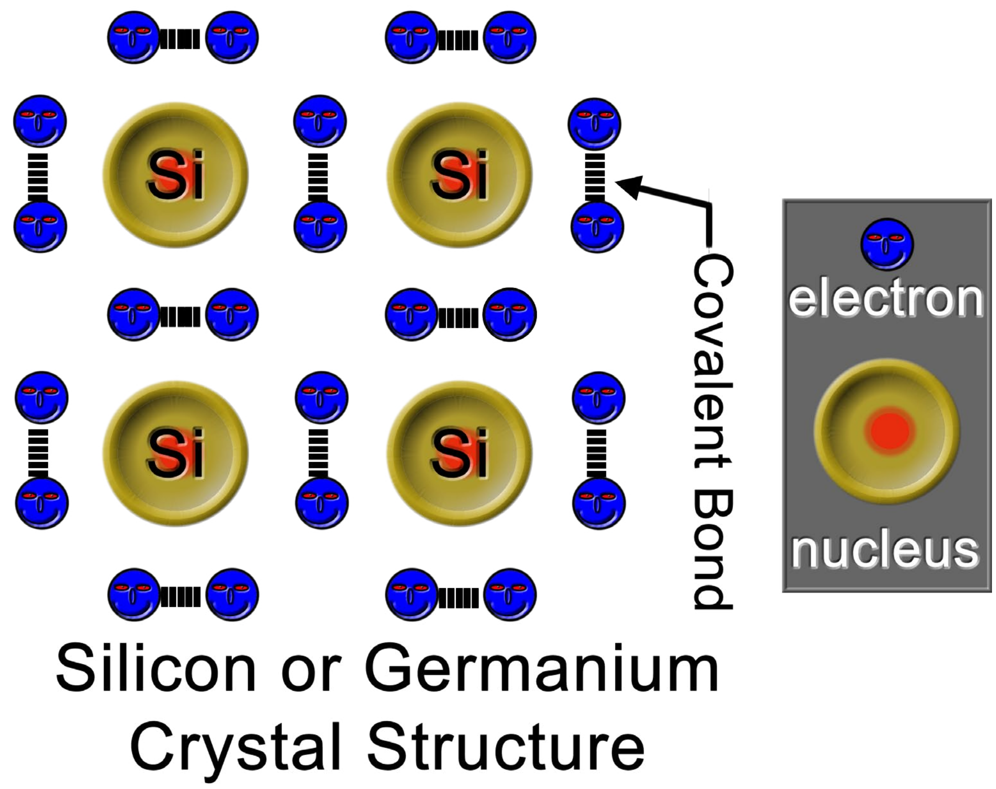
We have discussed conductors and insulators, but there are also elements that are in between. These are called **Semiconductors**. These elements exhibit some characteristics of both conductors and insulators. The most common semiconductor today is Silicon (Si). In the early development of solid state electronics Germanium (Ge) was also used.

Let's start with a review of basic atomic structure. An atom is made up of a Nucleus, which contains neutrons and protons, and electrons which orbit that nucleus in "orbits". Both Silicon and Germanium have 4 electrons in their outer orbit. These are called Valence electrons. The earliest models of atoms represented the electron orbits as spheres around the nucleus. Today's models are more complex and which orbits contain the Valence eletroncs is not obvious in the model drawings.

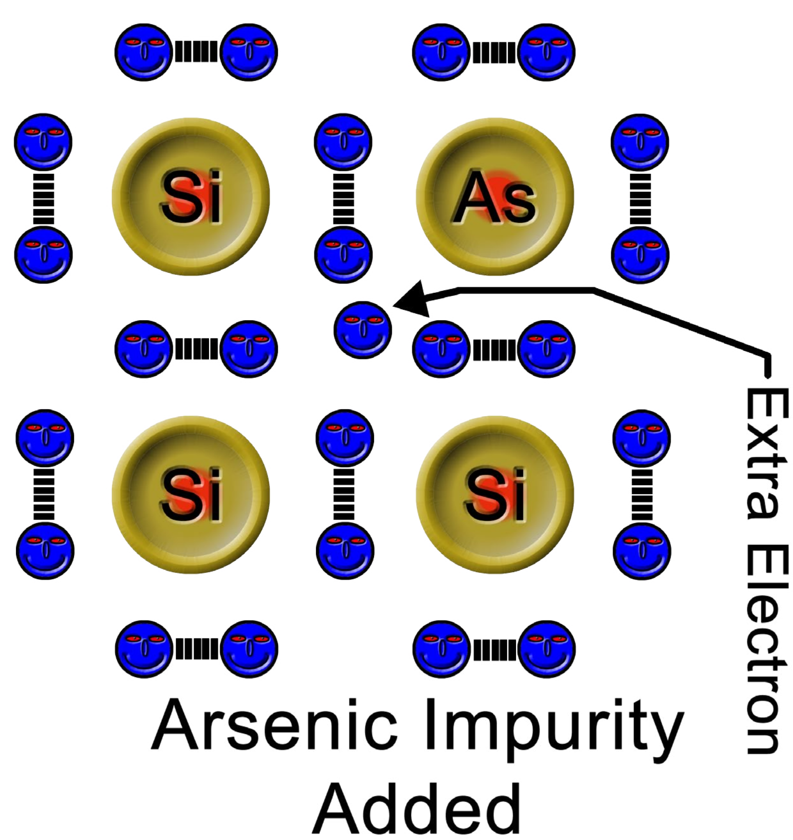




Both Silicon and Germanium form a Crystal Lattice structure (shown below). In a crystal lattice the valence electrons are shared by adjacent atoms. These shared electrons form **Covalent bonds** that create a crystal.



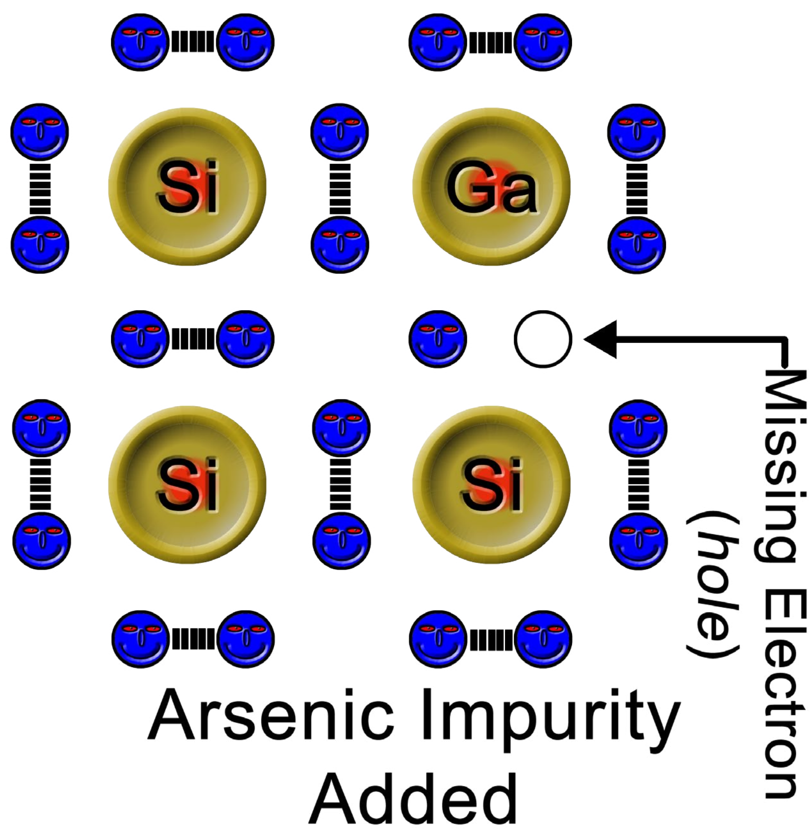
By themselves Silicon and Gallium are not of much use in electronics. They do have the benefit of being easily purified to a high degree. Once this is done impurities are added to form useful semiconductors in a process called **Doping**.



If an impurity is added, such as an atom of Arsenic (which has 5 Valence electrons), it forms an **N-type Crystal**. The addition of this impurity is called **Doping**. The impurity (because it has 5 Valence electrons) is called a **Pentavalent Impurity**. Antimony, bismuth and phosphorus are also pentavalent impurities. Because they have an extra electron, they are also called donor impurities. The additional electron from the Arsenic atom is left out of the crystal structure. It is not part of a covalent bond. This makes that electron easier to move.

Although there is no charge to this crystal, because it has more electrons than the pure silicon in the crystal, it will help to think of it as negative. (N for negative)

If a negative charge is put at one end of an N-type crystal and a positive is put at the other, the free electrons will be pushed from the negative end and pulled to the positive. Although this sounds like conductors we have already talked about, there are some important differences. In a typical conductor, such as copper, an increase in temperature will increase resistance. In an N-type crystal, however, an increase in temperature causes a decrease in resistance. It can also be combine with another crystal (to be discussed next!) to do really amazing things.

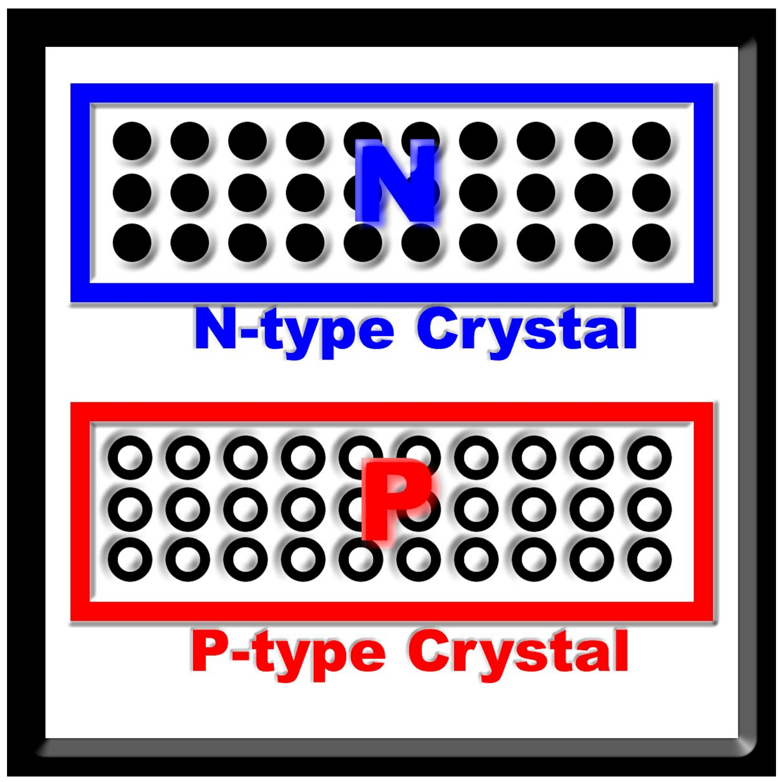


If instead of using Arsenic as an impurity, we use an element such as Gallium (which has 3 Valence electrons) we form a **P-type Crystal**. The addition of this impurity is again called Doping. This impurity (because it has 3 Valence electrons) is called a **Trivalent impurity**. Aluminum, indium, and boron are also used as trivalent impurities. The “missing” electron from the Gallium atom leaves a “Hole” in the crystal structure where there should be an electron. This Hole is ready to accept an electron. Because of this they are also called acceptor impurities. Again there is no actual charge to this crystal, but since it has fewer electrons than pure silicon,it will help to think of it as positive. (P for positive) If one end of a P-type crystal is given a negative charge and the other a positive, then it is said that the Holes, or missing electrons, move.

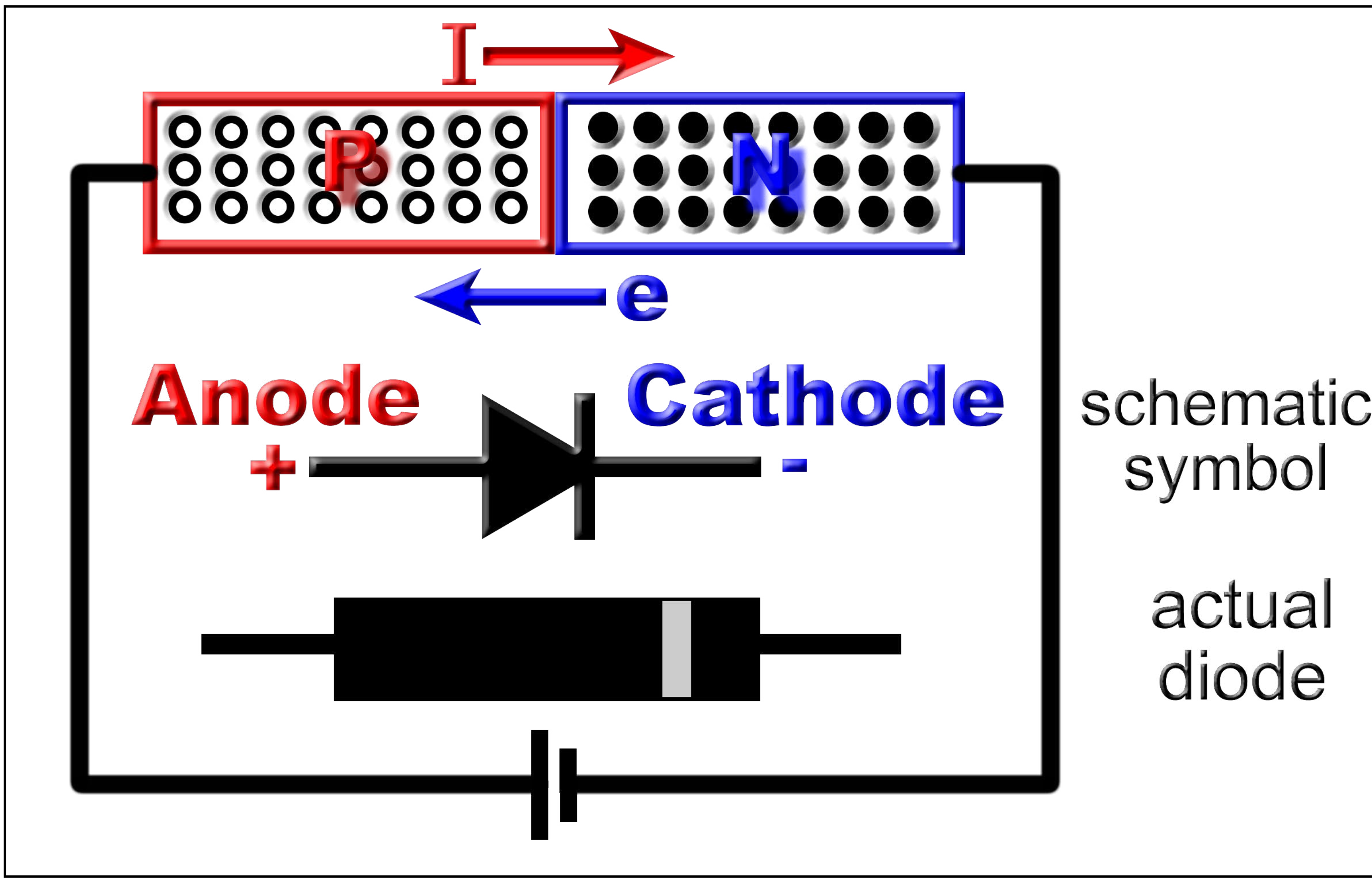
Electricity is the movement of electrons. With semiconductors you will hear "Hole Flow" discussed. Look at the picture here (http://www.wolfgangmichaelsound.com/JSOM/A112/LectureNotes/images/HoleFlow.gif) and decide if the electrons (little faces) are moving, or if the "Hole" (the box missing the electron) is moving.

You can look at it either way, that the electrons are moving or that the holes are moving. Holes can be thought of as conventional current flow. There are times when it will make sense to think in both ways.

The two types of crystals are often drawn as show below. Notice that the **N-type crystal** has electrons (filled in circles), while the **P-type crystal** has holes(empty circles).



6.2 Semiconductor Diodes



When an N crystal and a P crystal are attached together a **PN junction** is formed. This creates a solid state **Diode**. The P crystal (*remember P for Positive*) is called the **Anode** and the N crystal (*remember N for Negative*) is called the **Cathode**. The schematic diagram is shown above with the crystals, charges and electron flow. If the charge on the Anode is more positive than the charge on the Cathode, electrons will be pulled from the N crystal and into the holes in the P crystal. We have current flow through the diode. When these charges are correct (Anode more positive and Cathode more negative) it is said that the diode is **Forward Biased**.

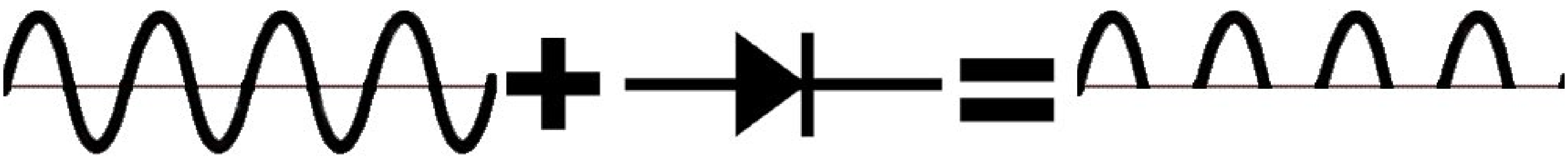
What would happen if the Anode were more negative than the Cathode? The more positive charge on the N crystal would try to pull electrons from the crystal, but there is no way for electrons to move through the P crystal. There would be no electron flow through the diode. The diode is then said to be **Reverse Biased**.

Diodes are rated for maximum voltage and current flow. The current flow rating is simple enough; it is the **Maximum Current** that can flow through the diode without destroying it. The voltage rating is **PIV** or **Peak Inverse Voltage**. This is the maximum voltage that can be reverse biased across the diode.

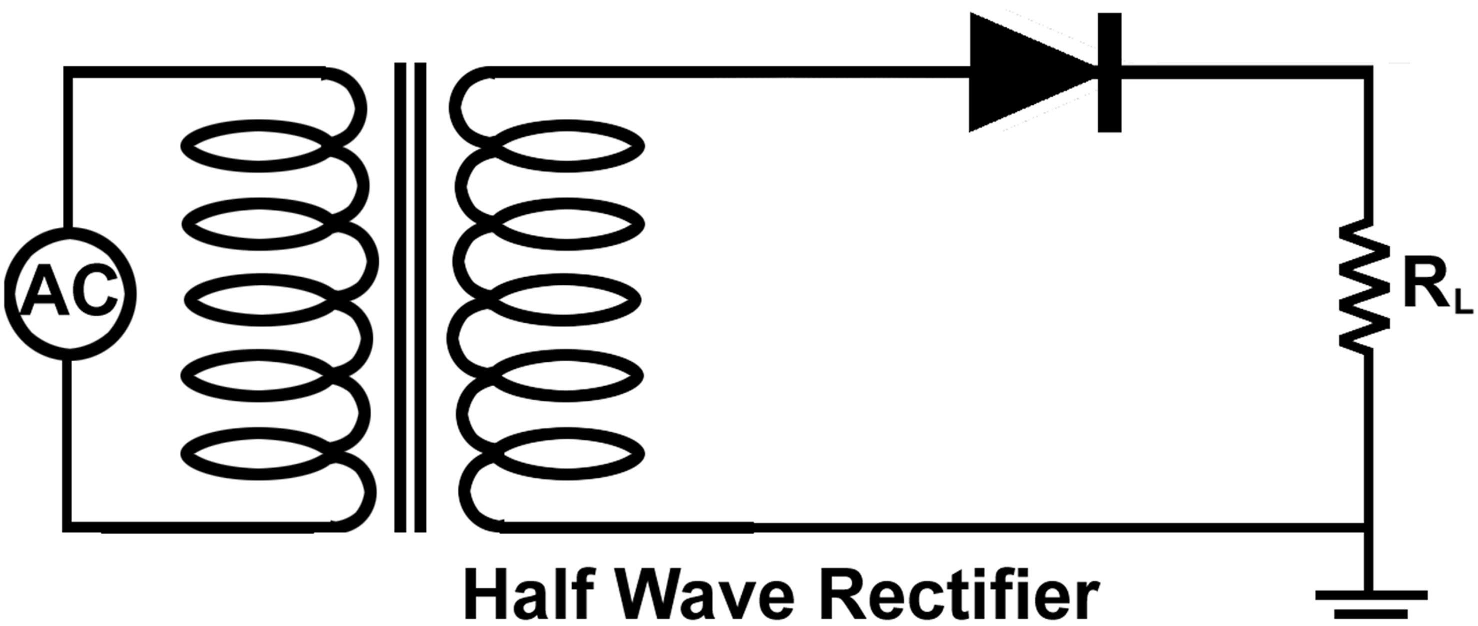
There is some energy used getting the electrons to move through the PN junction, in a Silicon junction this is typically 0.5 to 0.7 volts. For ease of math we will use 0.5 volts. This is called the **Breakover Voltage**. If you put a diode into a circuit with less than 0.5 volts there will be no current flow. If you use a circuit with 2 volts, you will be left with 1.5 volts; the diode has dropped 0.5 volts. Once the diode is forward biased it will always drop 0.5 volts (or it's specific breakover voltage). It is very important to remember that diodes do NOT follow ohms law.

6.3 Diodes As Rectifiers

The most common use for a diode is as a **Rectifier**. What happens if you put an AC signal through a diode? During a cycle, an AC signal is both positive and negative. Current will flow through the diode only when the anode is more positive than the diode.

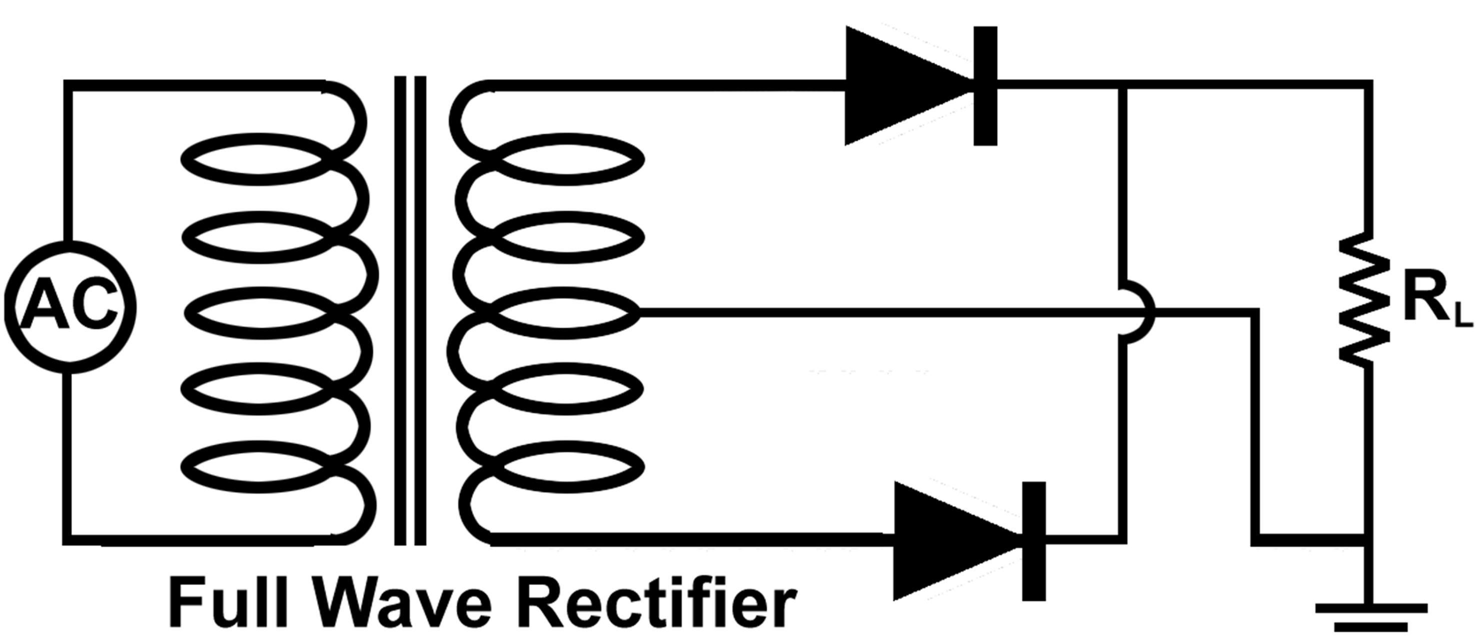


You will get current flow only during half of each AC cycle. The output voltage would then look like the drawing below. This is called a **Half Wave Rectifier** when used in the following power supply circuit. Note that half of every wave is lost.



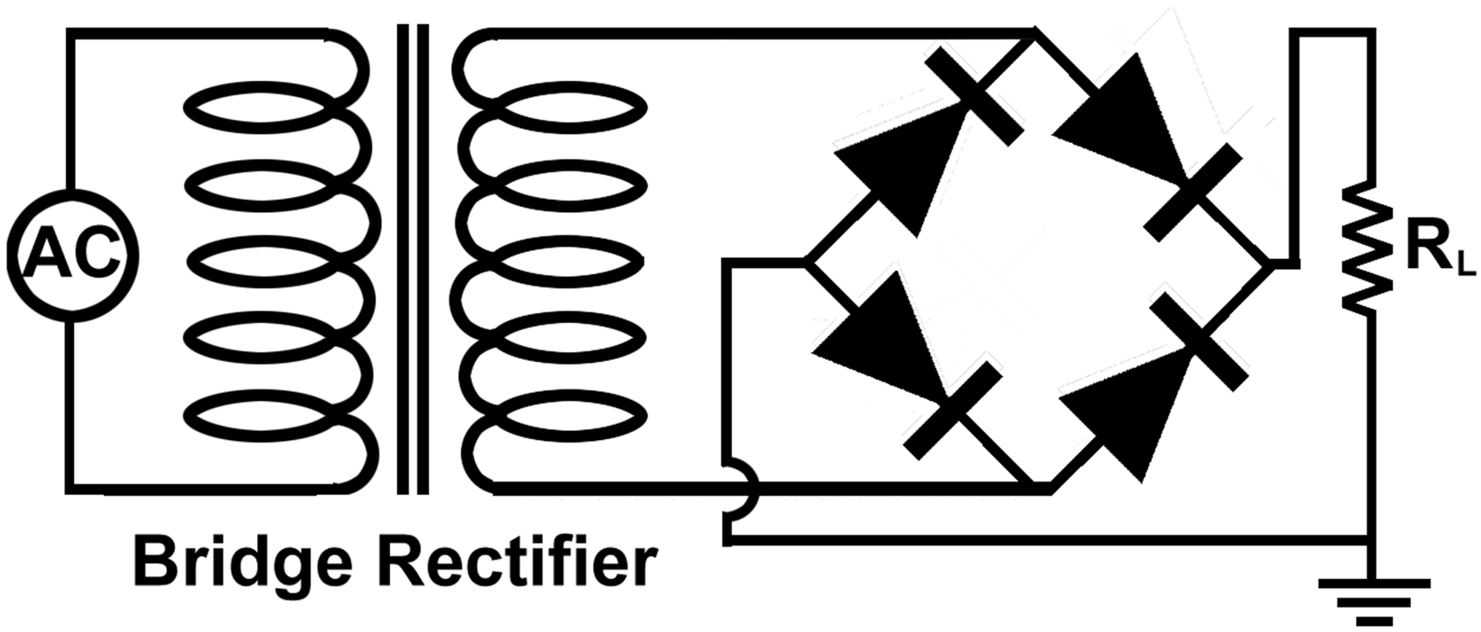
Half Wave Rectifier

Since it would be better (more efficient) if half of the wave was not lost a circuit can be designed that rectifies the entire wave. It is called, sensibly enough, a **Full Wave Rectifier**. There are two ways to construct a Full Wave Rectifier so that half of the wave is not lost. The simplest (though most costly) utilizes a center tapped power transformer and 2 two diodes. The center-tapped transformer is the reason for the high cost of this type of circuit. It is still not the most efficient rectification.



Full Wave Rectifier

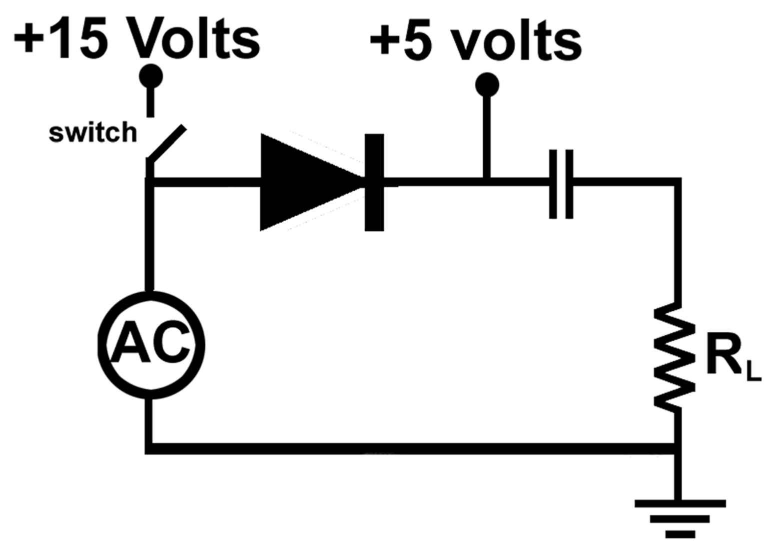
The most common type of rectifier used today is the **Bridge Rectifier.** It is a special type of Full Wave Rectifer. The bridge recitifier consists of four diodes and is usually sold as a single component that contains all four diodes. The bridge rectifier does not require a center-tapped transformer. More specifics on rectifiers will be given in the next chapter.



Bridge Rectifier

6.4 Diode As a Switch

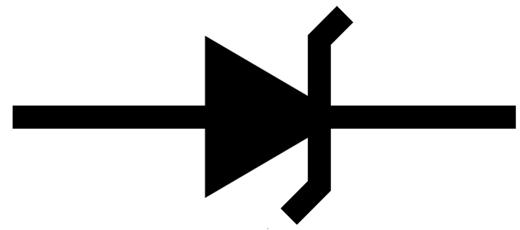
You can also use a diode as a switch. A diode will only allow current to pass when it is forward biased. Look at the circuit shown below.



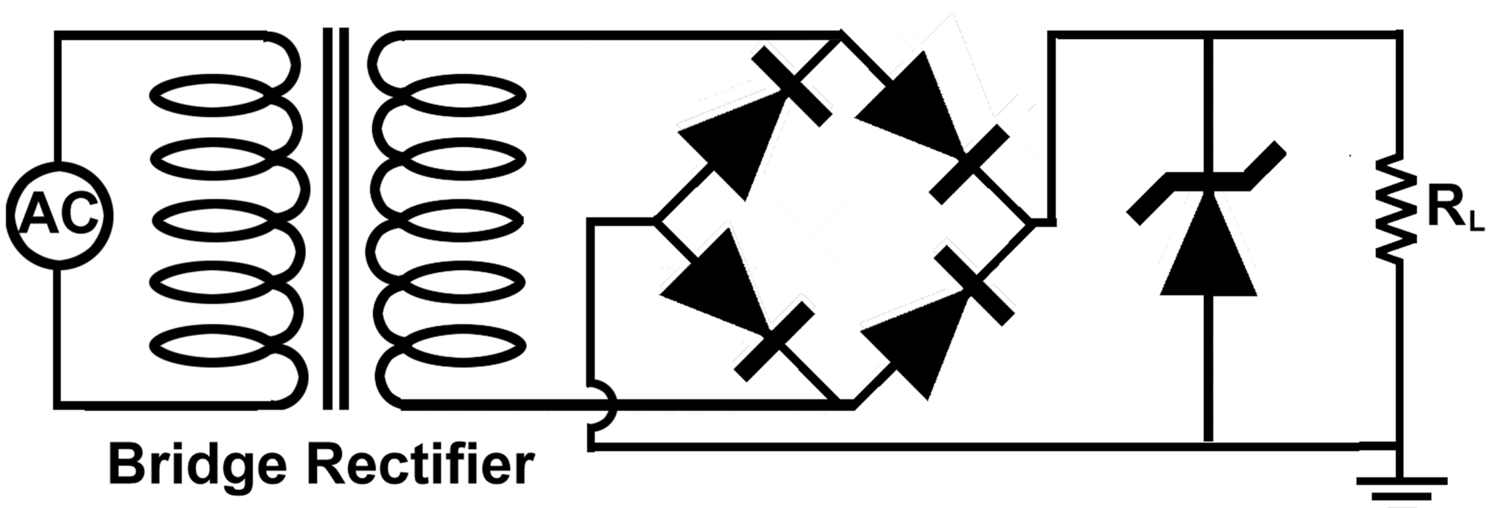
When the switch is open the diode is reverse biased and the AC source does not reach the load. When the switch is closed the diode is forward biased and current passes. The AC source reaches the load. Is there any variable that would make this circuit not function as was just described?

Yes, there is, if the AC source is large than 5 volts. With an AC source larger than 5 volts, the AC signal would be enough to forward bias the diode on the positive half of the cycle. This may not seem like a particularly useful circuit, but a circuit like this or a variation of it could be used as a remote controlled switch. If you place the switch and 15-volt source away from the rest of the circuit the AC signal could be controlled from a distance without running it through a long wire. The 15-volt source could also be very low current and control a very high current AC source.

6.5 Zener Diodes

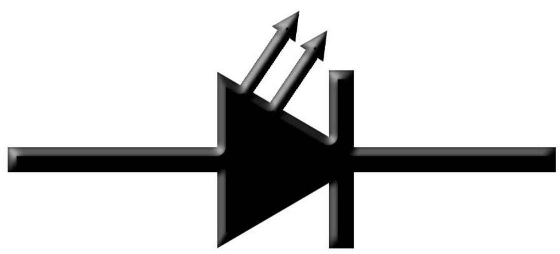


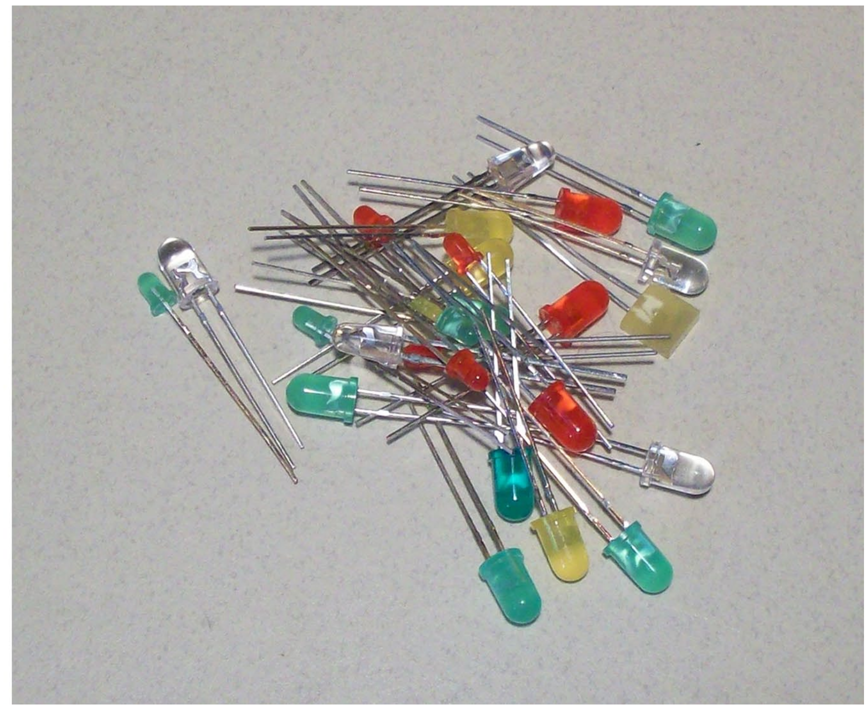
The most common special type of diode is the **Zener Diode**. With a conventional diode, when the PIV is reached, the PN junction is damaged and the diode stops working. In that case, it would be permanently damaged. If a conventional diode had a PIV of 1000 volts, you might be able to put 1001 volts on it without damaging the junction. The PIV rating is saying that you can put at least 1000 volts in reverse bias to the diode without damaging it. With a Zener Diode the PIV is a very accurate, specific voltage. In addition, when the PIV is reached, the junction is not damaged but allows current to flow. This current flow is reverse to direction current normally flows in a diode. So, with a Zener reverse biased over its PIV, current will flow from cathode to anode. Electrons would be flowing from anode to cathode. When it is forward biased a Zener diode functions just like any standard diode.



The circuit above is the most common use of the Zener. If the bridge rectifier puts out roughly 18 volts, it will vary depending on the AC voltage and the current draw of the load. AC voltages from wall outlets in the U.S. care typically 115, 117 or 120 volts. They can, however, be anywhere in a range from 108 to 130 volts. If you choose a 15-volt Zener diode you can regulate the voltage to the load as long as the output of the bridge never drops below 15 volts. Whenever the voltage goes above 15 volts, current starts to flow through the diode to ground. At that point the Zener will drop 15 Volts. Since it is connected in parallel with the load it will keep the voltage across the load at a stable 15 volts. What happens if the voltage goes below 15 volts? Below 15 volts the Zener behaves like any normal reverse biased diode. This means that it is, in effect, invisible to the circuit. That is why the bridge output must be above 15 volts. In addition to the voltage of the Zener, the wattage must also be specified. Since all the excess voltage is removed with current flow through the diode, it must be able to dissipate all of that power.

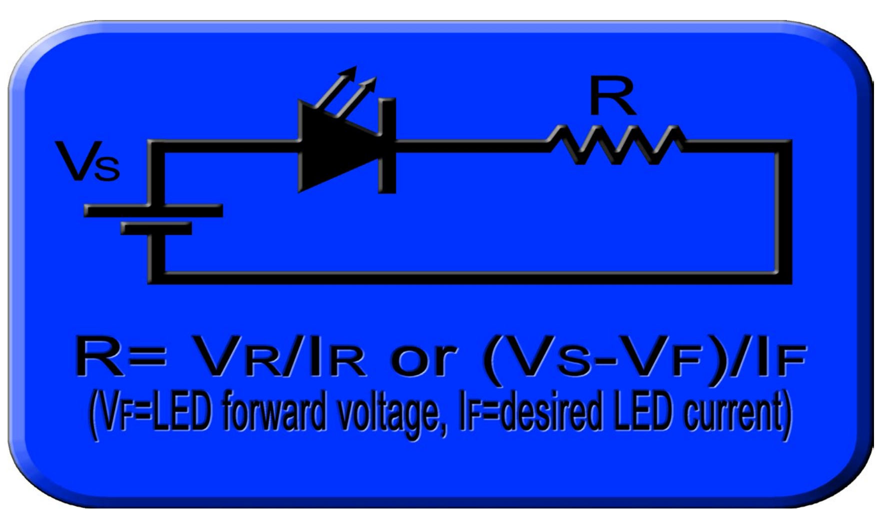
6.6 LEDs





Another type of diode is the **LED** or **Light Emitting Diode**. When LEDs are forward biased, the current flow is indicated with a light. LEDs can be colored (red and yellow and green are common) and can also be non-visible light such as infrared. LEDs need more voltage than the typical diodes 0.5 volts. Common forward bias voltages for LEDs are from 1.6 to 2.3 volts. Blue light emitting LEDs require 5 volts.

As with regular diodes, voltage and current do not have a linear relationship like they do for resistors (V=IR). For a PN junction, a small change in voltage can produce a huge change in current



If we want to use an L.E.D. in a circuit we must get rid of any voltage above the forward bias voltage of the L.E.D. This is done with a resistor in series with the L.E.D. This resistor is called a “current limiting resistor”. The value of the resistor is found using our old friend Ohms Law. The L.E.D. forward bias voltage is subtracted from the source voltage, what remains is the voltage the the resistor must drop.

The specifications for the L.E.D. will include the forward voltage voltage and the current at full brightness. Insert this current value and the voltage from the above calculation into Ohms Law and you will find the value of the resistor.

Memorization for Chapter 6

Breakover Voltage: The minimum voltage needed for current to flow through a diode. also the voltage that the diode drops when current is flowing.

Diode: A P-type crystal and a N-type crystal connected together. This creates a component that only allows current to flow in one direction.

Forward Bias: The condition needed for current to flow through a diode. The Anode is more positively charged and the Cathode is more negatively charged.

Maximum Forward Current: The maximum current that can flow continuously through a diode without damage occurring. Peak forward current may be higher. Diodes are specified by Peak Inverse Voltage and Maximum Forward Current.

N-type Crystal: A specially “doped” silicon crystal that has extra electrons in the crystal structure. This can be thought of the as the more Negative of the 2 crystal types. N=negative. In a diode this becomes the Cathode.

P-type Crystal: A specially “doped” silicon crystal that has extra holes (missing electrons) in the crystal structure. This can be thought of the as the more Positive of the 2 crystal types. P=positive. In a diode this becomes the Anode.

Reverse Bias: The condition where current will not flow through a diode. The is Cathode more positively charged and the Anode is more negatively charged.

Peak Inverse Voltage: The maximum reverse bias voltage that can exist without damage to the diode, or possibly current flow. Also known as PIV or Peak Reverse Voltage. Diodes are specified by Peak Inverse Voltage and Maximum Forward Current.

Rectification: Converting an AC signal into DC.

Semiconductor: Special type of material that is between a conductor and an insulator. It conducts or does not conduct depending on the voltage and current direction. The most common modern semiconductor is Silicon.

Zener Diode: A special type of diode that has a very specific PIV (called the Zener Voltage). When this voltage is reached current will flow in the reverse direction through the diode (current flowing cathode to anode).