Amateur Wireless Station Operators License Exam

Study material 2017

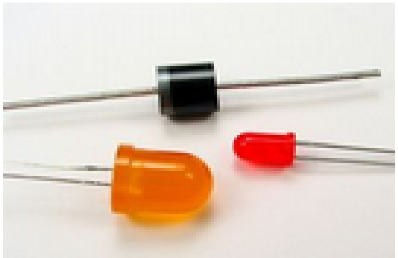
CHAPTER 3

Chapter 3: DIODES AND TRANSISTORS- PROPERTIES AND USE

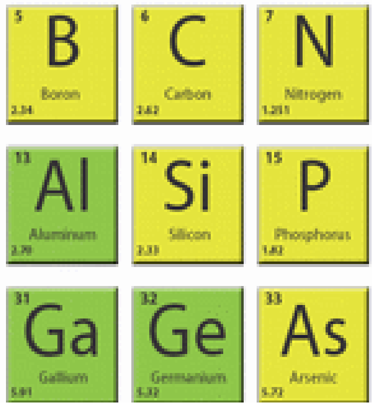
Semiconductors

Semiconductors have had a monumental impact on our society. You find semiconductors at the heart of microprocessor chips as well as transistors. Anything that's computerized or uses radio waves depends on semiconductors.

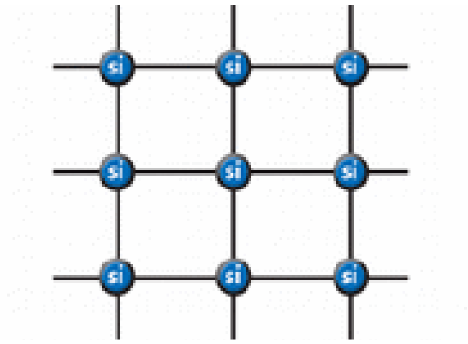
Today, most semiconductor chips and transistors are created with **silicon**. You may have heard expressions like "Silicon Valley" and the "silicon economy," and that's why -- silicon is the heart of any electronic device.



A **diode** is the simplest possible semiconductor device, and is therefore an excellent beginning point if you want to understand how semiconductors work. In this chapter, you'll learn what a semiconductor is, how doping works and how a diode can be created using semiconductors. But first, let's take a close look at silicon.



Silicon is a very common element -- for example, it is the main element in sand and quartz. If you look “silicon” up in the periodic table, you will find that it sits next to aluminum, below carbon and above germanium.
Carbon, silicon and germanium (germanium, like silicon, is also a semiconductor) have a unique property in their electron structure -- each has **four electrons in its outer orbital**. This allows them to form nice crystals. The four electrons form perfect covalent bonds with four neighboring atoms, creating a **lattice**. In carbon, we know the crystalline form as diamond. In silicon, the crystalline form is a silvery, metallic-looking substance.



In a silicon lattice, all silicon atoms bond perfectly to four neighbors, leaving no free electrons to conduct electric current. This makes a silicon crystal an insulator rather than a conductor.

Metals tend to be good conductors of electricity because they usually have “free electrons” that can move easily between atoms, and electricity involves the flow of electrons. While silicon crystals look metallic, they are not, in fact, metals. All the outer electrons in a silicon crystal are involved in **perfect covalent bonds**, so they can't move around. A pure silicon crystal is nearly an **insulator.** Very little electricity will flow through it. But you can change all this through a process called doping.

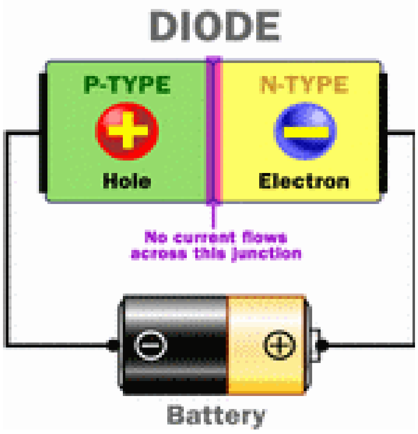
Doping Silicon

You can change the behavior of silicon and turn it into a conductor by **doping** it. In doping, you mix a small amount of an **impurity** into the silicon crystal.
There are two types of impurities:

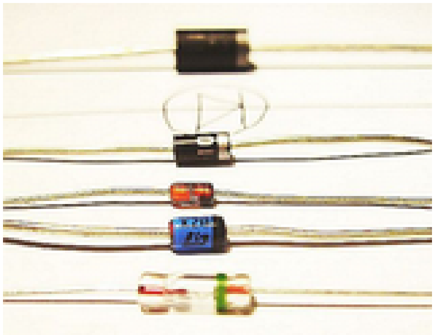
- **N-type** - In N-type doping, phosphorus or arsenic is added to the silicon in small quantities. Phosphorus and arsenic each have five outer electrons, so they're out-of-place when they get into the silicon lattice. The fifth electron has nothing to bond to, so it's free to move around. It takes only a very small quantity of the impurity to create enough free electrons to allow an electric current to flow through the silicon. N-type silicon is a good conductor. Electrons have a negative charge, hence the name N-type.

- **P-type** - In P-type doping, boron or gallium is the dopant. Boron and gallium each have only three outer electrons. When mixed into the silicon lattice, they form "holes" in the lattice where a silicon electron has nothing to bond to. The absence of an electron creates the effect of a positive charge, hence the name P-type. Holes can conduct current. A hole happily accepts an electron from a neighbor, moving the hole over a space. P-type silicon is a good conductor.
- A minute amount of either N-type or P-type doping turns a silicon crystal from a good insulator into a viable (but not great) conductor -- hence the name "semiconductor."

N-type and P-type silicon are not that amazing by themselves; but when you put them together, you get some very interesting behavior at the junction. That's what happens in a diode.
A **diode** is the simplest possible semiconductor device. A diode allows current to flow in one direction but not the other. You may have seen turnstiles at a stadium or a subway station that let people go through in only one direction. A diode is a one-way turnstile for electrons.
When you put N-type and P-type silicon together as shown in this diagram, you get a very interesting phenomenon that gives a diode its unique properties.

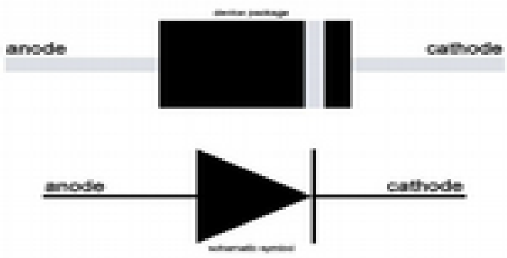


Even though N-type silicon by itself is a conductor, and P-type silicon by itself is also a conductor, the combination shown in the diagram does not conduct any electricity. The negative electrons in the N-type silicon get attracted to the positive terminal of the battery. The positive holes in the P-type silicon get attracted to the negative terminal of the battery. No current flows across the junction because the holes and the electrons are each moving in the wrong direction.
If you **flip the battery around**, the diode conducts electricity just fine. The free electrons in the N-type silicon are repelled by the negative terminal of the battery. The holes in the P-type silicon are repelled by the positive terminal. At the **junction** between the N-type and P-type silicon, holes and free electrons meet. The electrons fill the holes. Those holes and free electrons cease to exist, and new holes and electrons spring up to take their place. The effect is that **current flows** through the junction.



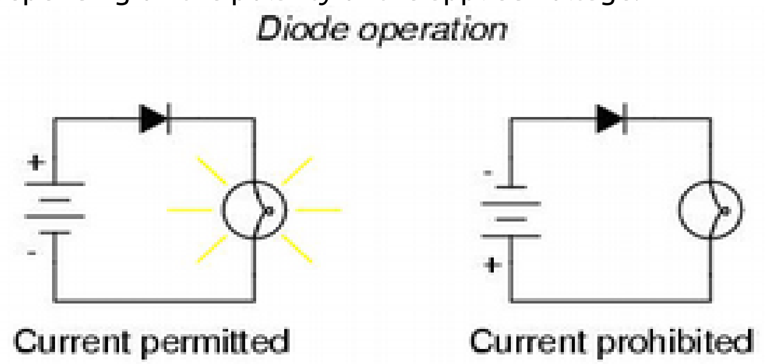
Diode

A diode is an electrical device allowing current to move through it in one direction with far greater ease than in the other. The most common kind of diode in modern circuit design is the semiconductor diode, although other diode technologies exist. Semiconductor diodes are symbolized in schematic diagrams such as Figure below. The term “diode” is customarily reserved for small signal devices, I ≤ 1 A. The term rectifier is used for power devices, I > 1 A.



Semiconductor diode device package and schematic symbol: Arrows indicate the direction of electron current flow.

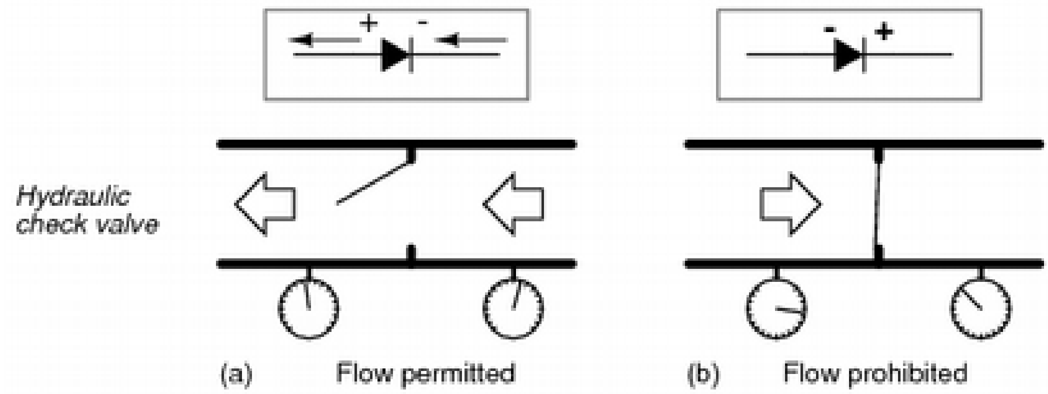
When placed in a simple battery-lamp circuit, the diode will either allow or prevent current through the lamp, depending on the polarity of the applied voltage.



Diode operation: (a) Current flow is permitted; the diode is forward biased. (b) Current flow is prohibited; the diode is reversed biased.

When the polarity of the battery is such that electrons are allowed to flow through the diode, the diode is said to be forward-biased. Conversely, when the battery is “backward” and the diode blocks current, the diode is said to be reverse-biased. A diode may be thought of as like a switch: “closed” when forward-biased and “open” when reverse-biased.
Oddly enough, the direction of the diode symbol's “arrowhead” points against the direction of electron flow. This is because the diode symbol was invented by engineers, who predominantly use conventional flow notation in their schematics, showing current as a flow of charge from the positive (+) side of the voltage source to the negative (-). This convention holds true for all semiconductor symbols possessing “arrowheads:” the arrow points in the permitted direction of conventional flow, and against the permitted direction of electron flow.

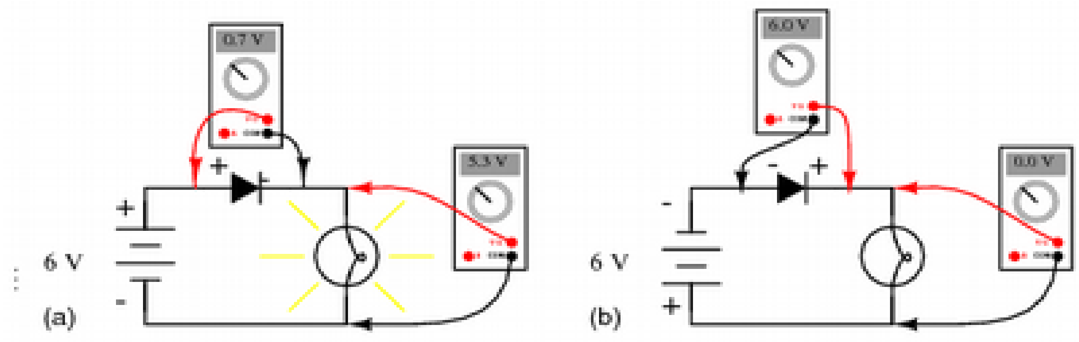
Diode behavior is analogous to the behavior of a hydraulic device called a check valve. A check valve allows fluid flow through it in only one direction as in Figure below.



Hydraulic check valve analogy: (a) Electron current flow permitted. (b) Current flow prohibited.

Check valves are essentially pressure-operated devices: they open and allow flow if the pressure across them is of the correct “polarity” to open the gate (in the analogy shown, greater fluid pressure on the right than on the left). If the pressure is of the opposite “polarity,” the pressure difference across the check valve will close and hold the gate so that no flow occurs.

Like check valves, diodes are essentially “pressure-” operated (voltage-operated) devices. The essential difference between forward-bias and reverse-bias is the polarity of the voltage dropped across the diode. Let's take a closer look at the simple battery-diode-lamp circuit shown earlier, this time investigating voltage drops across the various components in Figure below.

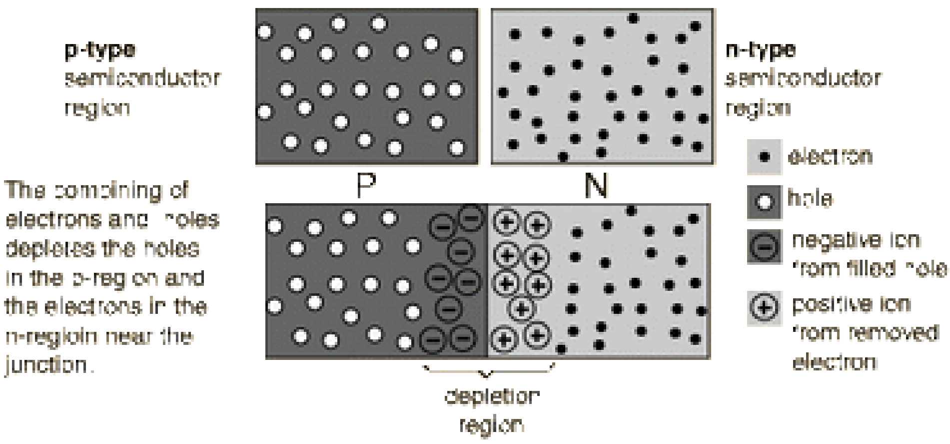


Diode circuit voltage measurements: (a) Forward biased. (b) Reverse biased.

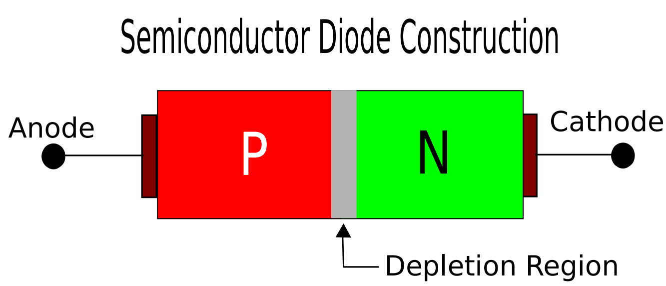
A **forward-biased** diode conducts current and drops a small voltage across it, leaving most of the battery voltage dropped across the lamp. If the battery's polarity is reversed, the diode becomes reverse-biased, and drops all of the battery's voltage leaving none for the lamp. If we consider the diode to be a self-actuating switch (closed in the forward-bias mode and open in the reverse-bias mode), this behavior makes sense. The most substantial difference is that the diode drops a lot more voltage when conducting than the average mechanical switch (0.7 volts versus tens of millivolts).

Depletion region

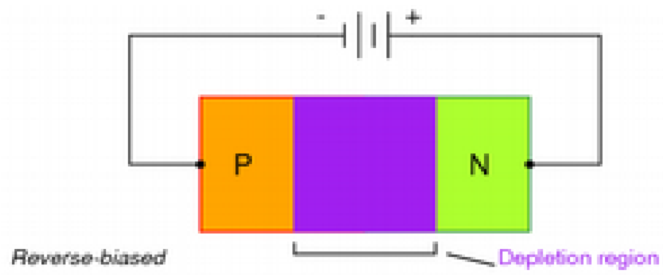
When a p-n junction is formed, some of the free electrons in the n-region diffuse across the junction and combine with holes to form negative ions. In so doing they leave behind positive ions at the donor impurity sites. Filling a hole makes a negative ion and leaves behind a positive ion on the n-side. A space charge builds up, creating a depletion region which inhibits any further electron transfer unless it is helped by putting a forward bias on the junction.



This forward-bias voltage drop exhibited by the diode is due to the action of the depletion region formed by the P-N junction under the influence of an applied voltage. If no voltage applied is across a semiconductor diode, the depletion region exists around the region of the P-N junction, prevents current flow. This is because,the depletion region is almost free of available charge carriers, and will acts as an insulator.

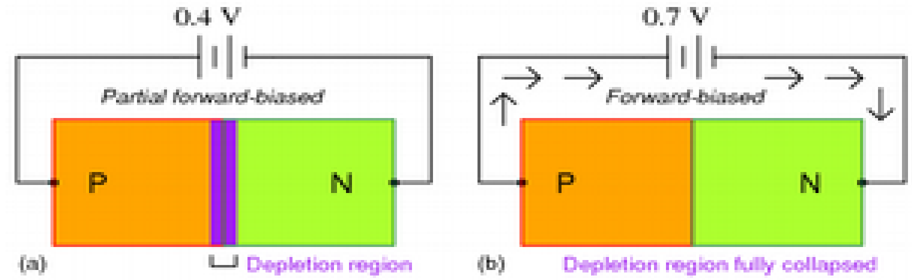


If a reverse-biasing voltage is applied across the P-N junction, this depletion region expands, further resisting any current through it. (Figure below)



Depletion region expands with reverse bias.

Conversely, if a forward-biasing voltage is applied across the P-N junction, the depletion region collapses becoming thinner. The diode becomes less resistive to current through it. In order for a sustained current to go through the diode; though, the depletion region must be fully collapsed by the applied voltage. This takes a certain minimum voltage to accomplish, called the forward voltage as illustrated in Figure below



Increasing forward bias from (a) to (b) decreases depletion region thickness.

For silicon (mostly used semiconductor material) diodes, the typical forward voltage is 0.7 volts, nominal. **For germanium (Rarely used semiconductor material) diodes, the forward voltage is only 0.3 volts.** The chemical constituency of the P-N junction comprising the diode accounts for its nominal forward voltage figure, which is why silicon and germanium diodes have such different forward voltages. Forward voltage drop remains approximately constant for a wide range of diode currents, meaning that diode voltage drop is not like that of a resistor or even a normal (closed) switch. For most simplified circuit analysis, the voltage drop across a conducting diode may be considered constant at the nominal figure and not related to the amount of current.

Actually, forward voltage drop is more complex. An equation describes the exact current through a diode, given the voltage dropped across the junction, the temperature of the junction, and several physical constants. It is commonly known as the diode equation

The Diode equation

$$I_D = I_S\,(e^{V_D/0.026} - 1)$$

Where,

I_D = Diode current in amps

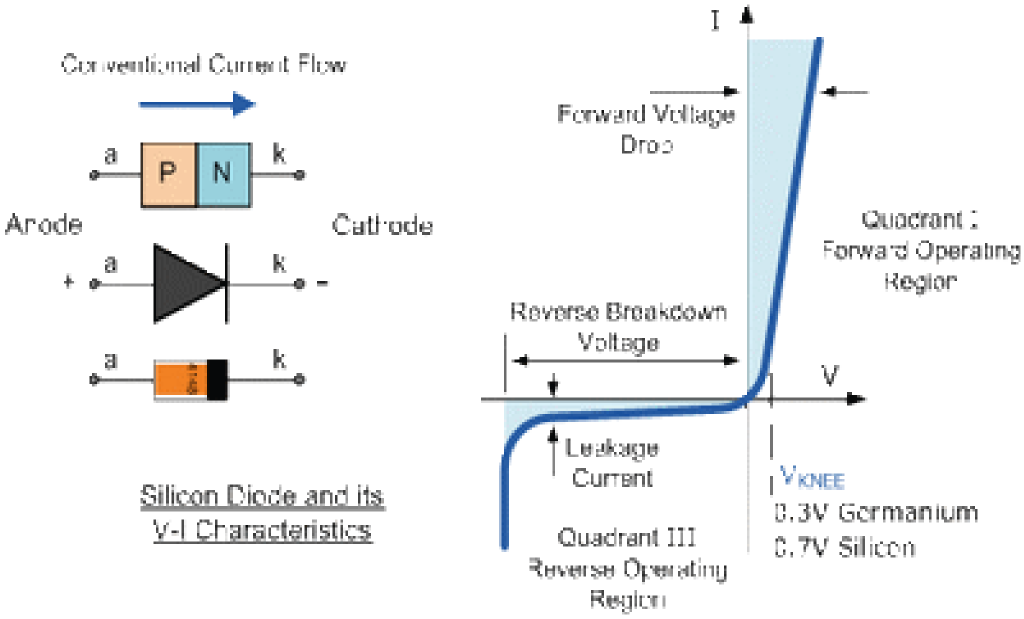
I_S = Saturation current in amps (typically 1×10^{-12} amps)

e = Euler's constant (~ 2.718281828)

V_D = Voltage applied across diode in volts

You need not be familiar with the "diode equation" to analyze simple diode circuits. Just understand that the voltage dropped across a current-conducting diode does change with the amount of current going through it, but that this change is fairly small over a wide range of currents. This is why many textbooks simply say the voltage drop across a conducting, semiconductor diode remains constant at 0.7 volts for silicon and 0.3 volts for germanium. However, some circuits intentionally make use of the P-N junction's inherent exponential current/voltage relationship and thus can only be understood in the context of this equation. Also, since temperature is a factor in the diode equation, a forward-biased P-N junction may also be used as a temperature-sensing device, and thus can only be understood if one has a conceptual grasp on this mathematical relationship.

A reverse-biased diode prevents current from going through it, due to the expanded depletion region. In actuality, a very small amount of current can and does go through a reverse-biased diode, called the leakage current, but it can be ignored for most purposes. The ability of a diode to withstand reverse-bias voltages is limited, as it is for any insulator. If the applied reverse-bias voltage becomes too great, the diode will experience a condition known as breakdown (Figure below), which is usually destructive. A diode's maximum reverse-bias voltage rating is known as the **Peak Inverse Voltage**, or **PIV**, and may be obtained from the manufacturer. Like forward voltage, the PIV rating of a diode varies with temperature, except that PIV increases with increased temperature and decreases as the diode becomes cooler -- exactly opposite that of forward voltage.



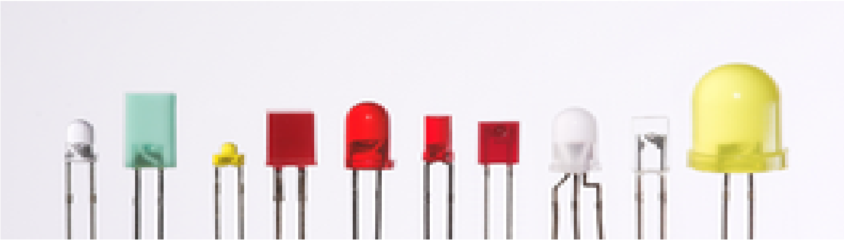
Diode curve: showing knee at 0.7 V forward bias for Silicon diode, and reverse breakdown.

Typically, the PIV rating of a generic “rectifier” diode is at least 50 volts at room temperature. Diodes with PIV ratings in the many thousands of volts are available for modest prices.

Summary

- A diode is an electrical component acting as a one-way valve for current.
- When voltage is applied across a diode in such a way that the diode allows current, the diode is said to be forward-biased.
- When voltage is applied across a diode in such a way that the diode prohibits current, the diode is said to be reverse-biased.
- The voltage dropped across a conducting, forward-biased diode is called the forward voltage. Forward voltage for a diode varies only slightly for changes in forward current and temperature, and is fixed by the chemical composition of the P-N junction.
- Silicon diodes have a forward voltage of approximately 0.7 volts.
- Germanium diodes have a forward voltage of approximately 0.3 volts.
- The maximum reverse-bias voltage that a diode can withstand without “breaking down” is called the Peak Inverse Voltage, or PIV rating.

Light emitting Diodes (LED)



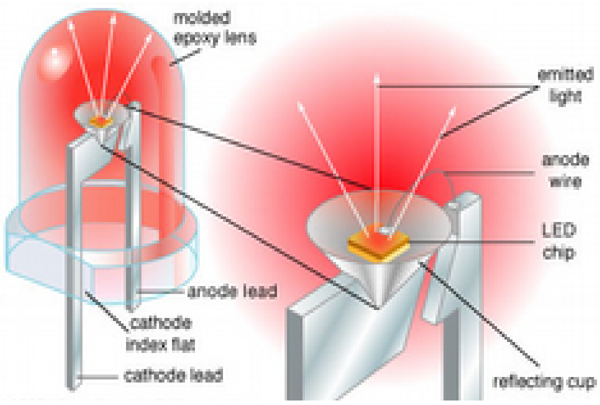
A light-emitting diode (LED) is a special kind of diode that glows when electricity passes through it. Most LEDs are made from a semi-conducting material called gallium arsenide phosphide.

LEDs can be bought in a range of colors. They can also be bought in forms that will switch between two colors (bi-color), three colors (tri-colour) or emit infra-red light.

In common with all diodes, the LED will only allow current to pass in one direction. The cathode is normally indicated by a flat side on the casing and the anode is normally indicated by a slightly longer leg. The current required to power an LED is usually around 20 mA.

How it works?

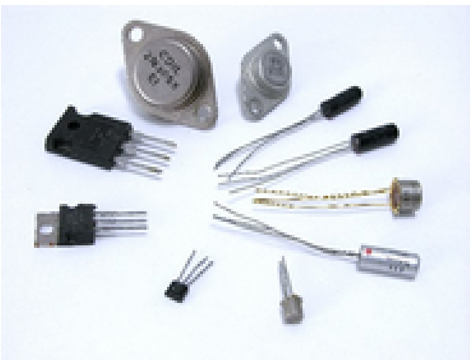
Light is a form of energy that can be released by an atom. It is made up of many small particle-like packets that have energy and momentum but no mass. These particles, called photons, are the most basic units of light. Photons are released as a result of moving electrons. In an atom, electrons move in orbitals around the nucleus. Electrons in different orbitals have different amounts of energy. Generally speaking, electrons with greater energy move in orbitals farther away from the nucleus.



For an electron to jump from a lower orbital to a higher orbital, something has to boost its energy level. Conversely, an electron releases energy when it drops from a higher orbital to a lower one. This energy is released in the form of a photon. A greater energy drop releases a higher-energy photon, which is characterized by a higher frequency.

As we saw in the last section, free electrons moving across a diode can fall into empty holes from the P-type layer. This involves a drop from the conduction band to a lower orbital, so the electrons release energy in the form of photons. This happens in any diode, but you can only see the photons when the diode is composed of certain material. The atoms in a standard silicon diode, for example, are arranged in such a way that the electron drops a relatively short distance. As a result, the photon's frequency is so low that it is invisible to the human eye. it is in the infrared portion (Can't be seen by naked eye) of the light spectrum. This isn't necessarily a bad thing, of course: Infrared LEDs are ideal for remote controls, among other things.

Transistor

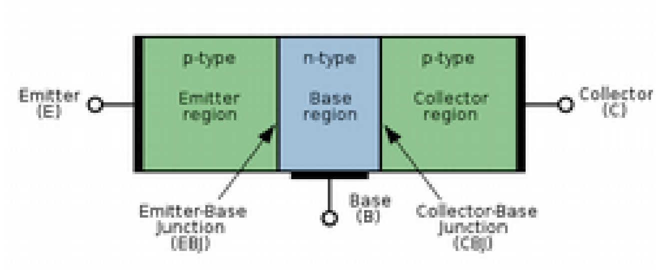


The name **"Transistor"** came from the word **transfer resistor**. These were the semiconductor devices which replaced the Vacuum tubes which lead to lot of developments in Semiconductor technology. It is used to amplify and switch electronic signals and electrical power. It is composed of semiconductor material with at least three terminals for connection to an external circuit. A voltage or current applied to one pair of the transistor's terminals changes the current through another pair of terminals. Because the controlled (output) power can be higher than the controlling (input) power, a transistor can amplify a signal. Today, some transistors are packaged individually, but many more are found embedded in integrated circuits.

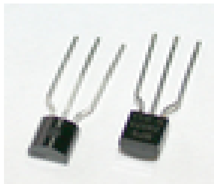
The transistor is the fundamental building block of modern electronic devices, and is ubiquitous in modern electronic systems. Following its development in the early 1950s, the transistor revolutionized the field of electronics, and paved the way for smaller and cheaper radios, calculators, and computers, among other things.

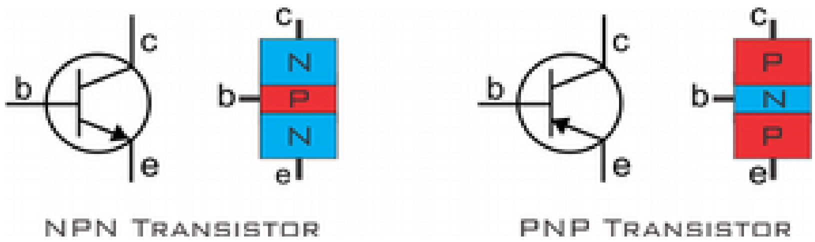
How BJT transistors work

A BJT (Bipolar Junction Transistor) transistor has inside two similar semi-conductive materials, and between them there is a third semi-conductive material of different type. So, if the two similar materials are P and the middle one is N, then we have a P-N-P or PNP transistor. Similarly, if the two materials are N and the middle one is P, then we have an N-P-N material or NPN.



Each transistor has 3 leads which we call base, collector and emitter, and we use the symbols b, c and e respectively. Each lead is connected to one of the 3 materials inside, with the base being connected to the middle one. The symbol of the transistor has an arrow on the emitter. If the transistor is a PNP, then the arrow points to the base of the transistor, otherwise it points to the output. You can always remember that the arrow points at the N material. These are the symbols(below figure):

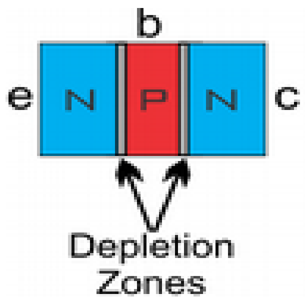


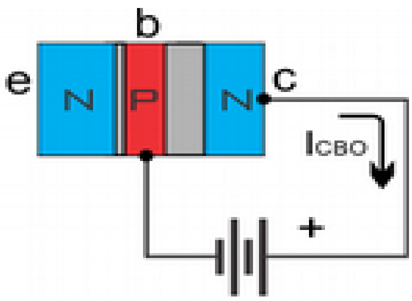


Transistor operation

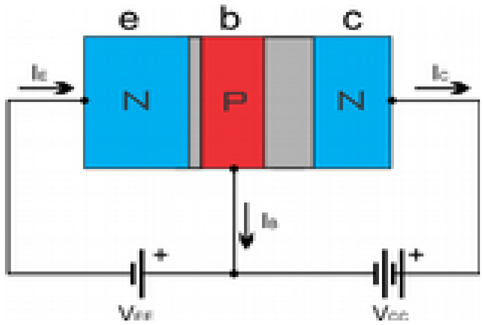
We will now explain the operation for the transistor, using an NPN type. The same operation applies for the PNP transistors as well, but with currents and voltage sources reversed.

With no power applied to the transistor areas, there are two depletion zones between the two P-N contacts. Suppose now that we connect a power source between the base and the collector in reverse-bias, with the positive of the source connected to the collector and the negative to the base. The depletion zone of the P-N contact between the base and the collector will be widened. Moreover, a slight current will flow withing this contact (due to impurities). This current is the reverse contact current and we will use the symbol I_{CBO}:





Now suppose that we connect another voltage supply between the emitter and the base in forward bias, with the positive of the source connected to the base and the negative connected to the emitter. The depletion zone between the emitter and the base will be shortened, and current (electrons) will flow when the voltage exceeds a specific level. This level depends on the material that the transistor is made of. Germanium (Ge) is the material that was originally used to make transistor, and later Silicon (Si) was used. For Germanium, the voltage is around 0.3 volts , and for Silicon the voltage is around 0.7 volts. Some of the electrons that go through the e-b depletion zone, will re-connect with holes in the base. This is the base current and we will use the I_B symbol for reference. In real life, this current is at the scale of micro-amperes.



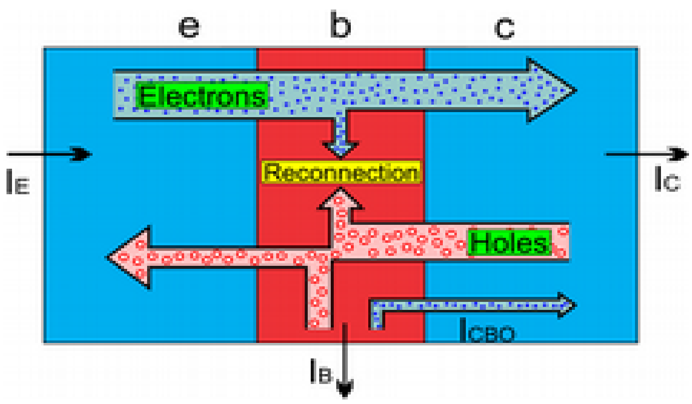
But most of the electrons will flow through the base (due to spilling) and will be directed to the collector. When these electrons reach the depletion area between the base and the collector, they will experience a force from the electric field which exists in this zone, and the electrons will pass through the depletion zone. The electrons will then re-connect with holes in the collector. The re-connected holes will be replaced with holes coming from the base-collector power supply (V_{CC}). The movement of these holes equals to a movement of electrons in the opposite direction, from the collector to the supply. In other words, the current that flows to the emitter will be divided into the small base current and the larger collector current:

$I_E = I_B + I_C$

Generally, the number of electrons that arrive at the collector is the 99% of the total electrons, and the rest 1% causes the base current. At the collector, except the electrons that come from the emitter, there is also the reverse current from the base-collector contact that we saw before. Both currents flow at the same direction, so they are added:

$I_{C'} = I_C + I_{CBO}$

The following drawing shows how the electrons and holes flow within the transistor:



This is generally what happens inside a transistor when voltage is applied. The purpose of this theory is to explain how can someone use the transistor to design an amplifier or a switch, so we will not go into many details. It is enough to know this basic operation.

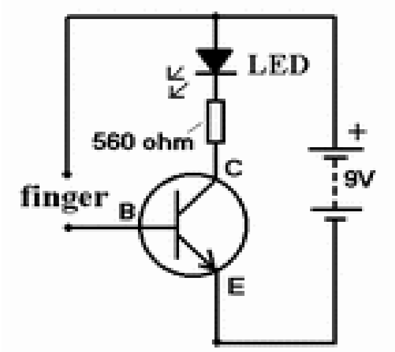
Transistors are heart of today's circuits. Transistors are the device which are primarily used for two purposes in today electronic circuits:

Amplifier: it can amplify the current or voltage of the input. Amplification is the process of increasing the strength of the signal by using external source.

Switch: The transistors are used in various modern electronic circuits. It can be used as switch to "ON" or "OFF" the flow of the current in the circuit.

The transistor amplifier

We have heard that a transistor can amplify about 100 times so we can make use of this property to boost the signal from the small current flowing through the body so that it can light an LED.



Carefully wire up the simple transistor circuit shown in Fig above. When one finger on one hand is placed on the positive battery terminal and the other finger on the other hand is connected to the base connection of the transistor a tiny current (of a magnitude that we have just calculated - ca. 0.1mA) flows into the BE circuit of the transistor. Because of the gain of the transistor this sets up a CE current (where the LED is connected) of roughly 100 times this:

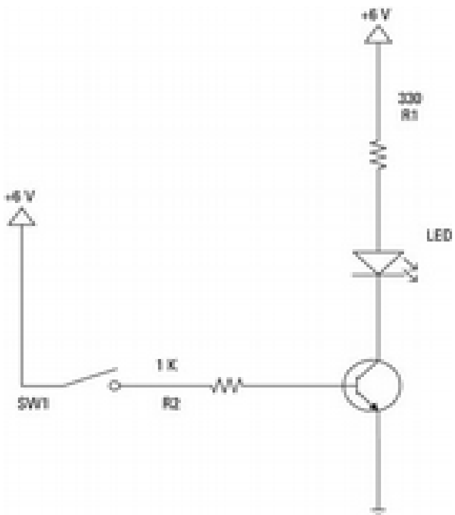
0.0002A(input to base from our finger) x 100 (transistor amplification factor) = 0.02A = 20mA and so the LED lights !!

(The resistance of the body is complex and will depend on the voltage applied and most importantly the contact resistance between the skin and wire connections. The body can present a wide range of resistance anywhere between 10,000 - 1,000,000 ohms. For the sake of argument let us say it is 50,000 ohms = 50k ohm.
We now get:
I = V / R = 9/ 50,000 = 0.0002A)

Transistor as a Switch

One of the most common uses for transistors in an electronic circuit is as simple switches. In short, a transistor conducts current across the collector-emitter path only when a voltage is applied to the base. When no base voltage is present, the switch is off. When base voltage is present, the switch is on.

In an ideal switch, the transistor should be in only one of two states: off or on. The transistor is off when there's no bias voltage or when the bias voltage is less than 0.7 V. The switch is on when the base is saturated so that collector current can flow without restriction.



This is a schematic diagram for a circuit that uses an NPN transistor as a switch that turns an LED on or off.

Look at the above circuit component by component:

LED: This is a standard 5 mm red LED. This type of LED has a voltage drop of 1.8 V and is rated at a maximum current of 20 mA.

R1: This 330 Ω resistor limits the current through the LED to prevent the LED from burning out. You can use Ohm's law to calculate the amount of current that the resistor will allow to flow. Because the supply voltage is +6 V, and the LED drops 1.8 V, the voltage across R1 will be 4.2 V (6 – 1.8). Dividing the voltage by the resistance gives you the current in amperes, approximately 0.127 A. Multiply by 1,000 to get the current in mA: 12.7 mA, well below the 20 mA limit.

Q1: This is a common NPN transistor. Any NPN transistor will work. R1 and the LED are connected to the collector, and the emitter is connected to ground. When the transistor is turned on, current flows through the collector and emitter, thus lighting the LED. When the transistor is turned off, the transistor acts as an insulator, and the LED doesn't light.

R2: This 1 kΩ resistor limits the current flowing into the base of the transistor. You can use Ohm's law to calculate the current at the base. Because the base-emitter junction drops about 0.7 V (the same as a diode), the voltage across R2 is 5.3 V. Dividing 5.3 by 1,000 gives the current at 0.0053 A, or 5.3 mA. Thus, the 12.7 mA collector current (ICE) is controlled by a 5.3 mA base current (I_{BE}).

SW1: This switch controls whether current is allowed to flow to the base. Closing this switch turns on the transistor, which causes current to flow through the LED. Thus, closing this switch turns on the LED even though the switch isn't placed directly within the LED circuit.

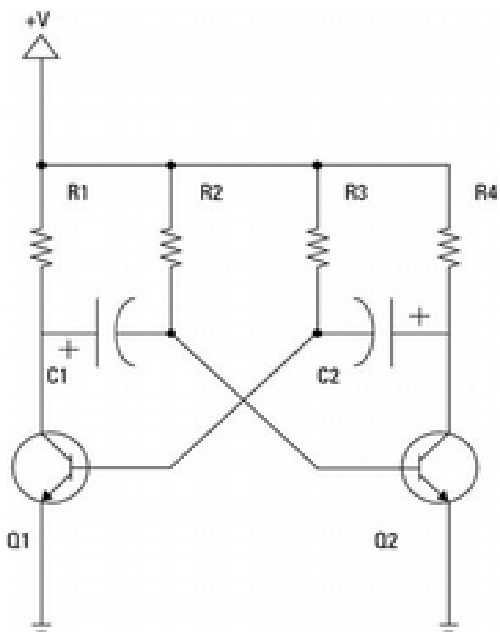
You might be wondering why you'd need or want to bother with a transistor in this circuit. After all, couldn't you just put the switch in the LED circuit and do away with the transistor and the second resistor? Of course you could, but that would defeat the principle that this circuit illustrates: that a transistor allows you to use a small current to control a much larger one. If the entire purpose of the circuit is to turn an LED on or off, by all means omit the transistor and the extra resistor. But in more advanced circuits, you'll find plenty of cases when the output from one stage of a circuit is very small and you need that tiny amount of current to switch on a much larger current. In that case, this transistor circuit is just what you need.

Transistor as an Oscillator

An oscillator is an electronic circuit that generates repeated waveforms. The exact waveform generated depends on the type of circuit used to create the oscillator. One of the most commonly used oscillator circuits is made from a pair of transistors that are rigged up to alternately turn on and off. This type of circuit is called a multi-vibrator.

If the circuit is designed to continuously cycle between the two transistors, it's called an astable multivibrator because the circuit never reaches a point of stability — that is, it never decides which of the two transistors should be on, so it just keeps flipping back and forth between the two.

Here is a schematic diagram for an astable multi-vibrator made from a pair of NPN transistors.



When you first power on this circuit, only one of the transistors turns on. You might think that they would both turn on, because the bases of both transistors are connected to +V, but it doesn't happen that way: One of them goes first. For the sake of discussion, assume that Q1 is the lucky one.

When Q1 comes on, current flows through R1 into the collector and on through the transistor to ground. Meanwhile, C1 starts to charge through R2, developing a positive voltage on its right plate. Because this right plate is connected to the base of Q2, positive voltage also develops on the base of Q2.

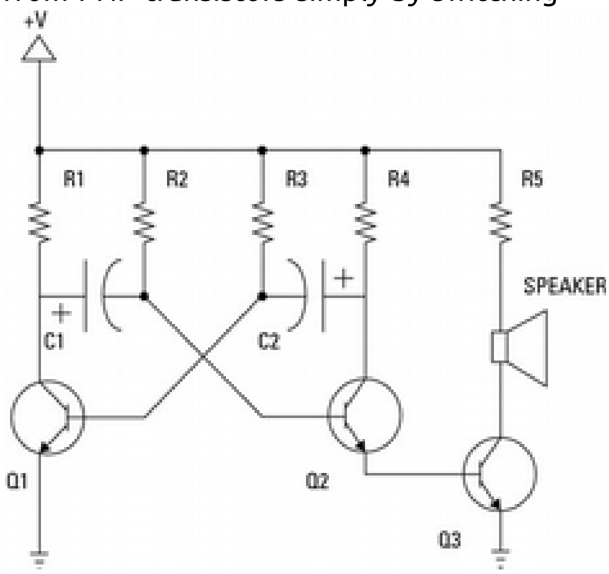
When C1 is charged sufficiently, the voltage at the base of Q2 causes Q2 to start conducting. Now the current flows through the collector of Q2 via R4, and C2 starts charging through R3. Because the right-hand plate of C2 is bombarded with positive charge, the voltage on the left plate of C2 goes negative, which drops the voltage on the base of Q1. This causes Q1 to turn off.

C1 discharges while C2 charges. Eventually, the voltage on the left plate of C2 reaches the point where Q1 turns back on, and the whole cycle repeats. The dueling capacitors alternately charge and discharge, turning the two transistors on and off, which in turn allows current to flow through their collector circuits.

Here are a few other interesting things to know about astable multi-vibrators:

The time that each half of the multi-vibrator is on is determined by the RC time constant formed by the capacitor charging circuits. Thus, you can vary the speed at which the circuit oscillates by adjusting the capacitor and resistor values.

You can, if you want, create an astable multi-vibrator from PNP transistors simply by switching the ground with the +V voltage source.



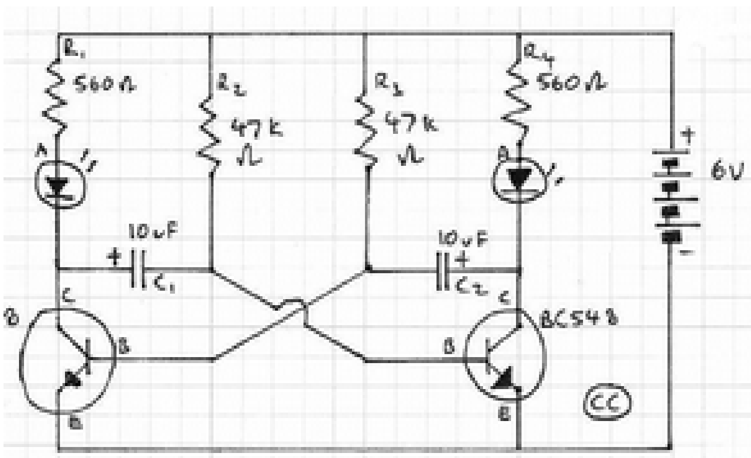
Output from the multi-vibrator circuit can be taken directly from the collector of either transistor. For example, you could place an LED or a speaker in series with R1 or R4 to see or hear the oscillator in action.

Alternatively, you can use a third transistor to couple the multi-vibrator with an output load. Just connect the emitter of one of the multi-vibrator transistors to the base of the third transistor and connect the load to the collector.

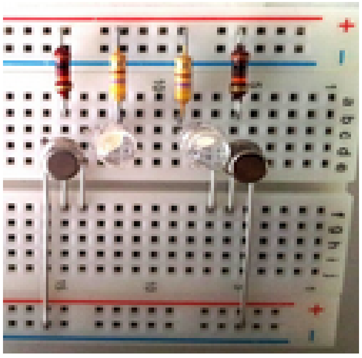
This arrangement has two advantages. First, the load itself interferes with the multivibrator circuit if you take it directly from the collector of Q1 or Q2. By using a third transistor, you isolate the load from the multivibrator circuit. Second, the output is much closer to a true square wave when the coupling transistor is used; without it, the output isn't a clean square wave because of the effects of the capacitor charging.

A simple LED Flasher

If you connect two LEDS in the above circuit as shown below, it will work as a simple LED flasher, which you already have seen. It is used in illuminating photographs and idols at home.



How it works?

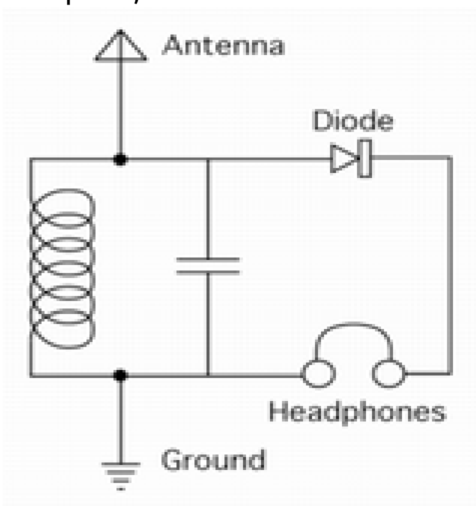


Imagine that R2 were omitted, and suppose the left side transistor (Q1) started out being turned on. Then the right side transistor (Q2) would have nothing to turn it on, and the left side transistor would be held on by current through R3, while the R4 and the LED would charge C2. The effect would be that the left LED would come on and stay on, while the right LED would never light.

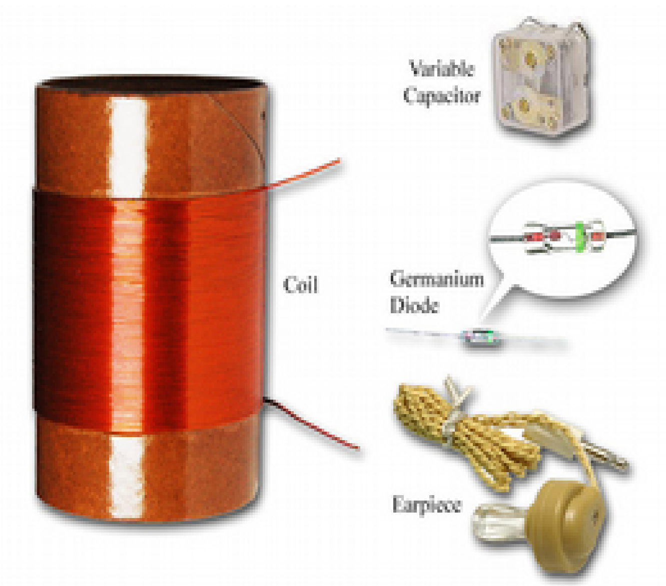
Now add R2. This will cause C1 to charge to -0.7 volts, until Q2 turns on. Once that happens, the charge on C2 would cause the base of Q1 to go negative, turning it off. When that happens, left-side LED current will start flowing through C1 and the base of Q2, turning it on even harder. Once Q2 has turned on, it will keep Q1 off until C2 charges to -0.7 volts.

Simple crystal radio.

A crystal radio is the distilled essence of a radio. It has very few parts, it needs no batteries or other power source, and it can be built in a short time out of things you can find around the house.
The reason a crystal radio does not need any batteries is the amazing capabilities of the human ear. The ear is extremely sensitive to very faint sounds. The crystal radio uses only the energy of the radio waves sent by radio transmitters. These radio transmitters send out enormous amounts of energy (tens of thousands of watts). However, because they are usually far away, and we have at most a few hundred feet of wire for an antenna, the amount of energy we receive with the crystal radio is measured in billionths of a watt. The human ear can detect sounds that are less than a millionth of even that.

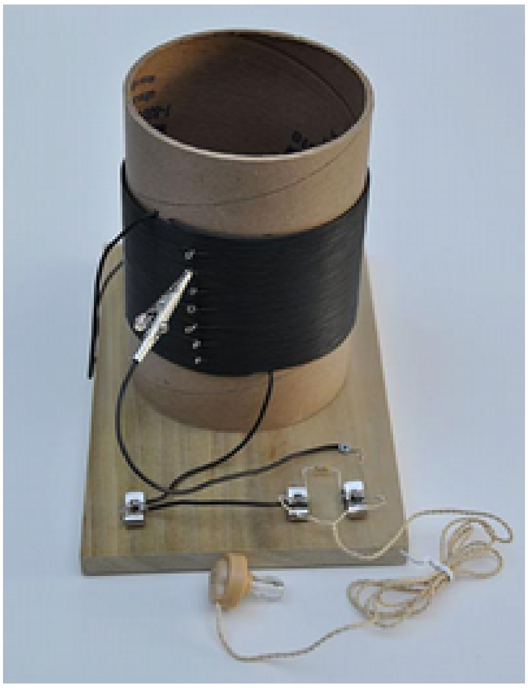


Building a crystal radio circuit is not very difficult and require little electronics or technical knowledge, you can make it with 2 to 4 components in a very short time. The crystal radio schematic shown above is very simple and one can easily build it in few minutes if all parts are available. This simple crystal radio circuit will receive many nearby radio stations and also receiver far radio stations which have strong signals.



Now start building the radio and first make coil, for making the coil use toilet roll or PVC pipe and then wind 80 turns of enameled copper wire on that roll. When winding is completed secure it with glue or sticky tape. Do not forget to scrape the wire enamel from both ends of the enameled wire with knife because all enameled wires are coated with enamel material and we have to remove that material to make connection. After completing the coil connect all parts like germanium diode, variable capacitor, coil and ear piece together to make a crystal radio as shown in the circuit diagram.

After building the radio connect the longest antenna wire to the radio circuit as shown in the picture and take it outside to the window and attach it to any tree or just put it out from the window.



You will also need to make an earth connection to the radio circuit for this connect a wire with the ground connection of the radio circuit and attach it with cold water pipe or water tap with crocodile clip. A good earth connection is required for a crystal receiver to work properly. It works better with earth connection but sometimes good results without earth connection as well.

When all done correctly as described, pick up the ear-piece and listen, you will hear some noises, adjust the screw on the variable capacitor until you hear any station sound. You can hear many stations on this crystal receiver circuit depending your location, and the length of the antenna wire. If you are receiving very low sound in the ear-piece try unwinding 4 to 5 turns of the coil. This is a basic and beginner circuit of radio so you have to make some small experiments to get better performance patiently, this will also increase your knowledge in electronics and you also understand how a radio works.

How A Crystal Radio Works ?

In order to understand the crystal radio receiver you first have to understand were the “signal” or radio wave comes from and how it was made.

The Transmitter

A radio station is used to broadcast a radio wave. The radio wave is sort of like dropping a pebble into a pond of water. The ripples or waves radiate outward from where the pebble was dropped in the water. Radio wave radiate outward from the radio stations antenna sort of like the waves in the pond. Radio waves are electromagnetic waves.

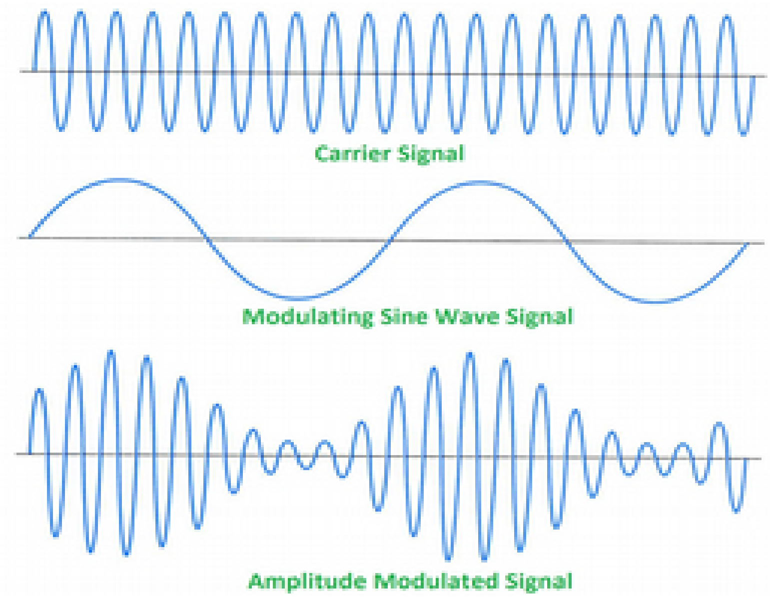
The AM radio band is from 530,000 Hz to 1,710,000 Hz. We use the designation k for 1000, so it would be written as 530 kHz to 1710 kHz.

Now for a sample radio station. It is “radio station 610 on the AM dial”. This means the radio station is broadcasting a radio wave of 610 kHz or as we now know, a radio wave that cycles 610,000 times a seconds! That’s correct, 610 thousand times each second!

OK, then how does that wave carry the sound?

The radio station has equipment that varies the strength or amplitude of the radio wave. It still cycles at the same rate, but it gets stronger or weaker according to the sound. If that amplitude is controlled by the sound say from a microphone (with other equipment), going up and down but is cycled at a fixed rate a second, you have a radio wave like the type coming from a radio station! The station is “modulating” or varying the amplitude of the radio wave. This is called Amplitude Modulation or AM.

In the figure below you can see a “un-modulated/carrier” wave at on the top example and an “amplitude modulated” wave in the bottom example. Please note that the cycles per second remain the same in both signals, but the amplitude changes in accordance with the “modulating signal” from a microphone or CD player.



Now we have this radio wave flying through the air hitting everything! That's right including you! Radio waves can travel at 186,000 miles a second in the air!

Interesting fact: a sound wave travels over 600 miles an hour (speed of sound), but a radio wave can travel at 186,000 miles a second! If you record a singer in a concert hall in Chennai and transmit it over radio waves, The radio wave could reach another part of world before the sound wave from the singer reaches to the listener who is sitting back in the concert hall.

We are going to use a very simple crystal radio for this explanation. See the beginning of topic crystal radio to see the schematic(circuit) diagram.

A coil is used in the circuit to make it resonant with the frequency we are receiving. By winding just the right amount of wire, the coil will become resonant, that means it will be able to store the energy of the radio wave we want to hear, while other radio waves not resonant will pass through the coil and out the other side to the ground.

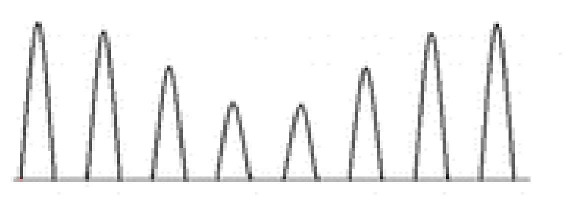
What is Resonance?

Resonance happens in electric circuits and in mechanical things. It is easier to understand in mechanical things first. If hang a small weight on a string one about 9 inches long (about 23 cm) it will swing back and forth one time each second. If you try to speed it up of slow it down, you can't. It swings at just one frequency, which is one cycle per second. That is resonance. The string and weight is resonant at one cycle per second. To make it slow down by half, make the string twice as long. The length of the string changes the resonant frequency. You can say that the length of the string “tunes” the resonant frequency.

For electricity, a coil and capacitor make a resonant circuit. The capacitor plates get an electric charge from other parts in the radio. That charge flows through the coil. As it does, it builds up a magnetic field in the coil. When all the charge is gone from the capacitor, the magnetic field makes the electricity keep on flowing a little. This charges the capacitor plates the opposite way. As the opposite charge builds up on the capacitor plates, it finally stops the charge flow in the coil. Then the charge in the capacitor plates makes electricity flow the opposite way through the coil. That builds up a magnetic field in the opposite direction. **The charge swings back and forth between the coil and capacitor at one certain frequency. That is the resonant frequency of the coil and capacitor**.

How signal are detected then?

A small amount of energy from the radio wave is captured by the antenna wire and is taken to the coil. The coil has to be designed just right to capture only the frequency we are trying to receive. In our case we are trying to receive our radio station above at 610 kHz. By winding just the right amount of wire on just the right diameter coil form, the coil will be what we call "resonant". All other radio waves not resonant will pass through the coil and out the other side to the ground. A small amount of the radio wave energy stored in the coil (our 610 kHz or 610,000 cycles per second) moves to the detector or the device called a diode. The energy is an alternating current signal (AC) at this point. The detector (diode) rejects half of the alternating current signal and the signal looks like figure below. Now the signal is a pulsating direct current (DC) signal.



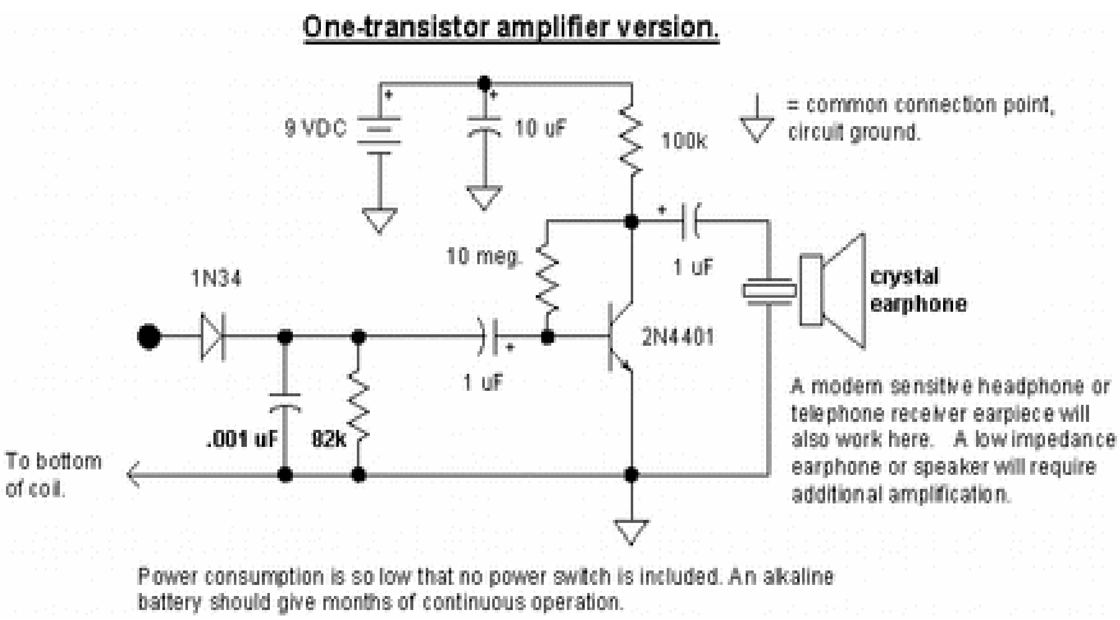
This allows the earphone to use the energy. If both sides of the wave were used, they would cancel each other out as they are opposite of each other. As this energy go into the earphone, the amplitude or strength of the signal varies because the wave is modulated. This energy is converted by mechanical means in the internal workings of the earphone. The sound waves exit the earphone which you perceive as the original sounds from the radio station.

Not discussed here is tuning the coil to get different frequencies. That can be done by adding more turns of wire around the coil form. Or removing some. On a simple radio, this is done by moving the diode up or down the taps on the radio in effect making the coil longer or shorter. This changes the inductance of the coil or makes it resonant to different frequencies.

Another way to do this is to add a variable capacitor across the coil. This adds or removes capacitance to the coil and changed the resonant frequency the coil will tune to.

Single Transistor Amplifier for your Crystal Radio

Connecting an amplifier to the output of the Germanium diode(IN34) will boost the audio level as shown below. The current consumption of this amplifier is quite low and a power switch is not included. Disconnect the battery when the receiver is stored for long periods.



“All life is an experiment. The more experiments you make the better.”
~Ralph Waldo Emerson, American Poet