Chapter 3
Semiconductor Devices

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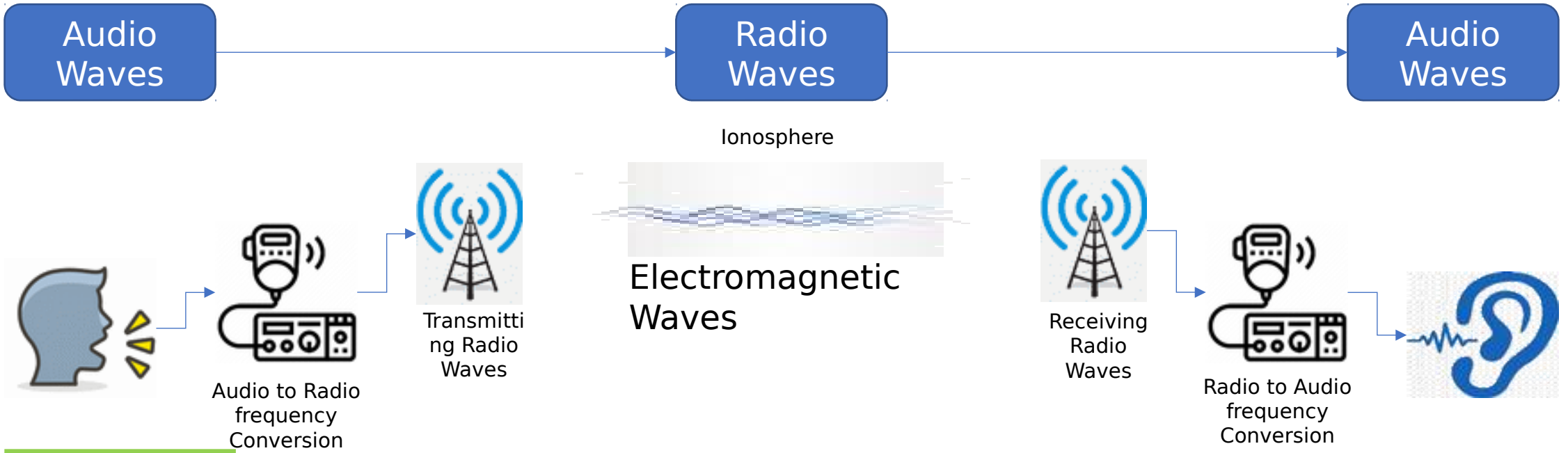
Chapter Scope

- Semiconductor Introduction
  - Atom
  - Periodic Table
  - Doping
  - N-Type
  - P-Type
- Diode
  - Forward Bias
  - Reverse Bias
  - LED
- Transistor
  - BJT
  - Transistor Operation
    - Depletion Zone
    - NPN
    - PNP
    - As Switch
    - As Amplifier
    - As Oscillator
    - Crystal Radio
    - Resonance

Concepts we will discuss:

1. Atom and Electrons
2. Conductors and insulators
3. AC and DC Basics
4. How current is created
5. Current flow direction
6. Voltage and pressure
7. Amplification

Radio Communication



What we learn

- Basic Concepts → Electricity, Electronic Components & Concepts, Laws, Circuits, Magnetism
- Radio Components and Wave → Receivers, Transmitter, Amplifiers, Antenna, Radio Wave Propagation
- Rules and Regulations → Indian Wireless Telegraphic Rules, Frequencies, Emissions, Important Signals & Calls, Call Signs, Q Codes, and the Amateur Radio Station
- Morse Code → Morse code receiving and sending at 8 words per minute speed

Semiconductor Introduction

Conductor – Electron jumps atom to atom

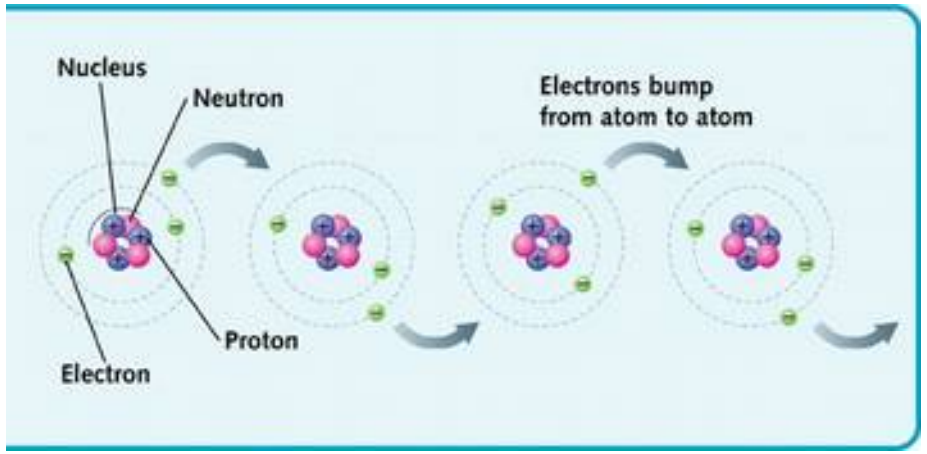
Insulator – Electron cannot jump atom to atom

Semiconductor – Conducts when enough pressure is given.

Adding impurity to an insulator or near insulator. This process is called **DOPING**

Things to remember

1. Atom and Electrons

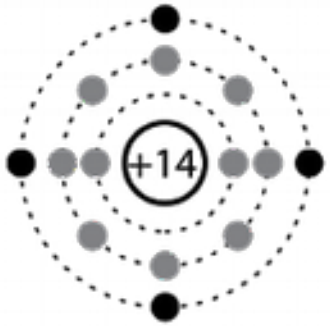


https://en.wikipedia.org/wiki/List_of_semiconductor_materials

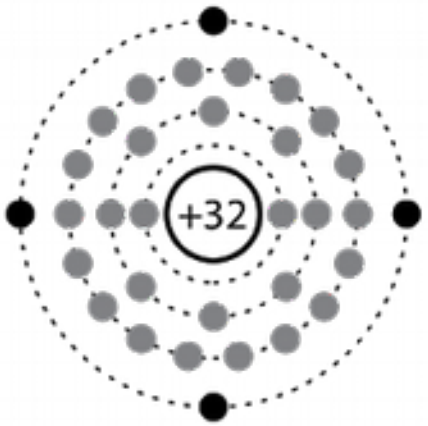
Commonly used semiconductor materials are

Silicon and Germanium

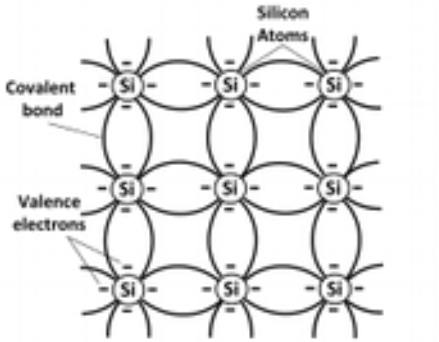
Silicon and Germanium



Silicon



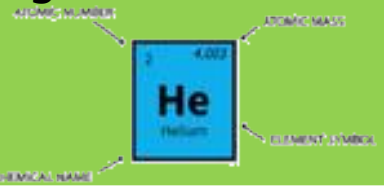
Germanium



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.

A pure silicon crystal is nearly an **insulator.** Very little electricity will flow through it.

Things to remember



Things to Understand

1. Germanium crystals will be damaged by excess heat, whereas, silicon crystals are not .

2. Peak Inverse Voltage ratings of Silicon diodes are greater than Germanium diodes.

3. Si is less expensive due to the greater abundance of element.

Silicon Doping

Adding impurity to Silicon. i.e. breaking the crystal nature / lattice by increasing or decreasing an electron.

N type doping

Phosphorus or arsenic is added to the silicon in small quantities.

Electrons have a negative charge, hence the name N-type

P type doping

Boron or gallium is the **dopant**. When mixed into the silicon lattice, they form "holes" in the Lattice.

The absence of an electron creates the effect of a positive charge, hence the name P-

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."

Things to Understand

N Type increases the electrons

P Type decreases the electrons.

Created the Semiconductors – What next?

P-N Junction – Diode

Things to Remember

1. N-Type, More Electron
2. P-Type, More Holes

- A **diode** is the simplest possible semiconductor device.
- A diode allows current to flow in one direction but not the other.

Diode Symbolic Representation

P-N Junction – Diode – Reverse Biased

A **diode** is the simplest possible semiconductor device.

A diode allows current to flow in one direction but not the other.

Things to Remember

1. N-Type, More Electron
2. P-Type, More Holes

- The negative electrons attracted to the positive terminal of the battery.
- The positive holes 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.

This combination is called *reverse bias*

Figure (a)

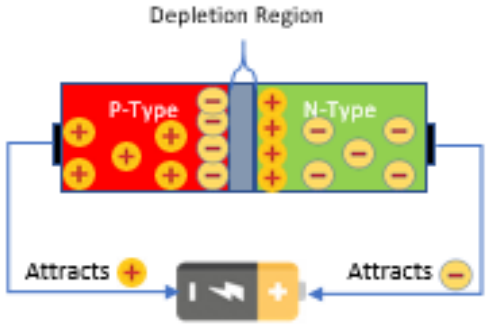
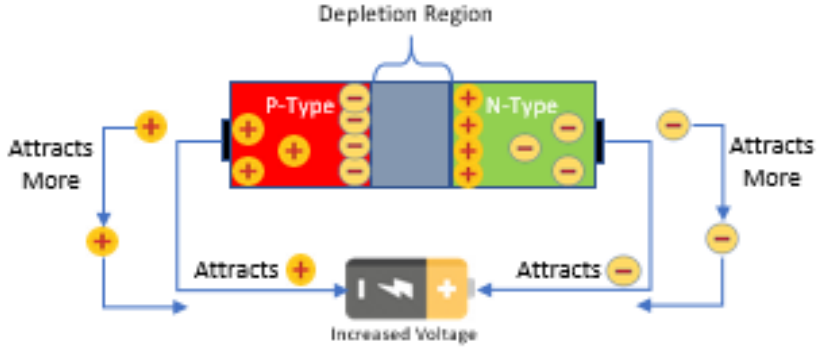
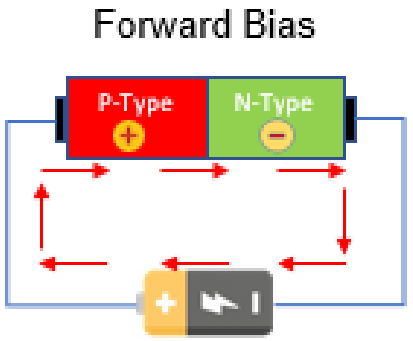


Figure (b)



P-N Junction – Diode – Forward Biased



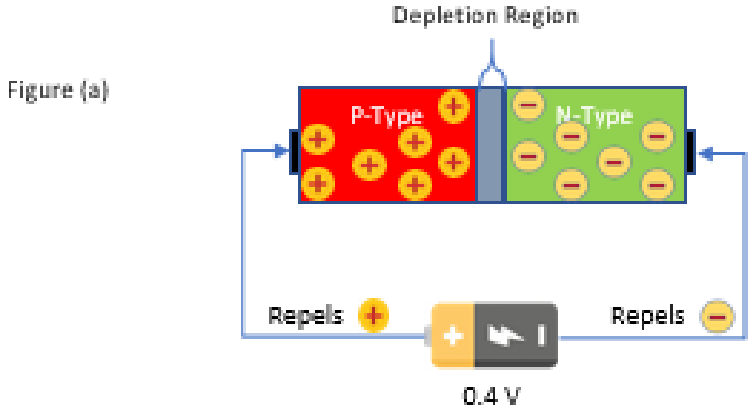
- The negative electrons are repelled by the negative terminal of the battery.
- The positive holes are repelled by the positive terminal of the battery.
- At the **junction** between the N-type and P-type silicon, holes and free electrons meet. The electrons fill the holes. Those holes and free electrons cease to exist, and new holes and electrons spring up to take their place. The effect is that **current flows** through the junction.

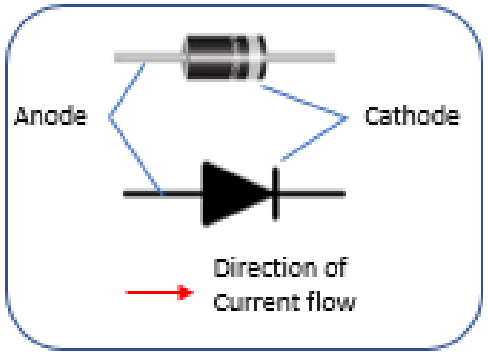
bias

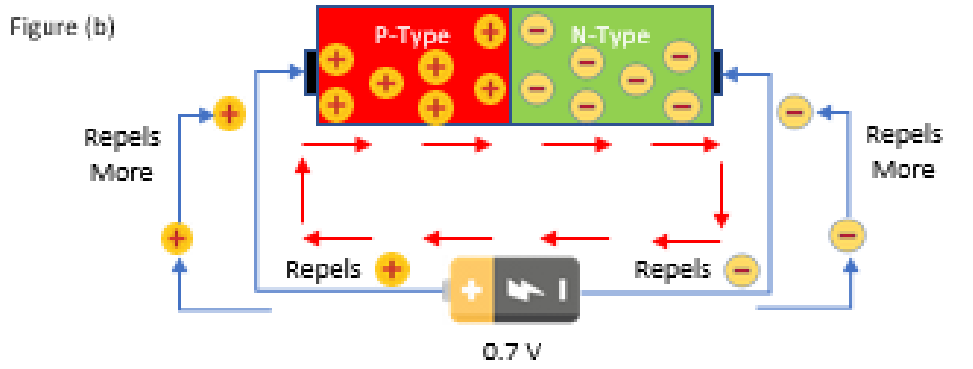
- *For Silicon Forward Bias Voltage is .7 V*
- *For Germanium Forward Bias Voltage*

Things to Remember

1. Conducts only DC
2. Rectifies AC and gives DC





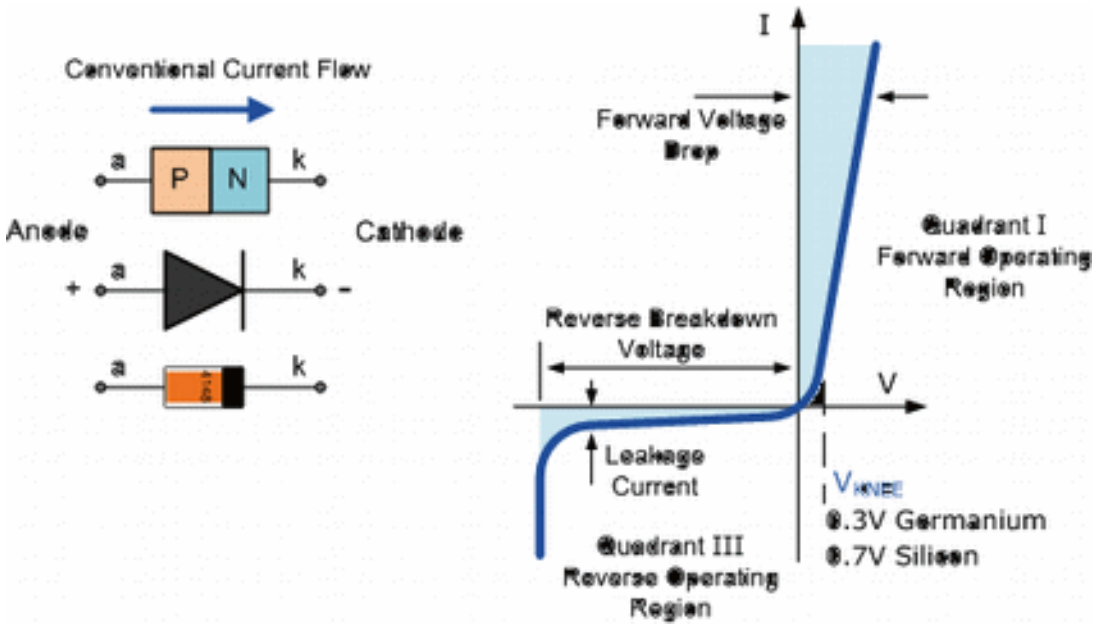


P-N Junction – Diode – VI Characteristics

Things to Remember

1. Reverse Bias

- A very small amount of current can and does go through a reverse-biased diode, called the leakage current.
- The ability of a diode to withstand reverse-bias voltages is limited, as it is for any insulator.
- If the reverse-bias voltage becomes too great, the diode will experience a condition known as breakdown, which is usually destructive.
- A diode's maximum reverse-bias voltage rating is known as the **Peak Inverse Voltage**, or **PIV.**
- 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.



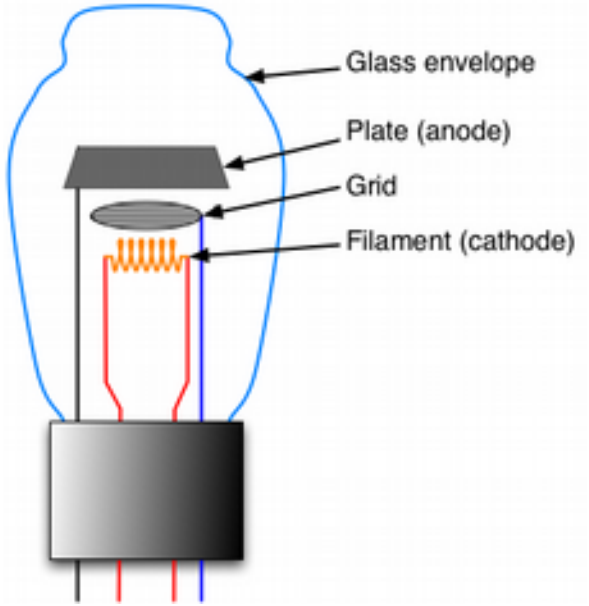
Transistor

- The name **"Transistor"** came from the word **transfer resistor**.
- Transistors replaced the Vacuum tubes.
- 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.

Electric Bulb

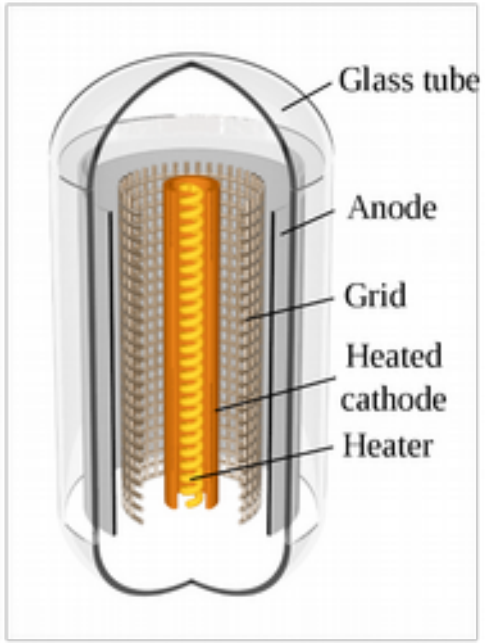
Vacuum Tube

Transistor – Vacuum Tubes



Triode

1. Cathode emits electrons
2. Anode gathers the electron [this makes the current flow.
3. Grid controls the flow of electron [increase or decrease]



Triode

Things to know

1. Vacuum tube, electron tube or simply Tube = American usage
2. Valve = British Usage

Transistor Vs Vacuum Tubes

A quick Comparison

1. Transistors are much more durable (vacuum tubes, like light bulbs, will eventually need to be replaced),
2. much smaller (imagine fitting 2 billion tubes inside an iPhone),
3. require much less voltage than tubes in order to function (for one thing, transistors don’t have a filament that needs heating)

Things to know

1. Vacuum tubes are big in size
2. Transistor are very small in size

Valve Radio

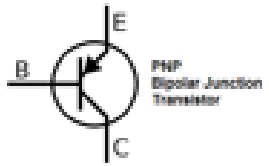
Transistor Radio

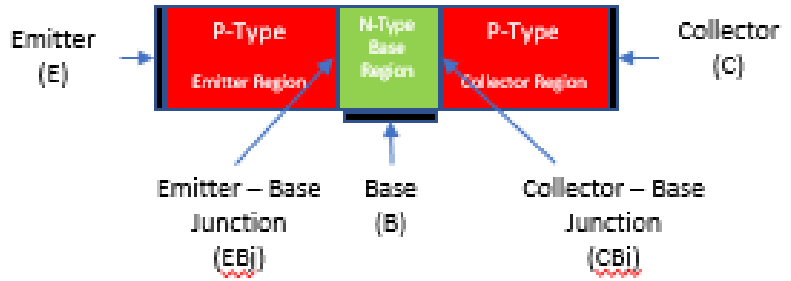
Transistor Packet Radio

Transistor – BJT - Bipolar Junction Transistor

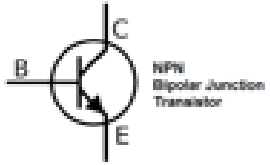
A BJT (Bipolar Junction Transistor) transistor has inside two similar semi-conductive materials, and between them there is a third semi-conductive material of different type.

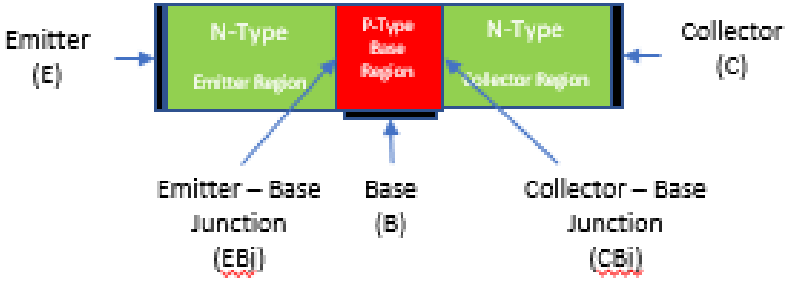
- Two P type semiconductor materials placed both the sides and the middle one is with N type, then we have P-N-P or PNP transistor.



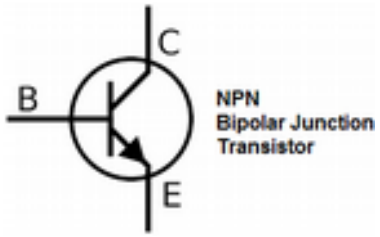


- Two N type semiconductor materials placed both the sides and the middle one is with P type, then we have N-P-N or NPN transistor.





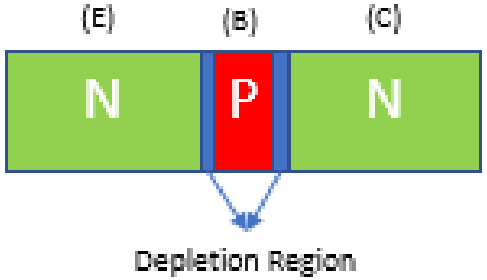
Transistor – BJT – Operation - NPN



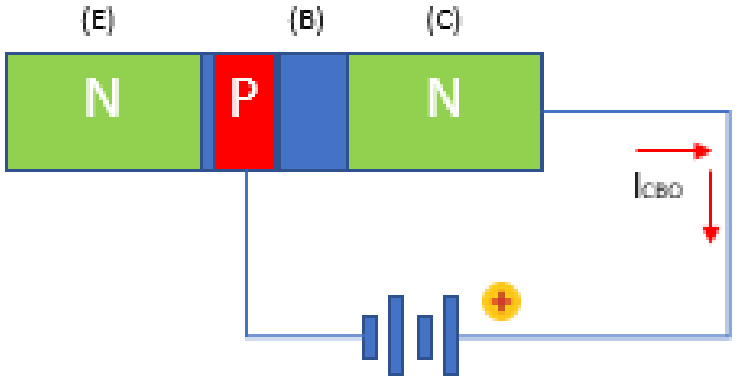
Things to remember

1. Diode Properties

With no power applied to the transistor areas, there are two depletion zones between the two PN contacts.



If we connect a power source between the base and the collector in reverse-bias, the depletion region between Base and Collector expands.

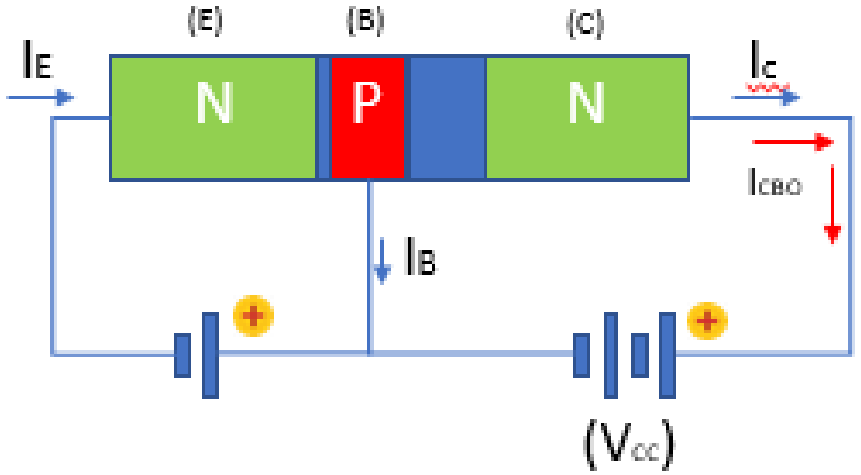


Transistor – BJT – Operation - NPN

Things to remember

1. Diode Properties

- Connect another voltage supply between the emitter and the base in forward bias, the depletion zone between the emitter and the base will be shortened and current (electrons) will flow.
- 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 IB symbol for reference. In real life, this current is at the scale of micro-amperes.
- Most of the electrons will spill over and will be directed to the
- collector.
- The electrons will pass over the depletion area between the base and the collector.
- 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 (VCC).
- The movement of these holes equals to a movement of electrons in the opposite direction, from the collector to the supply.



$$I_E = I_B + I_C$$

Transistor – BJT – Operation - NPN

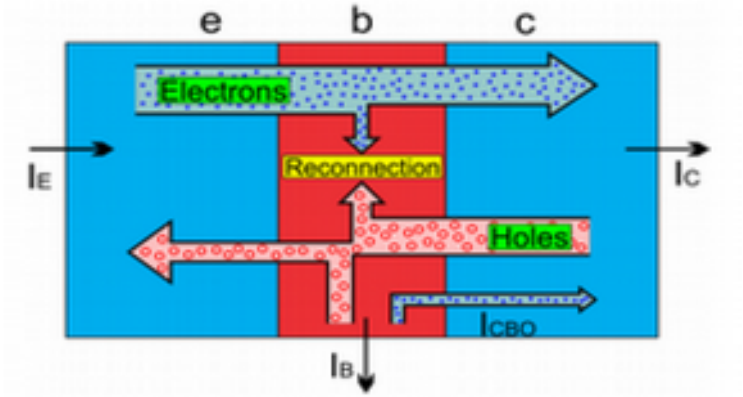
Things to remember

1. Diode Properties

- In other words, the current that flows to the emitter will be divided into the small base current and the larger collector current. Both currents flow at the same direction, so they are added $I_E = I_B + I_C$.

- 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.



$$I_E = I_B + I_C$$

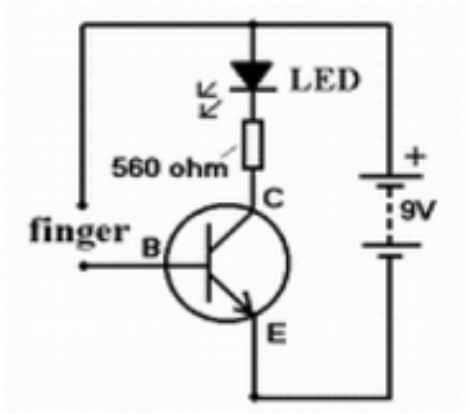
$$I_C = I_{CBO} + I_C$$

Transistor – As Amplifier

Things to remember

1. Transistor Properties

- 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 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:
- **I = V / R** = 9/ 50,000 = 0.0002ª. 50,000 Ohms is the resistance created by our body.
- 0.0002A(input to base from our finger) x 100 (transistor amplification factor) = 0.02A = 20mA
- and so the LED lights !!



Transistor – As Switch

Things to remember

1. Forward Bias Voltage

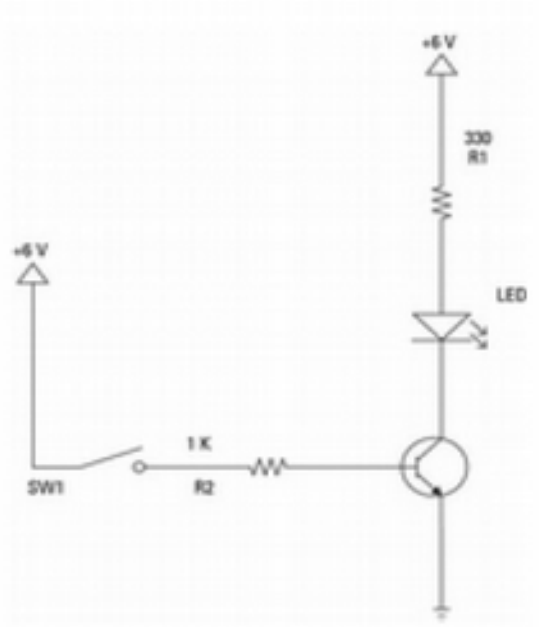
In an ideal switch, the transistor should be in only one of two
states: off or on.

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.

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.



Transistor – As Oscillator

An oscillator is an electronic circuit that generates repeated waveforms. 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.

assume that Q1is the lucky one.

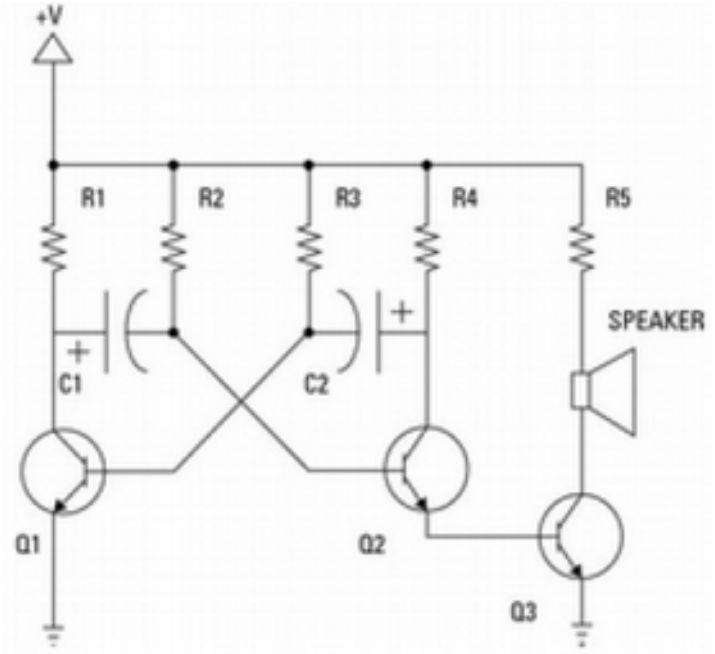
When Q1 comes on, current flows through R1 into the collector and on through the transistor to ground. Meanwhile, C1 starts to charge through R2, developing a positive voltage on its right plate. Because this right plate is connected to the base of Q2, positive voltage also develops on
the base of Q2.

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.

Things to remember

1. NPN Transistor operation



Crystal Radio

Things to remember

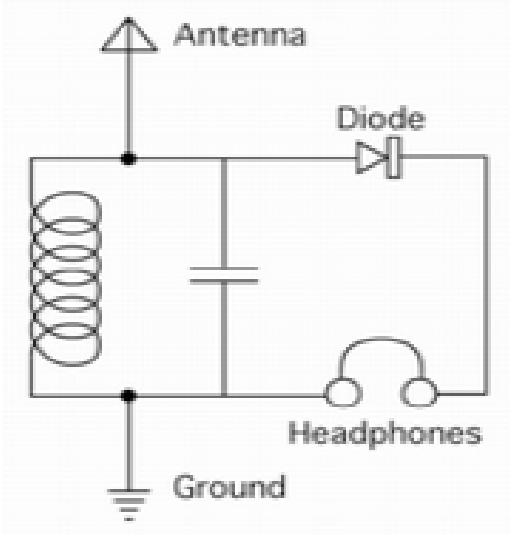
1. Inductor, Capacitor and Diode properties

Crystal radio is made up of few components without power source.

It uses below simple components ,

Coil, germanium diode, variable capacitor and ear piece.

Place them together to make a crystal radio as shown in the circuit diagram.

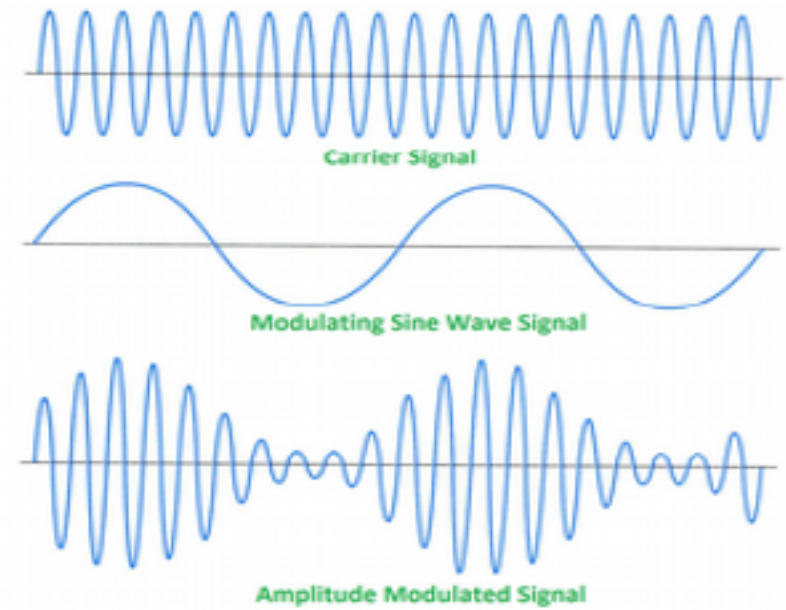


Crystal Radio

Transmitter – AM Band

Things to remember

- A radio station is used to broadcast a radio wave through antenna.
- 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.
- The radio station has equipment that varies the strength or amplitude of the radio wave.
- The frequency is fixed. But it gets stronger or weaker according to the sound. This is generated by the microphone.
- The amplitude is controlled going up and down but is cycled at a fixed rate a second. This “modulating” or varying the amplitude of the radio wave is called

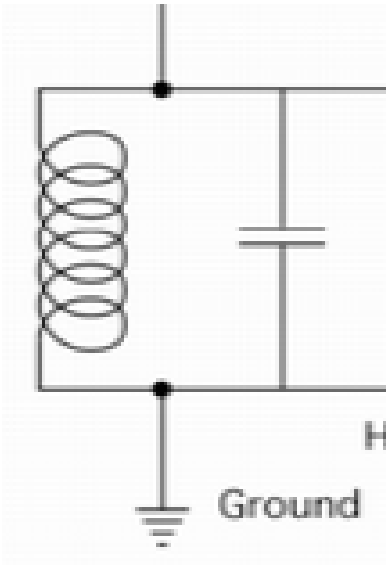


Resonance

- a coil and capacitor make a resonant circuit.
- Coil (Inductor stores energy in Magnetic field)
- Capacitor stores electrical potential energy.
- When all the capacitor charge is gone, the coil's magnetic field makes the electricity keep on flowing a little.
- This charges the capacitor plates the opposite way till the magnetic field is over.
- 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**

Things to remember

1. Inductor, Capacitor and Diode properties



Resonance Circuit

Resonance and Signal Detection

a coil and capacitor make a resonant circuit.

Coil (Inductor stores energy in Magnetic field)

Capacitor stores electrical potential energy.

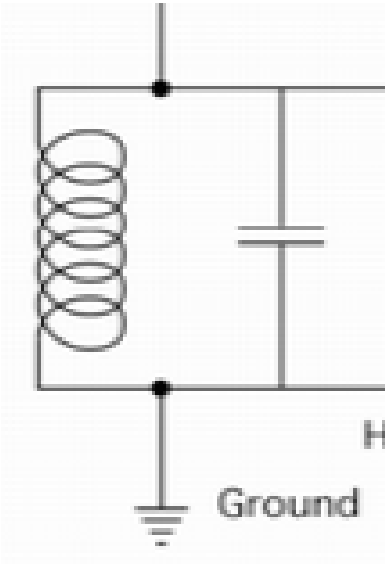
When all the capacitor charge is gone, the coil's magnetic field makes the electricity keep on flowing a little.

This charges the capacitor plates the opposite way till the magnetic field is over.

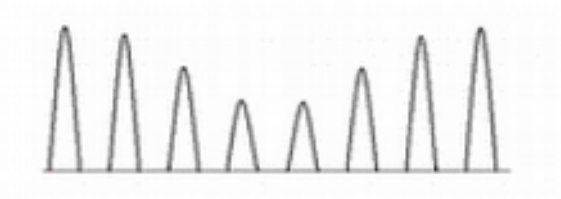
Then the charge in the capacitor plates makes electricity flow the opposite way through the coil. That builds up a magnetic field in the opposite direction.

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.

610 kHz or 610,000 cycles per second) moves to the detector or the device called a diode. This detector (diode) rejects half of the alternating current signal and convert that to direct current (DC) signal.



Resonance Circuit



Detected Signal

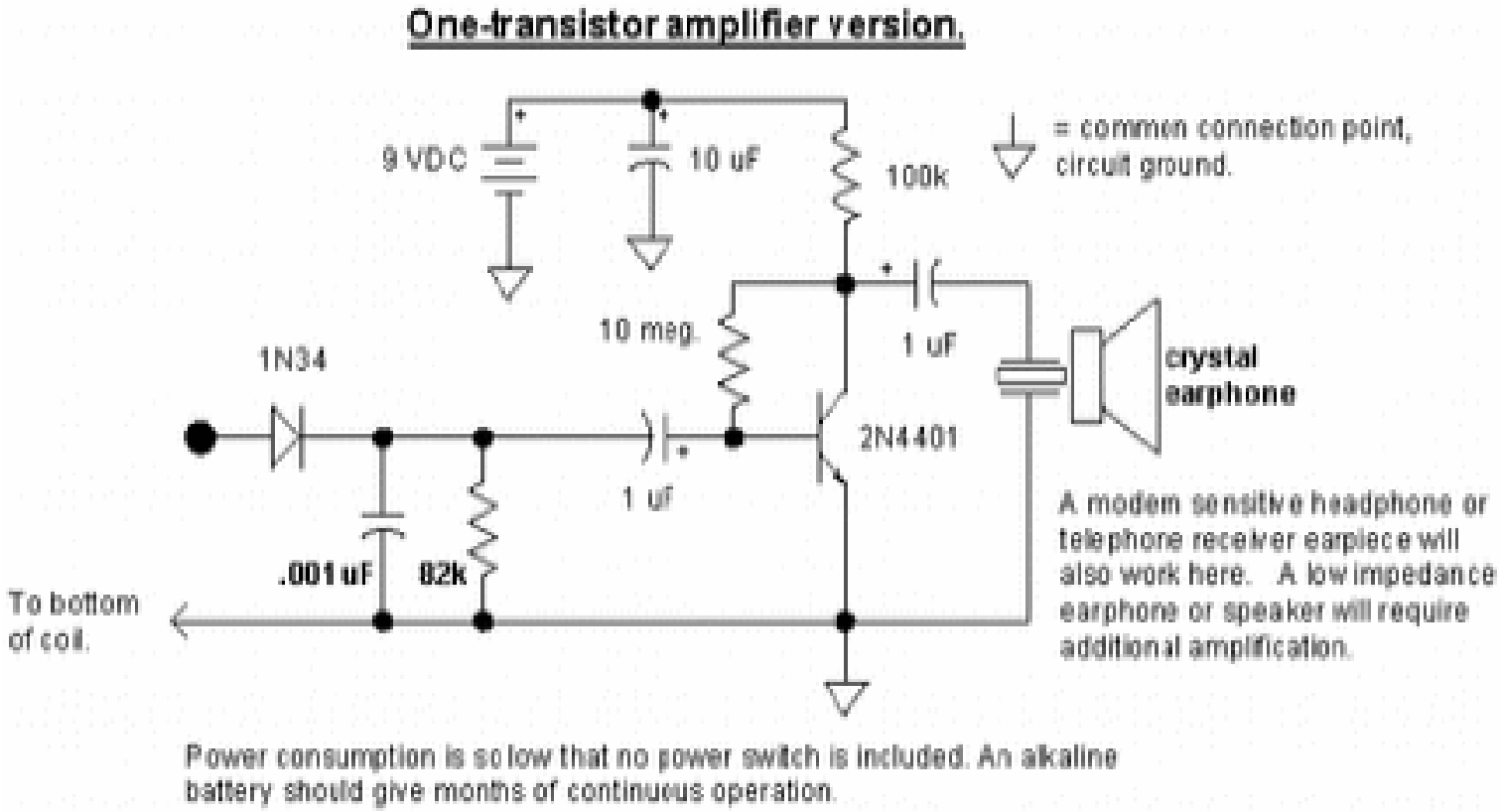
Things to remember

1. Inductor, Capacitor and Diode properties

Crystal Radio Amplifier

Things to remember

1. Transistor Operation



Thank you