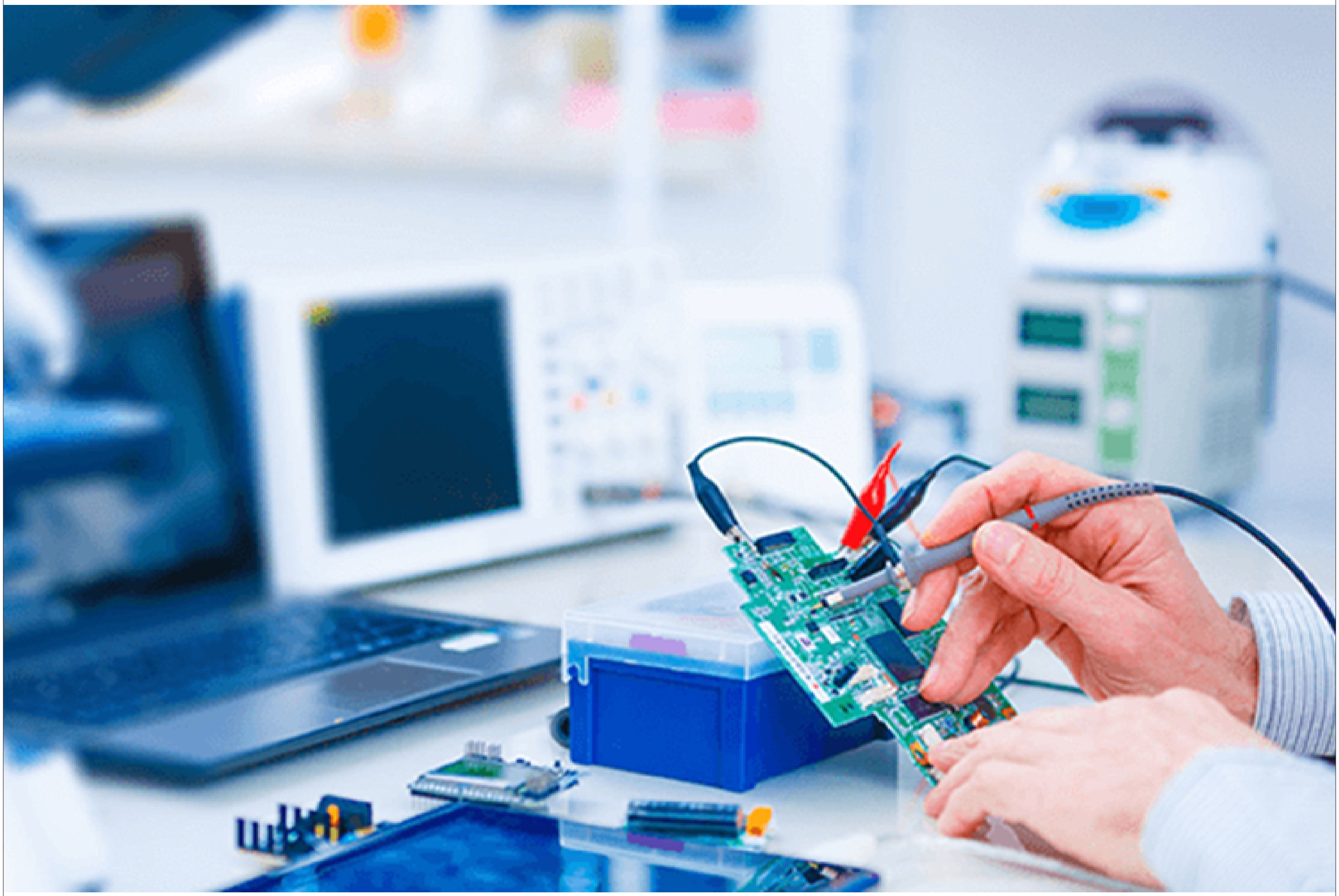
Internet of Things Hardware Development

IX



NAVTTC

National Vocational & Technical Training Commission (NAVTTC)

Textbook of

Internet of Things Hardware Development

Grade – IX

National Vocational and Technical Training Commission

H-9, Islamabad

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PREFACE

This book has been written to meet the requirements of Matric Tech to train the students in the trade Internet of Things (IoT). This book is specific for IoT hardware development. Matric-Tech in IoT has been introduced for the first time in the history of Pakistan. This textbook is the first national effort to describe all the topics related to IoT hardware development in a single book. A key attempt has been made to make the book interesting and useful. All the chapters presented in this book cover the required basic details in a manner understandable to the students of Matric Tech. All the chapters include assessments in form of MCQs, short questions and long questions.

The book covers 40% theoretical and 60% practical content. This content is equally helpful for the students of electronics, computer sciences and networking.

Any improvements and suggestions for the betterment of this book will be highly appreciated.

Executive Director
National Vocational & Technical Training Commission
(NAVTTC)

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Chapter 1

Basic Electrical Theory

After Studying this chapter, you will be able to

- define electricity.
- understand electrical quantities and their units.
- explain characteristics of conductors, insulator, semiconductor.
- describe power and energy and its difference.
- apply instruments to measure current, voltage, resistance.
- use oscilloscope to plot wave form.
- apply ohm's law for measuring current, voltage and resistance.
- define cell and batteries.
- describe the importance of cell and batteries.
- explain the types of cell and batteries.
- explain the charging procedure/principle of battery.
- use cell and battery as a series and parallel source.
- describe the components/parts of cell and battery.
- explain the construction and working principles of cells and batteries.
- explain the procedure for maintaining a battery.
- describe the importance of electrolyte in the battery.
- explain the testing procedure of batteries.
- explain the use of tools and equipment required for testing of batteries.
- calculate the size of battery for a specific circuit through different techniques.

Chapter 1

1.1 Basic Principle of Electricity

1.1.1 Electricity

Electricity is the flow of electricalenergy. Electricity is the secondary form of energy which means that other sources of energy i.e., kinetic energy, thermal energy and solar energy etc. are converted into electrical energy.

Do you know?

- In dams, kinetic energy of water is converted into electrical energy.

Point to Ponder

- Which type of energy is converted into electrical energy in coal-based power plants?

How does electricity get to your home?

Electricity is generated at dams and thermal power plants located in remote areas. The electricity that power plants generate is delivered to consumers over transmission and distribution power lines. This complex system sometimes called the “grid” includes substations, transformers, and power lines that connect electricity producers and consumers.

1.1.2 Electrical Quantities and Units

Electricity is represented by electricity quantities. There are three main electrical quantities:

I. Voltage
II. Current
III. Resistance

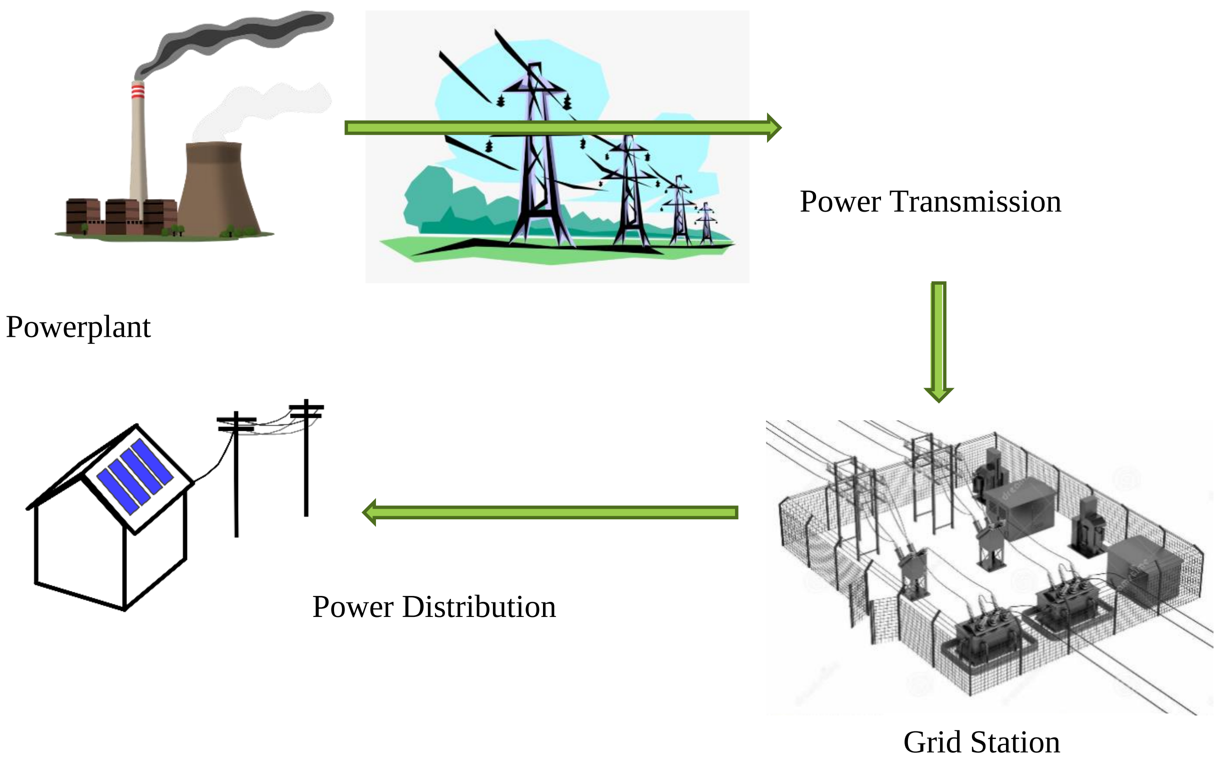


Fig. 1.1 Electricity from generation site to the home

Voltage

A voltage is a potential difference between two points of an electric circuit. A voltage is the pressure from an electrical power source that causes current in an electric circuit.A voltage is like a diffusion phenomenon as shown in Figure 1.2. A voltage is represented by *V* and is measured in volts (*V*).

Current

Flow of charges inside an electric circuit is called electric current. An electric power source such as a battery consists of high number of charged particles which creates a potential difference between two points of an electric circuit, causing current. Figure 1.3 shows an analogy between water and current. A current is represented by *I*and is measured in amperes (A).

Do you know?

- A voltage is just like diffusion phenomenon in an electric circuit.

Fig. 1.2 Diffusion of Electrons

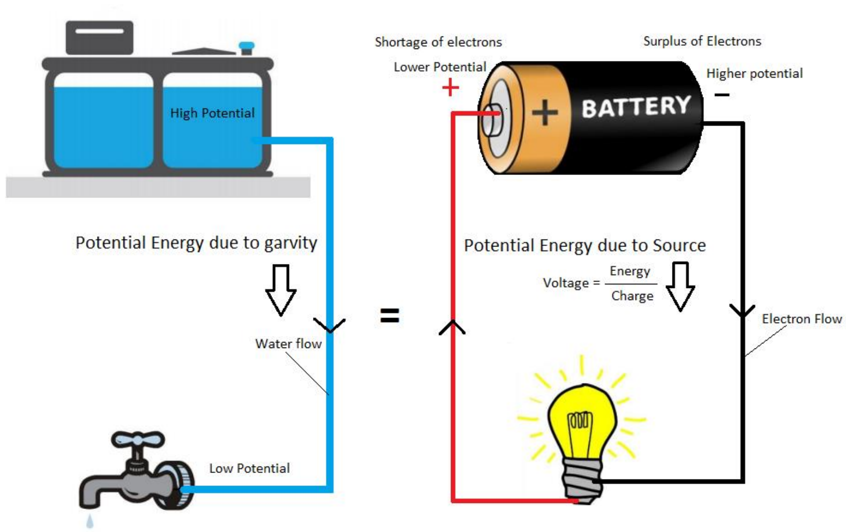


Fig. 1.3 Analogy between Electric Supply and Water Supply

Resistance

A resistance is a component opposing the current flow in an electric circuit. The higher the value of resistance, more will be the opposition. A resistance is represented by R and is measured in ohms (Ω).

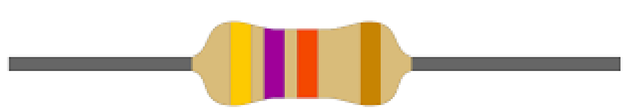


Figure 1.4 Resistance

AC and DC Quantities

There are two types of current. Direct Current (DC) and Alternating Current (AC). Magnitude (value) and direction of DC remains constant while AC keeps on changing its direction. Similarly, there exists AC and DC voltages.

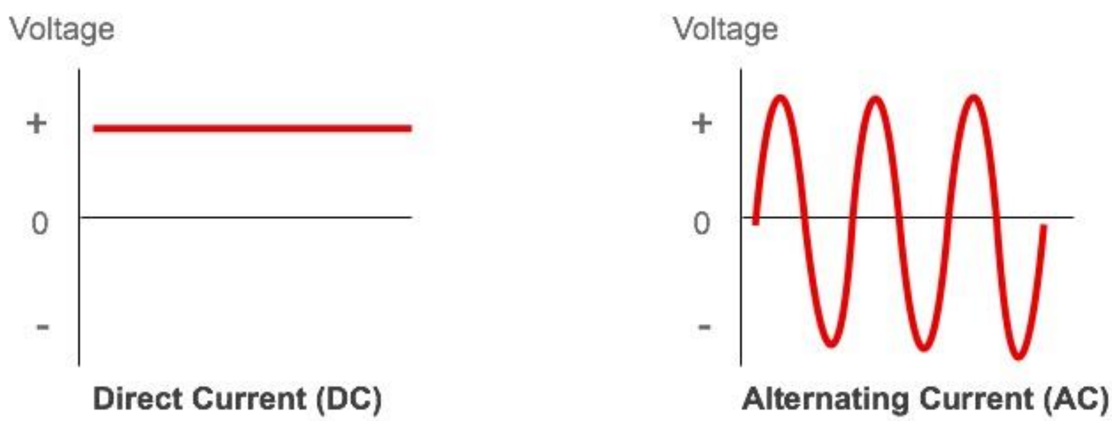


Figure 1.5 Difference between AC and DC

Point to Ponder

- Why there exists two different types of quantities: AC and DC voltage and current?

1.1.3 Conductors, Insulators and Semiconductors

Conductors

Current can flow in conductors. Conductors have free electrons on its surface which allow current to pass through easily. They are made up of atoms having free electrons. Copper, silver and aluminum are good conductors of electricity.

Insulators

Insulators are made up of material that do not allow electricity to pass through it. They are made up of atoms that do not have free electrons. Plastic, glass and rubber etc. are good insulators for electricity.

Chapter 1

Semi conductor

Semiconductors have limited free electrons so their conductivity lies between conductors and Insulators. Silicon and germanium are semiconductors.

Activity

- Identify conductors and insulators of heat in your home.

Point to Ponder

- Is a good conductor of heat also a good conductor of current?

1.1.4 Electrical Power and Energy

Electric Power

Electric power of an electric circuit or appliance is the rate at which it consumes energy. Unit of Power is Watt which is 1 Joule per second. Equation 1 represents power in terms of energy.

$$P = \frac{\Delta E}{\Delta t} \quad \text{-----------------------------(1)}$$

ΔE is work being done. So, equation 1.1 can be rewritten as:

$$P = \frac{W}{Q}\frac{Q}{t} \quad \text{----------------------------(2)}$$

Voltage is basically the work done (W) per unit charge (Q). While current is charge per unit of time. So, equation 1.2 can be rewritten as:

$$P = VI \quad \text{----------------------------(3)}$$

Electric Energy

It is a form of energy resulting from flow of electrons. It is usually derived from power. Most common unit of consuming energy is in terms of kWh, that is equivalent of using 1 kilowatt power for one hour. kWh is also used as a unit for computing electricity bill by energy suppliers.

Do you know?

- When purchasing an electric appliance, consumer asks for the power rating (Watts) of the appliance, which is the rate at which it will consume energy.

Activity

- Compute the static load (total power rating of all the appliances in your home).
- From your electric energy meter, note down the units which you have consumed.

1.1.5 Instruments to Measure Electrical Quantities

Ohm Meter

An ohm meter is a device to measure resistance. Connecting leads of ohm meter are connected with the resistance to measure and display the resistance on ohm meter.

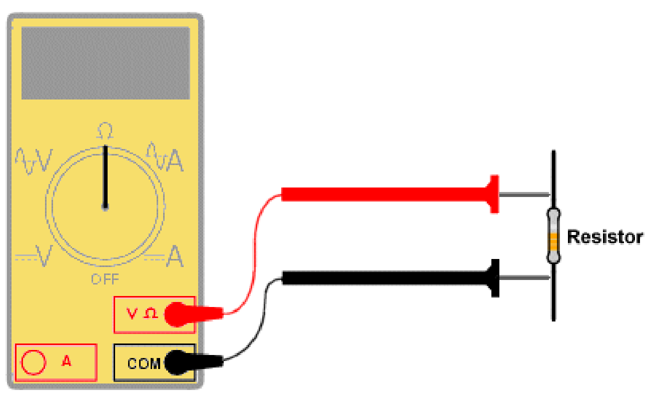


Figure 1.6 Ohm meter

Voltmeter

A voltmeter is used to measure voltages. Probes of voltmeter are connected with the terminals of the circuits across which voltages are to be measured. A voltmeter is always connected in parallel across a component whose voltages are to be measured.

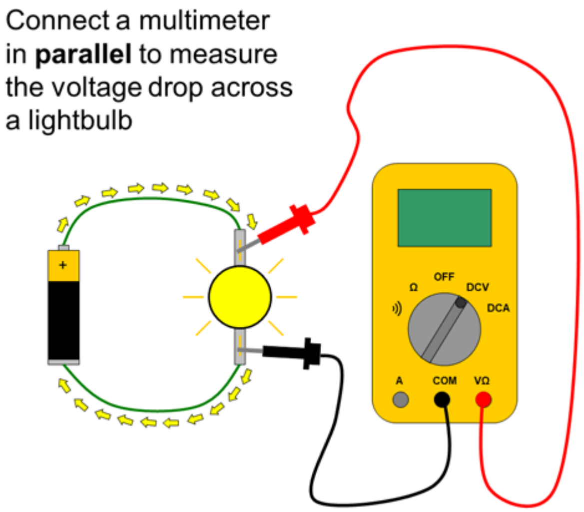


Fig 1.7 Volt meter

Ammeter

An ammeter is used to measure current. Probes of ammeter are connected with the terminals of the circuits across which current is to be measured. It should be noted that ammeter is always connected in series (as shown in Figure 1.8) in the circuit whose current is to be measured.

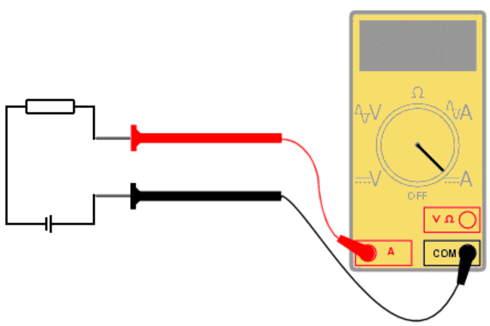


Fig 1.8 Ammeter

Digital Multi meter

A digital multi meter (DMM) is an instrument to measure different electrical quantities. Digital multi meters combine the testing capabilities of single-task meters—the voltmeter (for measuring volts), ammeter (amps) and ohmmeter (ohms).

Fig 1.9 DMM

Oscilloscope

An oscilloscope is a laboratory instrument commonly used to display and analyze the waveform of electronic signals. It draws a graph of the instantaneous signal voltage in terms of time.

There are multiple controls on an oscilloscope. Scale of x-axis and y-axis can be adjusted. There is a separate control to adjust the time scale of x-axis. To scale the y-axis, there is a knob called voltage/div. There are multiple channels on an oscilloscope. This means you can plot different signals simultaneously. To calibrate the oscilloscope, a probe is connected on an input of a channel and the other end is connected to the calibration terminal. The resulting waveform is then calibrated on the required scale.

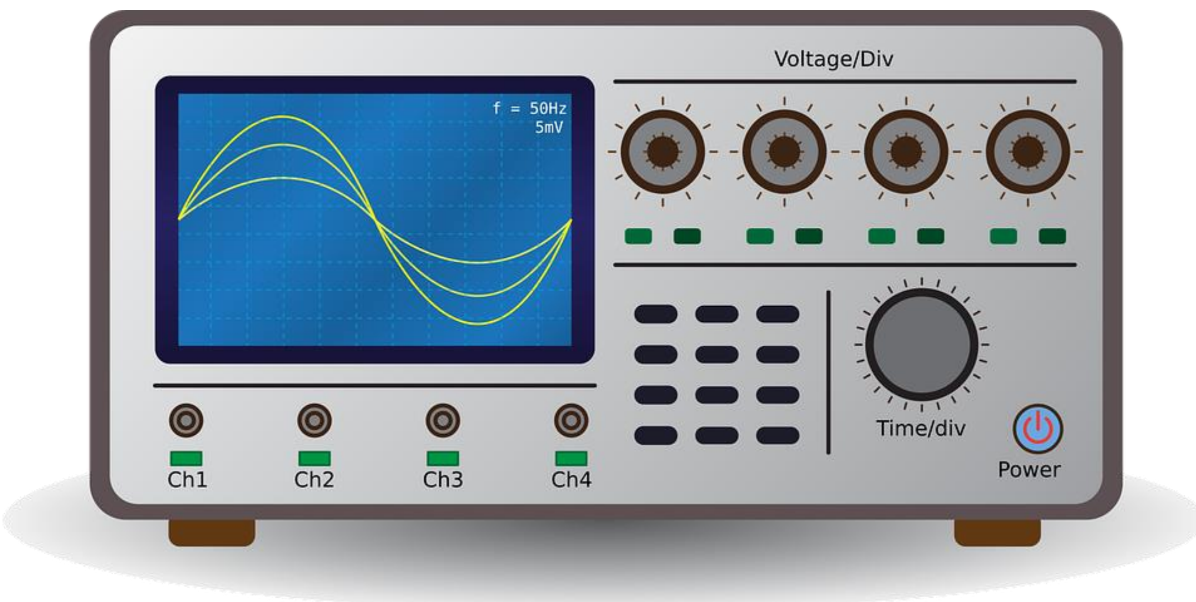


Fig 1.10 Oscilloscope

1.2 Ohm's Law

Ohm's law states that the current flowing in a circuit is directly proportional to the Voltage across it, given that all the physical quantities and temperature remains the same.

$$V \propto I \qquad \text{---------------------------(4)}$$

This means that higher the voltage across a component, more will be the current through it. Introducing a constant of proportionality in equation (4):

$$V = IR \text{ ----------------------------(5)}$$

Resistance (R) is the constant of proportionality. From equation (5), we can find the third parameter if we know two of them.

Example 1.1

If the resistance of an electric hearth is 50 Ω and a current of 3.2 A flows through the resistance. Find the voltage across resistance.

Solution:

If we are asked to calculate the value of voltage with the value of current and resistance given to us, then cover V in the triangle. Now, we are left with I and R or more precisely I × R.

Therefore, we use the following formula to calculate the value of V:

$V = I \times R$

Substituting the values in the equation, we get

$V = 3.2\ A \times 50\ ohms = 160\ V$

V = 160V

Example 1.2

A voltage source of 8.0 V is connected to a purely resistive electrical appliance (a light bulb). An electric current of 2.0 A flows through it. Assume the conducting wires to be resistance-free. Calculate the resistance offered by the electrical appliance.

Solution:

When we are asked to find out the value of resistance when the values of voltage and current are given, then we cover R in the triangle. This leaves us with only V and I, more precisely V ÷ I.

Substituting the values in the equation, we get

$R = V \div I$

$R = 8\ V \div 2\ A = 4\ \Omega$

R = 4 Ω

Calculating Electrical Power Using Ohm's Law

Ohm's Law can be used to rewrite equation 1.3. The power formula written in terms of ohm's law is:

$$P = (IR)\,I = I^2R \quad \text{----------------------------(6)}$$

or

$$P = V\,\frac{V}{R} = \frac{V^2}{R} \quad \text{----------------------------(7)}$$

Example 1.3

If the current and voltage of an electric circuit are given as 2.5A and 10V respectively. Calculate the electrical power?

Solution: Given measures are,

I = 2.5A and V = 10V

The formula for electric power is,

P = VI

P = 10 × 2.5 = 25watts

Example 1.4

Calculate the power of an electrical circuit consisting of resistance 3Ω and a current 4A flowing through this circuit?

Solution:

Given parameters are,

I = 4A and R = 3Ω

Electric power formula is,

$P = I^2R$

$P = 4^2 \times 3$

P = 16×3 = 48 watts

1.3 Cells and Batteries

Cell

Cell

A cell is a single unit device that converts chemical energy into electrical energy. Typical rating of a cell is 1.5V while 3.7V is also available. A cell can berechargeable or non-rechargeable.

Battery

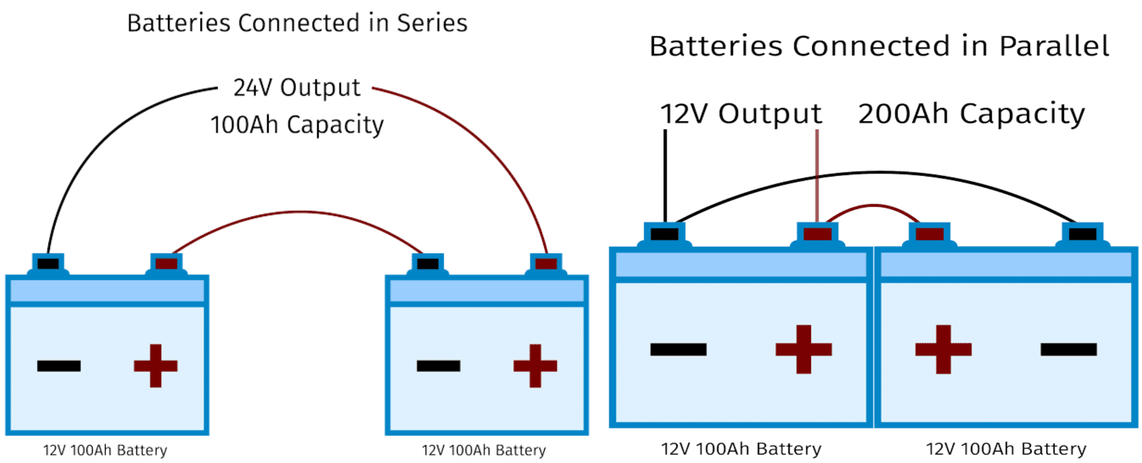
Battery

A battery is a group of cells connected together. Cells can be connected in series or parallel. Polarity of cells must be taken care of while forming a battery.

Series and Parallel Connection of Cells/Batteries

Different batteries can also be tied together to enhance voltage and current capacity.

Series Connection: A series connection is formed when positive terminal of one battery is connected with the negative terminal of the other battery. Series connection increases the voltage capacity of the battery bank but current capacity remains the same.



Series and Parallel Connection of Batteries

Parallel Connection: A parallel connection is formed when positive terminals are connected with positive terminals of other batteries and negative terminals are also connected together. Parallel connection increases the current capacity of the battery bank while voltage rating remains the same.

Point to Ponder

- What is the voltage rating of a UPS battery?
- Voltage of a battery is DC or AC.

Do you know?

- The voltage rating of a laptop battery is 19.5V and is usually formed of 6 cells.

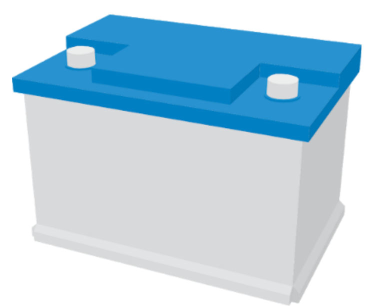
Importance of Batteries

- A battery provides portability to a device / appliance.
- The main purpose of the batteries is to store electrical energy.
- Rechargeable batteries enable multiple times usage of batteries.
- Size of battery is very crucial to use it in a specific application.

1.3.1 Types of Batteries

There are four main types of secondary batteries:

- Lead – Acid Batteries
- Nickel – Cadmium Batteries
- Nickel – Metal Hydride Batteries
- Lithium – Ion Batteries



Lead-Acid Battery

Lead–Acid Batteries: Lead-acid batteries are the most widely used batteries. They have 70 to 80% conversion efficiency. These batteries are mostly used in UPS and vehicles.

Ni-Cd Battery

Nickel–Cadmium Batteries: Ni-Cd batteries use Nickel Oxyhydroxide (NiOOH) as Cathode and Cadmium metal (Cd) as anode. These batteries usually have a voltage rating of

1.2V. These batteries are mostly used in photography equipment and power tools.

Nickel–Metal Hydride Batteries: These are relatively new type of batteries are an extended version of Nickel – Hydrogen Electrode batteries, which were exclusively used in aerospace applications (satellites). The positive electrode is the Nickel Oxyhydroxide (NiOOH) while the negative electrode of the cell is a metal alloy, where hydrogen is stored reversibly.

Ni-MH Battery

Lithium–Ion Batteries: A lithium-ion battery is a family of rechargeable battery types in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging. They have the best energy to weight ratios.

Lithium-Ion Battery

1.3.2 Components of a Battery

Cells are comprised of 3 essential components.

1. The **Anode** is the negative or reducing electrode that releases electrons to the external circuit and oxidizes during and electrochemical reaction.
2. The **Cathode** is the positive or oxidizing electrode that acquires electrons from the external circuit and is reduced during the electrochemical reaction.
3. The **Electrolyte** is the medium that provides the ion transport mechanism between the cathode and anode of a cell. Electrolytes are often thought of as liquids, such as water or other solvents, with dissolved salts, acids, or alkalis that are required for ionic conduction.

1.3.3 Working Principle of a Battery

A battery works on the oxidation and reduction reaction of an electrolyte with metals. When two dissimilar metallic substances, called electrode, are placed in a diluted electrolyte, oxidation and reduction reaction take place in the electrodes respectively depending upon the electron affinity of the metal of the electrodes. As a result of the oxidation reaction, one electrode gets negatively charged called *cathode* and due to the reduction reaction, another electrode gets positively charged called *anode*.

The cathode forms the negative terminal whereas anode forms the positive terminal of a battery. To understand the basic principle of battery properly, first, we should have some basic concept of electrolytes and electrons affinity. Actually, when two dissimilar metals are immersed in an electrolyte, there will be a potential difference produced between these metals.

It is found that, when some specific compounds are added to water, they get dissolved and produce negative and positive ions. This type of compound is called an electrolyte. The popular examples of electrolytes are almost all kinds of salts, acids, and bases etc. The energy released during accepting an electron by a neutral atom is known as electron affinity.

If two different kinds of metals are immersed in the same electrolyte solution, one of them will gain electrons and the other will release electrons.The metal with low electron affinity will gain electrons from the negative ions of the electrolyte solution. Whereas, the metal with high electron affinity will release electrons and these electrons come out into the electrolyte solution and are added to the positive ions of the solution. In this way, one of these metals gains electrons and another one loses electrons. Therefore, there will be a difference in electron concentration between these two metals.

This difference in electron concentration causes an electrical potential difference developed between the metals. This electrical potential difference or EMF can be utilized as a source of voltage in any electronics or electrical circuit. This is a general and basic working principle of a battery.

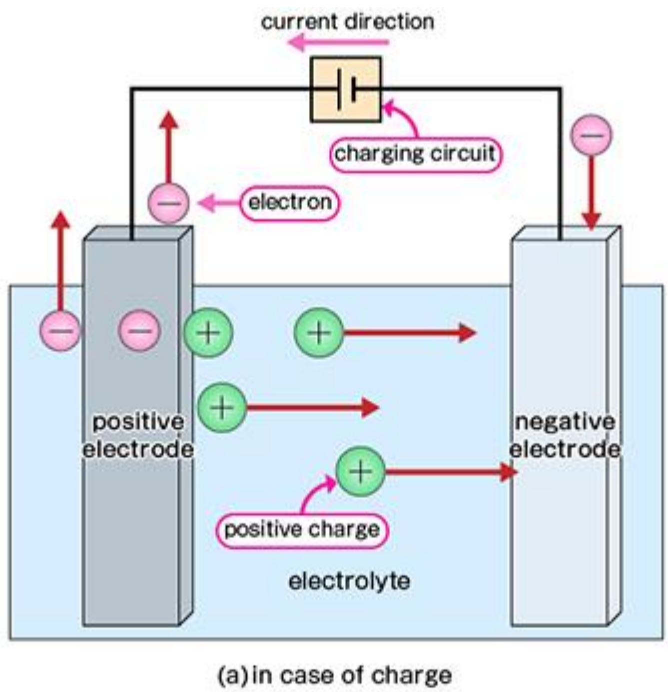


Fig 1.11 Construction and Working of a Battery

1.3.4 **Charging Principle of a Battery**

During charging of a battery, external DC source is applied to the battery. The negative terminal of the DC source is connected to the negative plate or anode of the battery and positive terminal of the source is connected to the positive plate or cathode of the battery. Now, due to external DC source, electrons will be injected in the anode. Reduction reaction takes place in the anode instead of cathode. Actually, in case of discharge of the battery, reduction reaction takes place at cathode. Due to this reduction reaction, the anode will regain electrons and returns to its previous state when the battery was not discharged.

As the positive terminal of the DC source is connected to the cathode, the electrons of this electrode will be attracted by this positive terminal of DC source. As a result, oxidation reaction takes place at the cathode and cathode material regains its previous state (when it was not discharged). This is the overall basic of charging of battery.

Note for lecture.

- Charging and discharging curves of a battery can also be explained here.

1.3.5 Maintaining a Battery

Maintenance increases battery life. Follow the following procedures for better maintaining a battery.

- Maintain electrolyte level of a battery.
- Regularly clean the terminals of a battery
- Battery should be charged slowly
- Allow the battery to cool down once it is fully charged.

1.3.6 Testing of a Battery

Visual Test

- Check the container, cover and terminals. If physical damage is present, replace the battery.
- Check the indicator (If the battery has the indicator). Always look right down when viewing the indicator and lightly tap the indicator on the battery to dislodge any air bubbles.

Voltage Test

- If voltage is below 12.4V, recharge the battery immediately.

Load Test

- Connect the battery tester to battery terminals.
- Measure the temperature of the battery around.
- Apply the load for 15 seconds and read the voltage.
- If the voltages drop significantly, recharge the battery and test again.
- If the battery fails the load test twice, replace it.

Gravity Test

The most accurate and direct way to test the state of charge of a battery cell is to determine the specific gravity of the battery electrolyte. The higher the specific gravity of the electrolyte the higher the state of charge.

Hydrometer: Hydrometer is used to perform gravity test. Hydrometers come in many sizes and shapes. A hydrometer with a float is recommended, contained in a glass vessel with a rubber bulb to draw the acid into the tube. Stay away from floating-colored balls as the extra inaccuracy results in very subjective testing. The hydrometer should give you a numeric reading directly from the instrument. A good hydrometer is accurate to +/- 0.005 points so 1.265 could read from 1.260-1.270. The instrument accuracy should be known.

Test

- It is recommended to disconnect the battery especially if on a high rate of charge/discharge.
- Remove vent cap. Carefully insert the hydrometer into the cell, not pushing down on the top of the plates.
- Carefully draw liquid into the hydrometer and avoid "bumping" the hydrometer. Be careful the float is not flooded (too much liquid) or sticking to the sides of the glass tube.
- Obtain a reading by looking directly at the float.
- Repeat steps 3-5 to reconfirm reading.
- Record the cell number and result.

Tools for Testing a Battery

If you have a non-sealed battery, it is highly recommended that you use a good quality temperature compensating hydrometer. There are two basic types of hydrometers, the floating ball, and the gauge. The gauge type tends to be much easier to read and doesn't involve the need to decipher colored balls. Battery hydrometers can be purchased at an auto parts or battery store.

To test a sealed battery or to troubleshoot a charging or electrical system, you will need a digital voltmeter with 0.5 percent (or better) accuracy. A digital voltmeter can be purchased at an electronics store. Analog (needle type) voltmeters are not accurate enough to measure the millivolt differences of a battery's state-of-charge or measure the output of the charging system. A battery load tester is optional.

1.3.7 Battery Life

A 10 Ah battery delivering 1A, would last 10 hours. If delivering 10A, it would last for only 1 hour, or if delivering 5A, it would last only for 2 hours.
In other words, you can have “any time” as long as when you multiply it by the current, you get 10Ah (the battery capacity).
So, no more confusion on how to calculate battery life.
For a 18650 2500mAh(2.5Ah) battery with a device that draws 500mA(0.5A) you have:
2.5Ah/0.5A=5 Hours

Key Points

- Electricity is the secondary form of energy which means that other sources of energy i.e., kinetic energy, thermal energy and solar energy etc. are converted into electrical energy.
- The electricity that power plants generate is delivered to consumers over transmission and distribution power lines.
- A voltage is a potential difference between two points of an electric circuit.
- Flow of charges inside an electric circuit is called electric current.
- Magnitude and Direction of DC remians constant while AC keeps on changing its direction.
- Conductors have free electrons on its surface which allow current to pass through easily.
- Semiconductors have limited free electrons so their conductivity lies between conductors and Insulators.
- Electric power of an electric circuit or appliance is the rate at which it consumes energy.
- $P = VI$
- Most common unit of consuming energy is in terms of kWh, that is equivalent of using 1 kilowatt power for one hour.
- An ohm meter is a device to measure resistance.
- A voltmeter meter is a device to measure voltage.
- An ammeter is used to measure current.
- $V = IR$
- $P = (IR)\, I = I^2 R$
- $P = V\,\frac{V}{R} = \frac{V^2}{R}$
- There are three main components of a battery: Anode, Cathode and Electrolyte.

Exercise

Multiple Choice Questions

1. An ohm meter is used to measure

   a. Resistance b. Voltage c. Current d. None of these

2. A voltmeter is used to measure

   a. Resistance b. Voltage c. Current d. None of these

3. An ammeter is used to measure

   a. Resistance b. Voltage c. Current d. None of these

4. In series connection following remains the same

   a. Resistance b. Voltage c. Current d. None of these

5. In parallel connection following remains the same

   a. Resistance b. Voltage c. Current d. None of these

Write short answer of the following

1. Define Electricity.
2. How is electricity transmitted form power plants to your homes?
3. Define Voltage, Resistance and Current.
4. What is the difference between AC and DC quantities?
5. Differentiate between conductors, insulators and semiconductors.

Answer the following question in detail

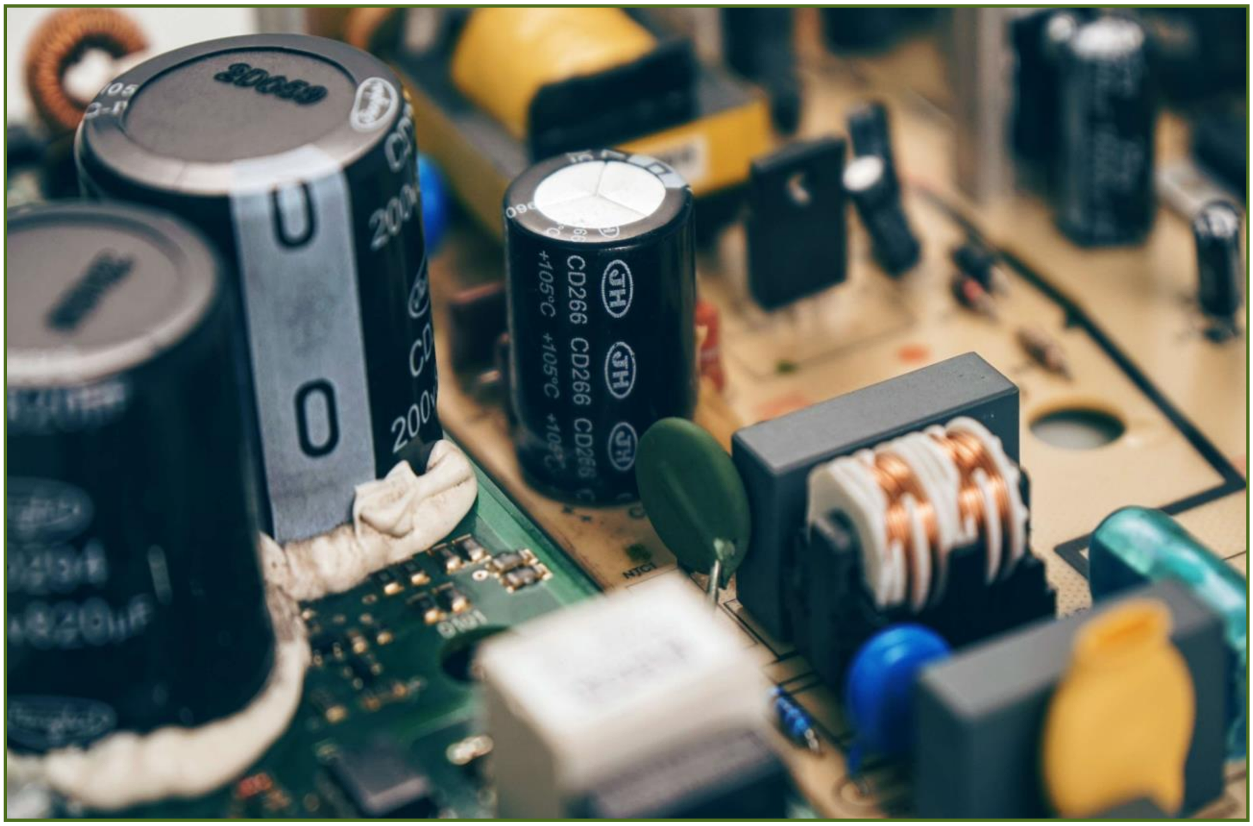
1. Differentiate between electric power and electric energy.
2. Describe Ohm meter.
3. Describe Ammeter.
4. Describe Voltmeter.
5. Differentiate between cells and batteries.

Solve the Following Problems

1. If the resistance of an electric hair dryer is 80 Ω and a current of 2.2 A flows through the resistance. Find the voltage between two points.
2. An EMF source of 10.0 V is connected to a purely resistive electrical appliance. An electric current of 1.5 A flows through it. Consider the conducting wires to be resistance-free. Calculate the resistance offered by the electrical appliance.
3. If the current and voltage of an electric circuit are given as 3.5A and 9V respectively. Calculate the electrical power?
4. Calculate the power of an electrical circuit consisting of resistance 6Ω and a current 4.5A flowing through this circuit?
5. Calculate the power of an electrical circuit consisting of resistance 7Ω and a voltage of 20V across it?

Chapter 2

Electric Circuits



After Studying this chapter, you will be able to

- describe electric circuits and its basic components.
- explain the construction of series circuit for calculation of current, voltage and resistance.
- explain the construction of parallel circuit for calculation of current, voltage and resistance.
- explain the construction of combinational circuit for calculation of current, voltage and resistance.
- defineKirchhoff's voltage law.
- solve combinational circuit using KVL.
- construct a series parallel combinational circuit to verify KVL.
- defineKirchhoff's current law.
- solve combinational circuit using KCL.
- construct a series parallel combinational circuit to verify KCL.

Electric charges need a conductive path to flow. An electric circuit is a closed path to allow the flow of electrons. It usually includes a voltage source and a load. There can be other components as well to control the parameters of the circuit.

2.1 Basic Components of Electric Circuits

There are following basic components of electric circuits:

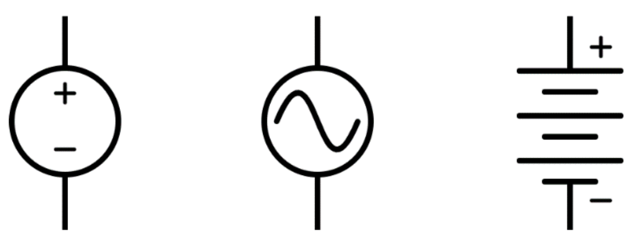
- Conducting Wire
- Voltage Source
- Load
- Resistors
- Capacitors

Conducting Wire

A conducting wire forms a path for the flow of electrons. It is used to connect different electrical components together. It should be a good conductor. Lesser the resistance of the wire, higher will be the conductance. It is a good practice to incorporate the resistance of conducting wire while solving an electric circuit.

Voltage Source

A voltage source is an essential component in an electric circuit. It acts as a source of electrons and hence causes current. There can be different types of voltage sources in a circuit i.e., battery, power supply and DC adapter etc. These sources can be AC or DC voltage sources. Different symbols used for the voltage source are given below:



Symbols of Voltage sources

Load

Load is the consumer of electric current. It can be an appliance i.e., light bulb and fan etc. Load can be resistive, capacitive and inductive. Current consumed in a circuit is decided by the load. Lower the resistance of the load, more will be the current.

Do you know?

All appliances in a home is always connected in parallel.

Point to Ponder

- Which types of load an energy saver bulb and electric fan are?

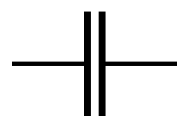
Resistors

Resistor is one of the basic elements of an electric circuit. They are commonly used to reduce the current flowing in a certain branch of an electric circuit. Its symbol is:

Symbol of Resistor

Capacitors

A capacitor is an electrical component to store electrical energy. It is created using two conductors placed next to each other and there is an insulator in between them. It stores electrical energy in its electric field. It blocks the DC but allows AC to pass through it. Its symbol is:



Symbol of Capacitor

2.1.1 Series Connections in Electric Circuits

In series connection, there is a single path for the current flow. All the components are connected end to end such that current flowing in the circuit remains the same. The sum of voltage across each element in a series circuit is equal to the total voltage of the power supply. Total resistance of the circuit is equal to the sum of individual resistances.

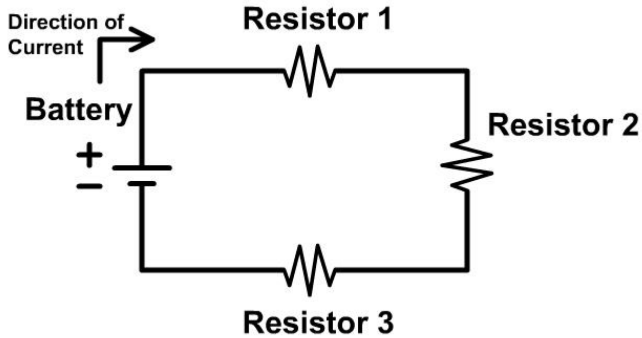


Fig. 2.1 Series Circuit

2.1.2 Parallel Connections in Electric Circuits

In a parallel connection, there can be multiple paths for the current flow. All the components are connected to a set of common points of the circuit such that the voltage across each component remains the same. The sum of current in each branch of a parallel circuit is equal to the total current flowing in the circuit. Total resistance of the circuit is less than the resistance of individual resistances.

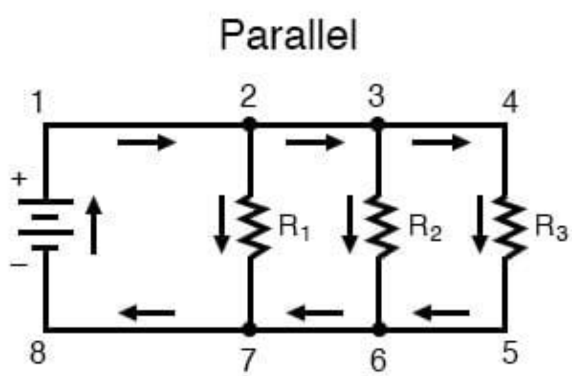


Fig. 2.2 Parallel Circuit

2.1.3 Series-Parallel Connections in Electric Circuits

When the components are connected in such a way that neither series rule nor parallel rule apply, then we have to identify individual portions of the circuit that are either connected in series or in parallel. Take the following circuit, for instance:

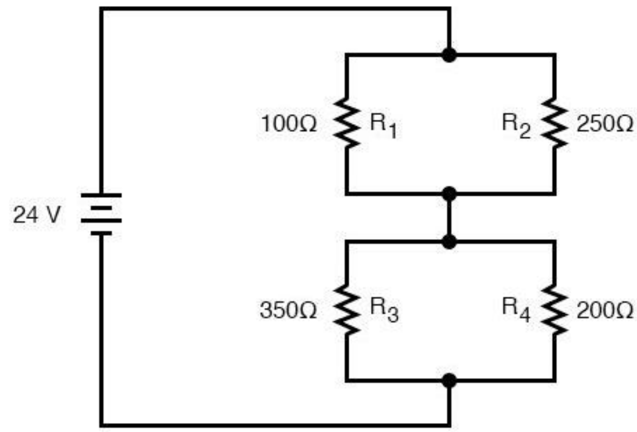


Fig. 2.3 Series Parallel Circuit

Here, R_1 and R_2 are connected in parallel. Similar is the case with R_3 and R_4. These two sets of resistance are then connected in series.

2.2 Kirchhoff's Voltage Law

Kirchhoff's Voltage Law (KVL) states that the sum of voltages inside a closed loop in an electric circuit is always equal to zero. In other words, the sum of all voltages across components which supply electrical energy (such as cells or generators) must equal the sum of all voltages across the other components (resistance, capacitors etc.) in the same loop. This law is a consequence of both charge conservation and the conservation of energy.

As charge carriers flowing through a circuit pass through a component, they either gain or lose electrical energy, depending upon the component (cell or resistor, for example). This is due to the fact that work is done on or by them as a result of the electric forces inside the components. The total work done on a charge carrier by electric forces in supply components (such as cells) must be equal to the total work done by the charge carrier in other components (such as resistors and lamps). This means that the sum of all potential differences across the components involved in a circuit's loop must be zero if we count voltages across supply components as positive and across 'electricity using' components as negative.

Figure 2.4 gives an example of KVL. We go around the circuit in the direction of the arrow, which is the direction in which we think current will flow. On passing the battery, the potential increases by 6V. We then lose 4V on passing the 2Ω resistor to give a new potential of 2V. Finally, the potential drops by 2V in the 1Ω resistor. So, the total voltage inside a loop is zero.

$$6V - 4V - 2V = 0$$

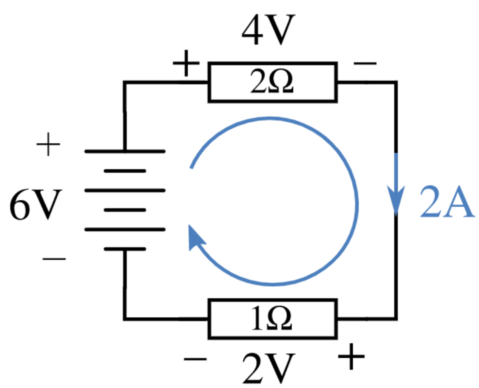
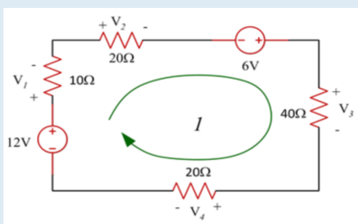


Fig. 2.4

Example 2.1

Find the current *I* and voltage *V* over each resistor.



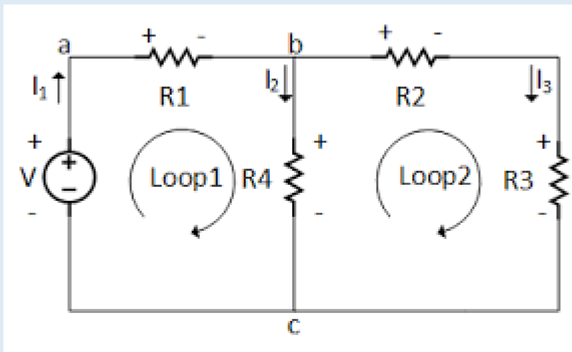
Solution:
Apply KVL:
$12V - V_1 - V_2 + 6V - V_3 - V_4 = 0$
Putting the values of Voltages using Ohm's Law:
12V – (I X 10 Ω) - (I X 20 Ω) + 6V - (I X 40 Ω) - (I X 20 Ω) = 0
I X 90 Ω = 18V
I = 18V / 90 Ω = 0.2 A
Now Applying Ohm's law to find voltages:
V_1 = 0.2 X 10 = 2 V
V_2 = 0.2 X 20 = 4 V
V_3 = 0.2 X 40 = 8V
V_4 = 0.2 X 20 = 4V

Note for teacher:

- Give an example of circuit containing multiple voltage sources. Ask the students to apply KVL in the circuit.

Example 2.2

Find the current *I* and voltage *V* over each resistor, where as
$R_1 = 5\Omega$, $R_2 = 10\Omega$, $R_3 = 5\Omega$, $R_4 = 10\Omega$
And V = 20Volts



Solution:

There are two loops (closed paths) in the circuit, loop 1 with two resistors and a single voltage source, wherein loop 2 there is no voltage source, three resistors only.

The next step is to write equations for each loop. Based on the sign and current name assigned, as shown below.

Loop 1:

$V = I_1 R_1 + I_2 R_4$

$0 = I_3 R_2 + I_3 R_3 – I_2 R_4$

Notice the negative sign in the second equation, it is because of being opposite in direction of loop arrow i.e., for R_2 and R_3 it is (+ -) but for R4 it is (- +).

It should be noted that

$I_1 = I_2 + I_3$

Now, put the value of I_1, which will give you two simultaneous equations with unknown variable I_2 and I3. The value of these currents can be easily computed.

$V = (R_1 + R_4) I_2 + R_1 I_3$

$0 = - R_4 I_2 + (R_3 + R_2) I_3$

Let's put the values of resistors and the voltage source,

$$20 = (5 + 10)I_2 + 5I_3 \text{——}(1)$$

$$0 = -10I_2 + (5 + 10)I_3 \text{——}(2)$$

Now multiply the equation (1) by -3 and add with the equation (2)

$$0 = -10I_2 + (15)I_3 \text{——}(2)$$

$$-60 = -45I_2 - 15I_3 \text{——}(1)$$

Adding the above two equations will give us the equation (3)

$$-60 = -55I_2 + 0 - (3)$$

$$I_2 = -\frac{60}{-55} = 1.09Amp$$

Now putting the current I2 in the equation (2) to get current I3

$$0 = -10(1.09) + 15I_3$$

$$I_3 = 10\frac{(1.09)}{15} = 0.72Amp$$

By applying KCL to the node b, the following equation can be obtained,

$$I_1 = I_2 + I_3$$

Now putting the values of the current will give us the value of I1

$$I_1 = 1.09 + 0.72 = 1.81Amp$$

Now, it is easy to find any parameter of the circuit, just use the ohm’s law, as shown below

$$V_3 = I_3R_3 = 0.72(5) = 3.6Volts$$

$$V_2 = I_3R_2 = 0.72(10) = 7.2Volts$$

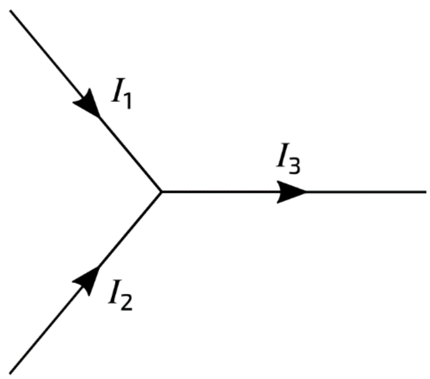
$$V_4 = I_2R_4 = 1.09(10) = 10.9Volts$$

$$V_1 = I_1R_1 = 1.81(5) = 9.05Volts$$

2.3 Kirchhoff’s Current Law

Kirchhoff’s Current Law (KCL) states that the current flowing towards a node (or a junction) must be equal to the current flowing away from it. This is a consequence of charge conservation.

Current flow in circuits occurs when charge carriers travel around the circuit. Current is defined as the rate at which this charge passes any point in the circuit. A fundamental concept in physics is that charge will always be conserved. In the context of circuits this means that, since current is the rate of flow of charge, the current flowing into a point must be the same as current flowing out of that point.

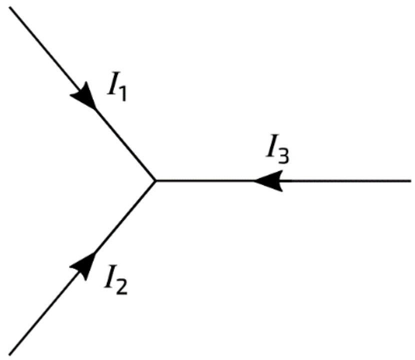


Applying KCL on figure:

$$I_1 + I_2 = I_3$$

It is important to note what is meant by the signs of the current in the diagram. A positive current means that the currents are flowing in the directions indicated on the diagram. Directions are the direction in which any positive charges would flow, that is from the plus of the battery round the circuit to the minus.

The standard way of displaying Kirchhoff's current law is by having all currents either flowing towards or away from the node, as shown in Figure 2:

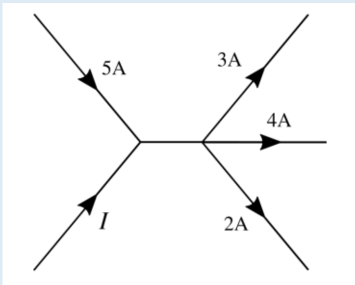


Here, at least one of the currents will have a negative value (in the opposite direction to the arrows on this diagram) and Kirchhoff's current law here would be written as:

$$I_1 + I_2 + I_3 = 0$$

Example 2.3

What is the value of I in the circuit segment shown in Figure?



Solution:

Apply KCL:

$I + 5A = 3A + 4A + 2A$

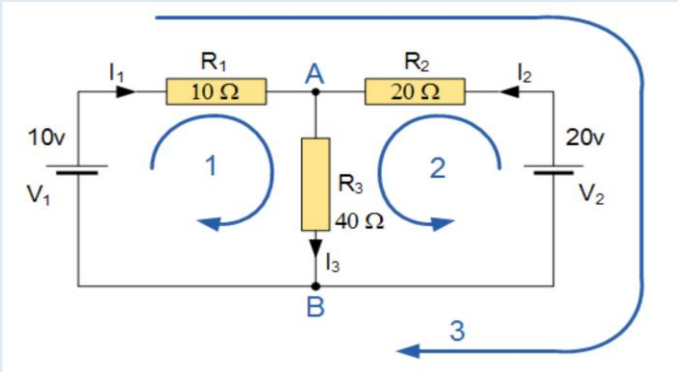
$I = 4A$

Interesting Information

- In 1845 Kirchhoff first announced Kirchhoff's laws, which allow calculation of the currents, voltages, and resistances of electrical networks. Extending the theory of the German physicist Georg Simon Ohm, he generalized the equations describing current flow to the case of electrical conductors in three dimensions. In further studies, he demonstrated that current flows through a conductor at the speed of light.

Example 2.4

Find the current flowing in the 40Ω Resistor, R_3



Solution:

The circuit has 3 branches, 2 nodes (A and B) and 2 independent loops.

Using Kirchhoffs Current Law, KCL the equations are given as:

At node A : $I_1 + I_2 = I_3$

At node B : $I_3 = I_1 + I_2$

Using Kirchhoffs Voltage Law, KVL the equations are given as:

Loop 1 is given as : $10 = R_1 I_1 + R_3 I_3 = 10 I_1 + 40 I_3$

Loop 2 is given as : $20 = R_2 I_2 + R_3 I_3 = 20 I_2 + 40 I_3$

Loop 3 is given as : $10 - 20 = 10 I_1 - 20 I_2$

As I3 is the sum of I1 + I2 we can rewrite the equations as;

Eq. No 1 : $10 = 10 I_1 + 40(I_1 + I_2) = 50 I_1 + 40 I_2$

Eq. No 2 : $20 = 20 I_2 + 40(I_1 + I_2) = 40 I_1 + 60 I_2$

We now have two "Simultaneous Equations" that can be reduced to give us the values of I_1 and I_2

Substitution of I_1 in terms of I_2 gives us the value of I_1 as -0.143 Amps

Substitution of I_2 in terms of I_1 gives us the value of I_2 as +0.429 Amps

As : $I_3 = I_1 + I_2$

The current flowing in resistor R_3 is given as : $-0.143 + 0.429 = 0.286$ Amps

and the voltage across the resistor R_3 is given as : $0.286 \times 40 = 11.44$ volts

The negative sign for I_1 means that the direction of current flow initially chosen was wrong, but never the less still valid. In fact, the 20v battery is charging the 10v battery.

Key Points

- An Electric Circuit is a closed path to allow the flow of electrons.
- A voltage source acts as a source of electrons and hence causes current.
- A voltage is a potential difference between two points of an electric circuit.
- Resistors are commonly used to reduce the current flowing in a certain branch of an electric circuit.
- A capacitor stores electrical energy in its electric field.
- A capacitor blocks the DC but allows AC to pass through it.
- In series connection, there is a single path for the current flow.
- The sum of current in each branch of a parallel circuit is equal to the total current flowing in the circuit.
- Kirchhoff's Voltage Law (KVL) states that the sum of voltages inside a closed loop in an electric circuit is always equal to zero.
- Kirchhoff's Current Law (KCL) states that the current flowing towards a node (or a junction) must be equal to the current flowing away from it.

Exercise

Multiple Choice Questions

1. KVL states that sum of ______ in loop is always zero.

   a. Resistance b. Voltage c. Current d. None of these

2. KCL states that sum ______ flowing at a node is always zero.

   a. Resistance b. Voltage c. Current d. None of these

3. _____ can store electrical charge.

   a. Resistance b. Capacitor c. Inductor d. None of these

4. In series connection following remains the same

   a. Resistance b. Voltage c. Current d. None of these

5. In parallel connection following remains the same

   a. Resistance b. Voltage c. Current d. None of these

Write short answer of the following

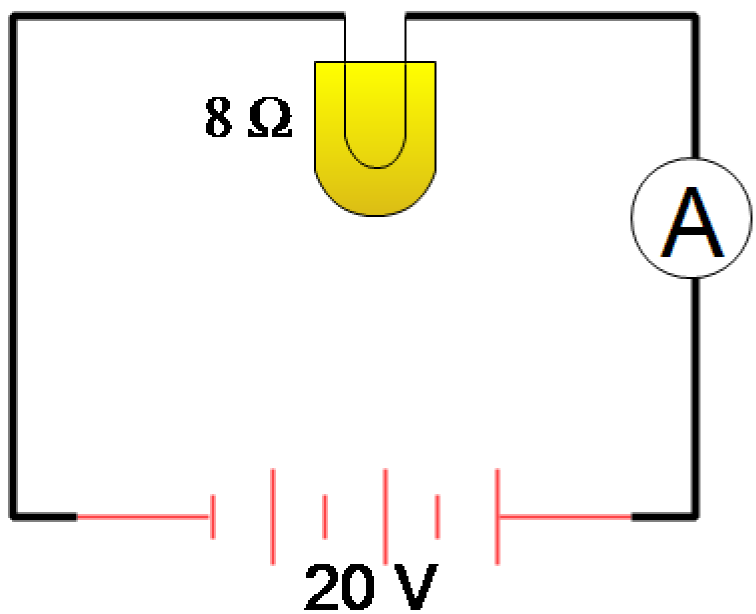
1. What is an electric circuit?
2. What are the components in an electric circuit?
3. Define Voltage, Resistance and Current.
4. What is a capacitor?
5. Differentiate between series and parallel circuits.

Answer the following question in detail.

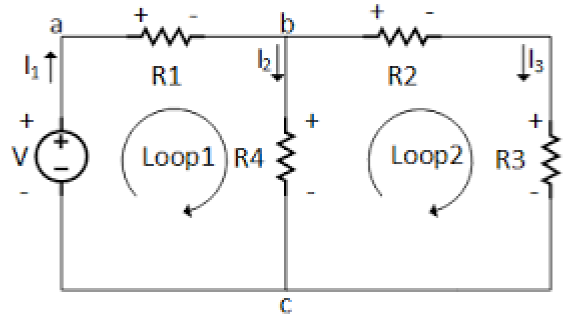
1. Describe KCL.
2. Describe KVL.

Solve the Following

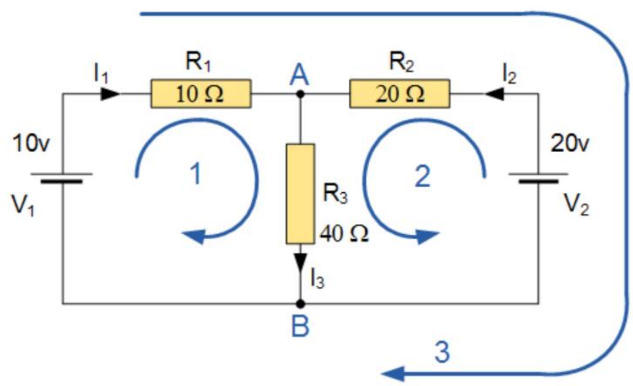
1. If the resistance of an electric hair dryer is 80 Ω and a current of 2.2 A flows through the resistance. Find the voltage between two points.
2. An electronic device has a resistance of 20 ohms and a current of 15 A. What is the voltage across the device?
3. In the circuit shown below, how much current does the ammeter show?



4. Find the current *I* and voltage *V* over each resistor, where R_1 = 13Ω, R_2 = 15Ω, R_3 = 5.5Ω, R_4 = 11Ω and V = 25Volts.

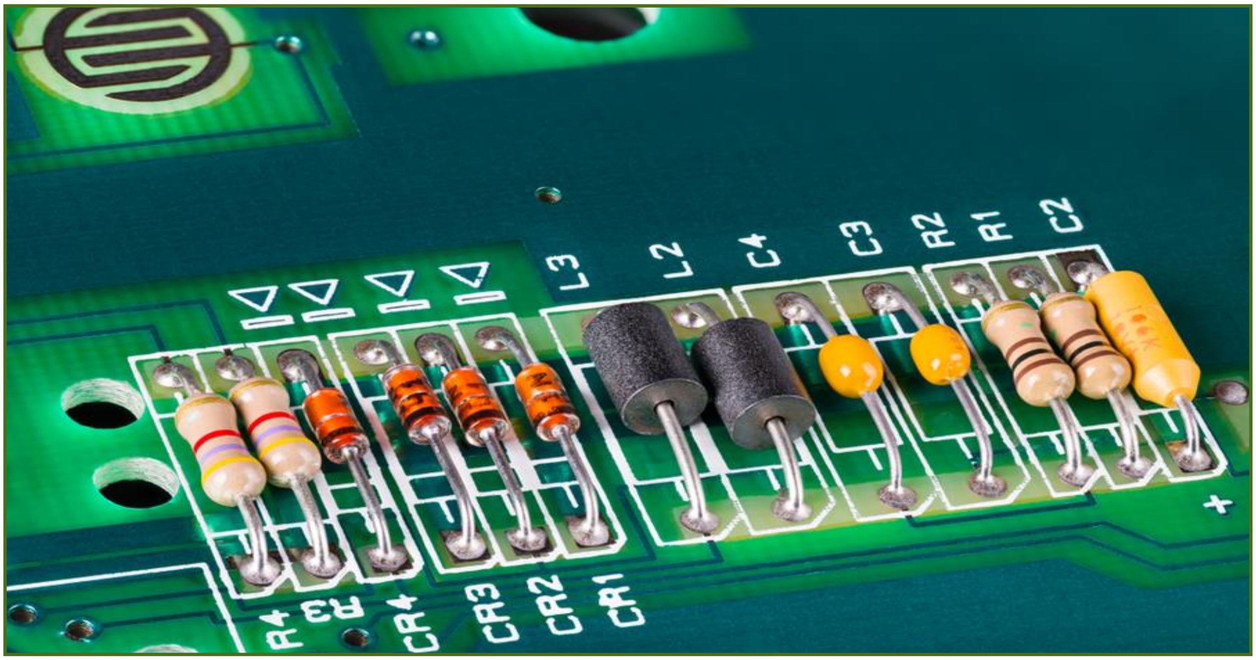


5. Find the voltages across R_1, R_2 and R_3.



Chapter 3

Fundamental Electronics-I for IoT



After Studying this chapter, you will be able to:

- define PN junction.
- define diode.
- understand working principle of diode.
- identify current voltage and power rating of diode.
- understand forward and reverse biasing.
- apply diodes as rectifier (half wave, full wave).
- construct a series parallel combinational circuit to verify KCL.
- defineZener diode.
- explain characteristics of Zener diode.
- current voltage and power rating of Zener diode.
- understand the voltage and current regulation.
- differentiate between load and line regulation.
- understand the application Zener diode in a circuit.
- introduce to transistor.
- define bipolar junction transistor.
- construct transistor and its working principle.
- explain application of transistor.

Chapter 3

3.1 P-N Junction

A p-n junction is a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor.

The p-side or the positive side of the semiconductor has an excess of holes and the n-side or the negative side has an excess of electrons. In a semiconductor, the p-n junction is created by the method of doping. The process of doping is explained in further detail in the next section.

3.1.1 Formation of P-N Junction

If different semiconductor materials are used to make a p-n junction, there will be a grain boundary that would prevent the movement of electrons from one side to the other by scattering the electrons and holes and thus, we use the process of doping.Consider a thin p-type silicon semiconductor sheet. If we add a small amount of pentavalent impurity to this, a part of the p-type Si (Silicon) will get converted to n-type silicon. This sheet will now contain both p-type region and n-type region and a junction between these two regions. The processes that follow after the formation of a p-n junction are of two types – diffusion and drift. As we know, there is a difference in the concentration of holes and electrons at the two sides of a junction, the holes from the p-side diffuse to the n-side and the electrons from the n-side diffuse to the p-side. These give rise to a diffusion current across the junction.

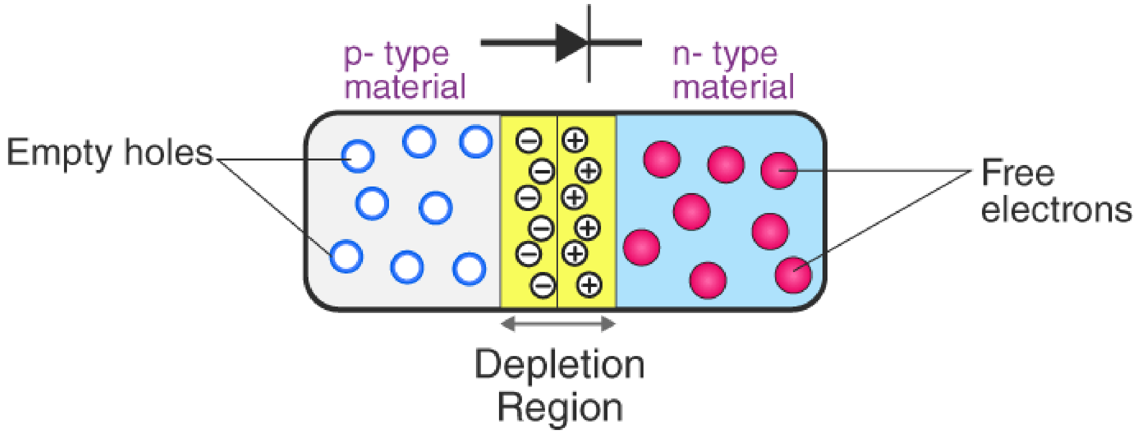


Fig. 3.1 PN junction

When an electron diffuses from the n-side to the p-side, an ionized donor is left behind on the n-side, which is immovable. As the process goes on, a layer of positive charge is developed on the n-side of the junction. Similarly, when a hole goes from the p-side to the n-side, and ionized acceptor is left behind in the p-side, resulting in the formation of a layer of negative charges in the p-side of the junction. This region of positive charge and negative charge on either side of the junction is termed as the depletion region. Due to this positive space charge region on either side of the junction, an electric field direction from a positive charge towards the negative charge is developed. Due to this electric field, an electron on the p-side of the junction moves to the n-side of the junction. This motion is termed as the drift. The direction of drift current is opposite to that of the diffusion current.

3.2 Diode

A diode is defined as a two-terminal electronic component that only conducts current in one direction (as long as it is operated within a specified voltage level). An ideal diode will have zero resistance in one direction, and infinite resistance in the reverse direction.

Although in the real world, diodes cannot achieve zero or infinite resistance. Instead, a diode will have negligible resistance in one direction (to allow current flow), and very high resistance in the reverse direction (to prevent current flow).

Semiconductor diodes are the most common type of diode. These diodes begin conducting electricity only if a certain threshold voltage is present in the forward direction (i.e., the “low resistance” direction). The diode is said to be “forward biased” when conducting current in this direction. When connected within a circuit in the reverse direction (i.e., the “high resistance” direction), the diode is said to be “reverse biased”.

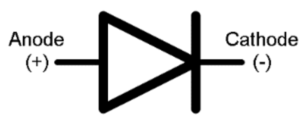
A diode only blocks current in the reverse direction (i.e., when it is reverse biased) while the reverse voltage is within a specified range. Above this range, the reverse barrier breaks. The voltage at which this breakdown occurs is called the “reverse breakdown voltage”.

When the voltage of the circuit is higher than the reverse breakdown voltage, the diode is able to conduct electricity in the reverse direction (i.e., the "high resistance" direction). This is why we say diodes have a high resistance in the reverse direction – not an infinite resistance.

A P-N junction is the simplest form of the semiconductor diode. In ideal conditions, this P-N junction behaves as a short circuit when it is forward biased, and as an open circuit when it is in the reverse biased.

Diode Symbol

The symbol of a diode is shown below. The arrowhead points in the direction of conventional current flow in the forward biased condition. That means the anode is connected to the p side and the cathode is connected to the n side.



Symbol of Diode

We can create a simple P-N junction diode by doping pentavalent or donor impurity in one portion and trivalent or acceptor impurity in the other portion of silicon or germanium crystal block.

These dopings make a PN junction in the middle part of the block. We can also form a P-N junction by joining a p-type semiconductor and n-type semiconductor together with a special fabrication technique. The terminal connected to the p-type is the anode. The terminal connected to the n-type side is the cathode.

3.2.1 Working Principle of a Diode

A diode's working principle depends on the interaction of n-type and p-type semiconductors. An n-type semiconductor has plenty of free electrons and a very few numbers of holes. In other words, we can say that the concentration of free electrons is high and that of holes is very low in an n-type semiconductor. Free electrons in the n-type semiconductor are referred to as majority charge carriers, and holes in the n-type semiconductor are referred to as minority charge carriers.

A p-type semiconductor has a high concentration of holes and a low concentration of free electrons. Holes in the p-type semiconductor are majority charge carriers, and free electrons in the p-type semiconductor are minority charge carriers.

3.2.2 Forward Biased Diode

A diode is forward biased if a positive terminal of a source is connected to the p-type side and the negative terminal of the source is connected to the n-type side of the diode. Initially, there is no current flowing through the diodebecause the majority charge carriers still do not get sufficient impact of the external field to cross the depletion region. As we know that the depletion region acts as a potential barrier against the majority charge carriers. This potential barrier is called forward potential barrier. The majority charge carriers start crossing the forward potential barrier only when the value of externally applied voltage across the junction is more than the potential of the forward barrier. For silicon diodes, the forward barrier potential is 0.7 volt and for germanium diodes, it is 0.3 volt.

When the externally applied forward voltage across the diode becomes more than the forward barrier potential, the free majority charge carriers start crossing the barrier and contribute the forward diode current. In this situation, the diode behaves as a short-circuited path, and the forward current gets limited by only externally connected resistors to the diode.

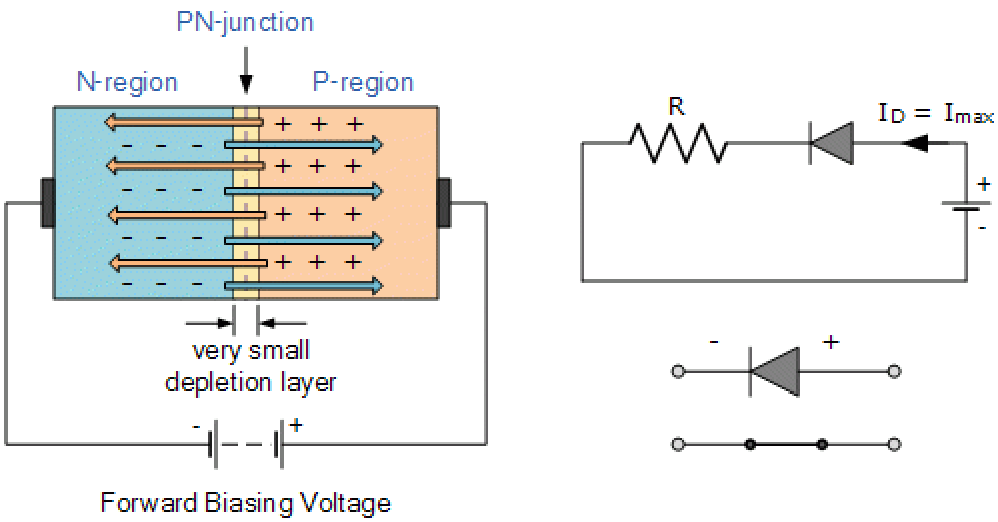


Fig. 3.2 Forward biased diode

3.2.3 Reverse Biased Diode

A diode is reverse biased ifthe negative terminal of the voltage source is connected to the p-type side and the positive terminal of the voltage source to the n-type side of the diode. Due to the electrostatic attraction of the negative potential of the source, the holes in the p-type region would be shifted more away from the junction leaving more uncovered negative ions at the junction. In the same way, the free electrons in the n-type region would be shifted more away from the junction towards the positive terminal of the voltage source leaving more uncovered positive ions in the junction.

As a result of this phenomenon, the depletion region becomes wider. This condition of a diode is called the reverse biased condition. At that condition, no majority carriers cross the junction, and they instead move away from the junction. In this way, a diode blocks the flow of current when it is reverse biased.

As we know that there are always some free electrons in the p-type semiconductor and some holes in the n-type semiconductor. These opposite charge carriers in a semiconductor are called minority charge carriers.In the reverse biased condition, the holes find themselves in the n-type side would easily cross the reverse-biased depletion region as the field across the depletion region does not present rather it helps minority charge carriers to cross the depletion region. As a result, there is a tiny current flowing through the diode from positive to the negative side. The amplitude of this current is very small as the number of minority charge carriers in the diode is very small. This current is called reverse saturation current.

If the reverse voltage across a diode is increased beyond a safe value, a number of covalent bonds are broken to contribute a huge number of free electron-hole pairs in the diode. This is due to higher electrostatic force and due to higher kinetic energy of minority charge carriers colliding with atoms. The huge number of such generated charge carriers would contribute a huge reverse current in the diode. If this current is not limited by an external resistance connected to the diode circuit, the diode may permanently be destroyed. This phenomenon is called *Avalanche Breakdown.*

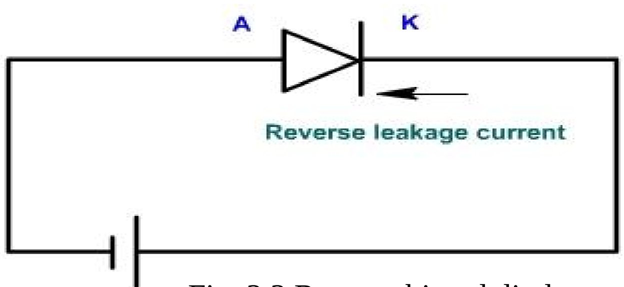


Fig. 3.3 Reverse biased diode

3.2.4 IV **Characteristics of a Diode**

Curve in Figure 3.3 indicates Current vs Voltage relationship in a diode. The forward portion of the curve indicates that the diode conducts when the P-region is made positive and the N-region negative.The diode conducts almost no current in the high resistance direction, i.e., when the P region is made negative and the N-region is made positive. Now the holes and electrons are drained away from the junction, causing the barrier potential to increase. This condition is indicated by the reverse current portion of the curve.The dotted section of the curve indicates the ideal curve, which would result if it were not for avalanche breakdown. Figure 3.3 shows the static characteristic of a junction diode.

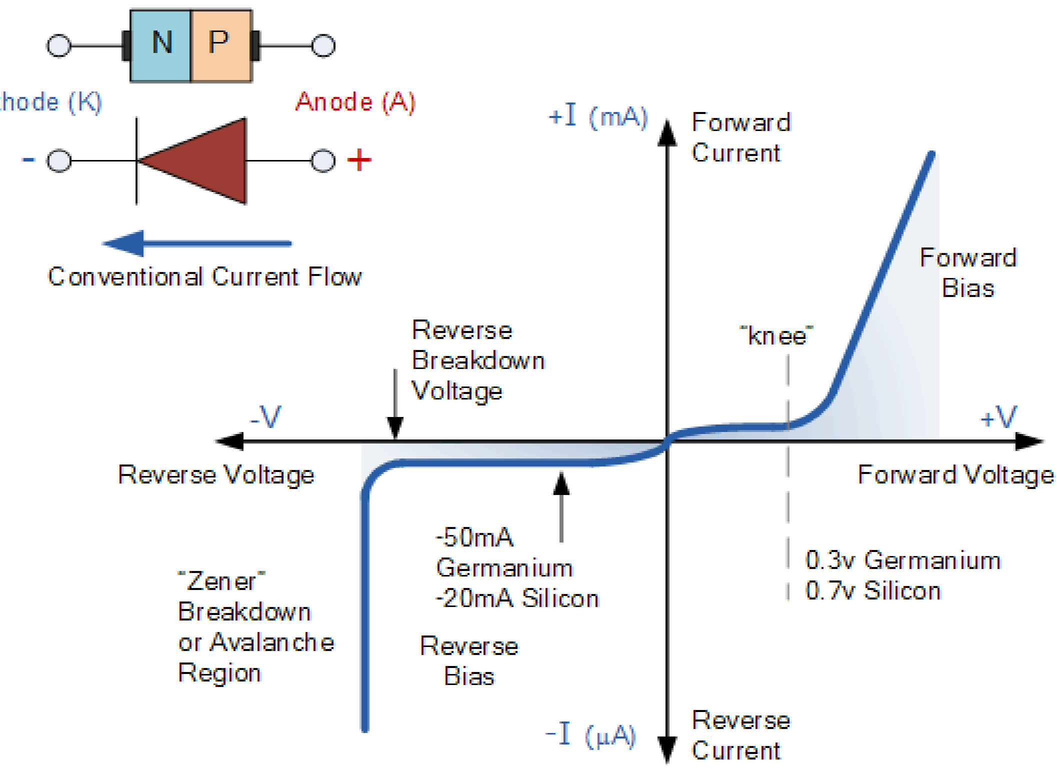


Fig. 3.3 IV characteristics of a diode

3.2.5 Rectification Circuits

The main application of p-n junction diode is in rectification circuits. These circuits are used to convert AC signals to DC signals. Diode rectifier gives an alternating voltage which pulsates in accordance with time.

There are two primary methods of diode rectification:

- Half Wave Rectifier
- Full Wave Rectifier

Half Wave Rectifier

In a half-wave rectifier, one half of each AC input cycle is rectified. When the p-n junction diode is forward biased, it offers a little resistance and when it is reversing biased it provides high resistance. During one-half cycles, the diode is forward biased when the input voltage is applied and in the opposite half cycle, it is reverse biased.

The half-wave rectifier has both positive and negative cycles. During the positive half of the input, the current will flow from positive to negative which will generate only a positive half cycle of the AC supply. When AC supply is applied to the transformer, the voltage will be decreasing at the secondary winding of the diode. All the variations in the AC supply will reduce, and we will get the pulsating DC voltage to the load resistor.

In the second half cycle, the current will flow from negative to positive and the diode will be reverse biased. Thus, at the output side, there will be no current generated, and we cannot get power at the load resistance. A small amount of reverse current will flow during reverse bias due to minority carriers.

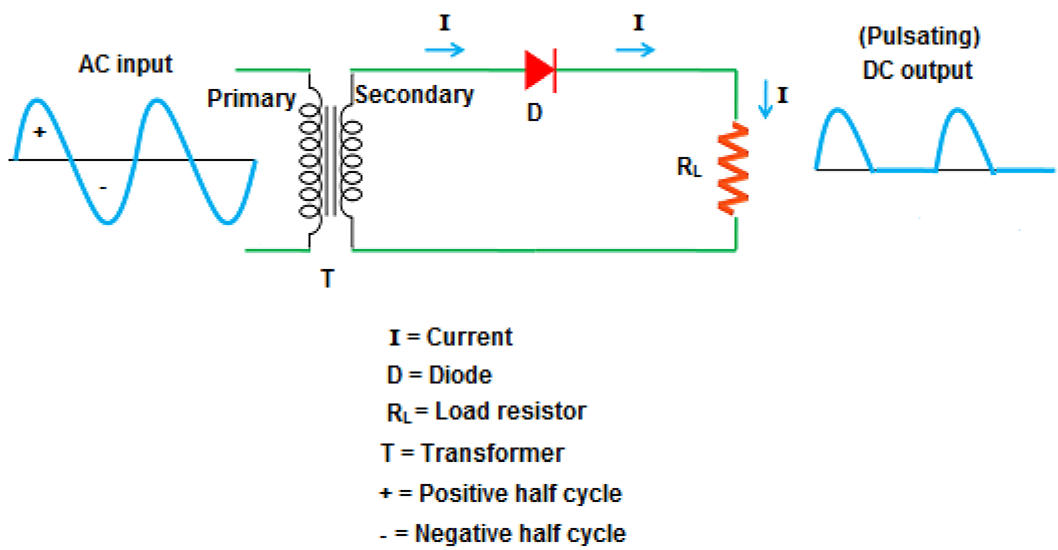


Fig. 3.4 Half wave rectifier

Full Wave Rectifier

Full-wave rectifier circuits are used for producing an output voltage or output current which is purely DC. The main advantage of a full-wave rectifier over half-wave rectifier is that the average output voltage is higher in full-wave rectifier.Ripple produced in full-wave rectifier is less as compared to the half-wave rectifier.

The full-wave rectifier utilizes both halves of each AC input. When the p-n junction is forward biased, the diode offers low resistance and when it is reversing biased it gives high resistance. The circuit is designed in such a manner that in the first half cycle if the diode is forward biased then in the second half cycle it is reverse biased and so on.

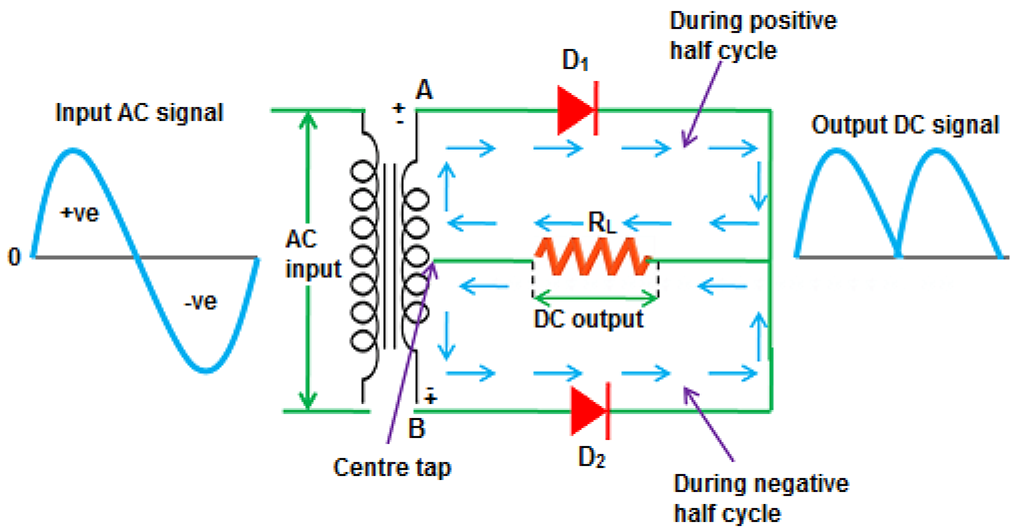


Fig. 3.5 Full wave rectifier

Do you know?

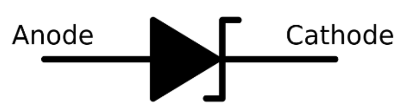
Filtering capacitors are used to convert pulsating DC voltage into a constant DC voltage.

Point to Ponder

- Where are rectifiers being used?

3.3 Zener Diode

A heavily doped semiconductor diode which is designed to operate in reverse direction is known as the Zener diode. In other words, the diode which is specially designed for optimizing the breakdown region is known as the Zener diode. The symbolic representation of Zener diode is shown in the figure.

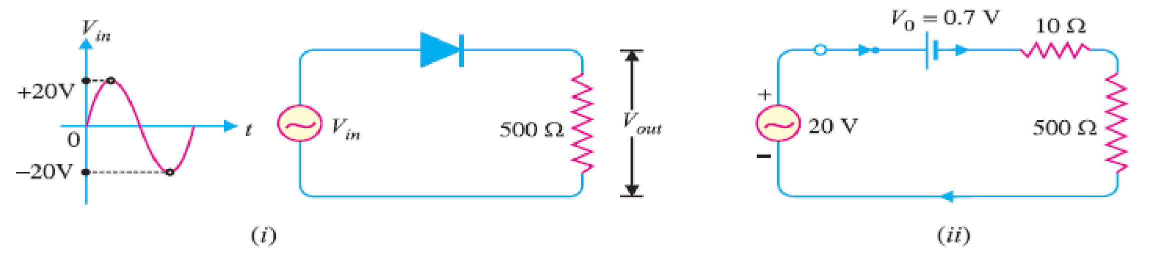


Symbol of a Zener Diode

Example 3.1

An AC voltage of peak value 20 V is connected in series with a silicon diode and load resistance of 500 Ω. If the forward resistance of diode is 10 Ω, Find:

(i) peak current through diode
(ii) peak output voltage
(iii) What will be these values if the diode is assumed to be ideal?



Solution:

Peak input voltage = 20 V

Forward resistance, r_f = 10 Ω

Load resistance, R_L = 500 Ω

Potential barrier voltage, V_0 = 0.7 V

The diode will conduct during the positive half-cycles of AC input voltage only.

$V_4 = 0.2 \text{ X } 20 = 4V$

(i) The peak current through the diode will occur at the instant when the input voltage reaches positive peak i.e. $V_{in} = V_F = 20$ V.

$$\therefore \quad V_F = V_0 + (I_f)_{peak}\,[r_f + R_L] \quad \ldots(i)$$

$$\text{or} \quad (I_f)_{peak} = \frac{V_F - V_0}{r_f + R_L} = \frac{20 - 0.7}{10 + 500} = \frac{19.3}{510}\text{ A} = \mathbf{37.8\ mA}$$

(ii) Peak output voltage:

$$\text{Peak output voltage} = (I_f)_{peak} \times R_L = 37.8\text{ mA} \times 500\ \Omega = \mathbf{18.9\ V}$$

(iii) Ideal diode case:

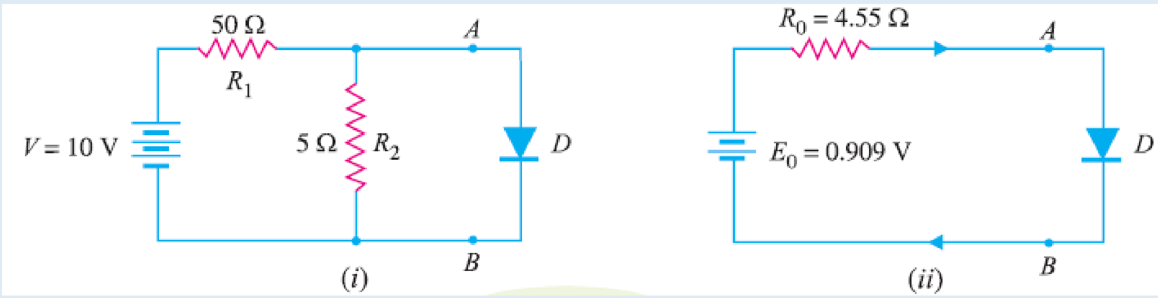
$$\text{or} \quad (I_f)_{peak} = \frac{V_F}{R_L} = \frac{20\text{ V}}{500\ \Omega} = \mathbf{40\ mA}$$

$$\text{Peak output voltage} = (I_f)_{peak} \times R_L = 40\text{ mA} \times 500\ \Omega = \mathbf{20\ V}$$

Example 3.2

Find the current through the diode in the circuit shown:

(i) Assume the diode to be ideal.



Solution:

We shall use Thevenin's theorem to find current in the diode.

E_0 = Thevenin's voltage

= Open circuited voltage across *AB* with diode removed

$$= \frac{R_2}{R_1 + R_2} \times V = \frac{5}{50 + 5} \times 10 = 0.909 \text{ V}$$

R_0 = Thevenin's resistance

= Resistance at terminals *AB* with diode removed and battery replaced by a short circuit

$$= \frac{R_1 R_2}{R_1 + R_2} = \frac{50 \times 5}{50 + 5} = 4.55\ \Omega$$

Fig shows Thevenin's equivalent circuit. Since the diode is ideal, it has zero resistance

$$\therefore \quad \text{Current through diode} = \frac{E_0}{R_0} = \frac{0.909}{4.55} = 0.2 \text{ A} = \mathbf{200 \text{ mA}}$$

3.3.1 Zener Diode Circuit Diagram:

The circuit diagram of the Zener diode is shown in the figure below. The Zener diode is used in reverse bias. The reverse biasing means the n-type material of the diode is connected to the positive terminal of the supply and the P-type material is connected to the negative terminal of the supply. The depletion region of the diode is very thin because it is made of the heavily doped semiconductor material.

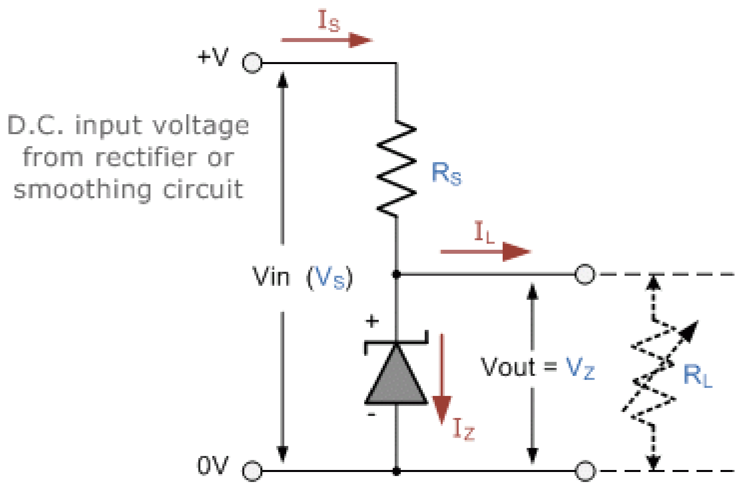


Fig. 3.6 Zener diode circuit diagram

3.3.2 **Working of Zener Diode**

The Zener diode is made up of heavily doped semiconductor material. The heavily doped means the high-level impurities is added to the material for making it more conductive. The depletion region of the Zener diode is very thin because of the impurities. The heavily doping material increases the intensity of the electric field across the depletion region of the Zener diode even for the small reverse voltage.

When no biasing is applied across the Zener diode, the electrons remain in the valence band of the p-type material and no current flow through the diode. The band in which the valence electrons (outermost orbit electron) place is known as the valence band electron. The electrons of the valence band easily move from one band to another when the external energy is applied across it.

When the reverse bias applies across the diode and the supply voltage is equal to the Zener voltage then it starts conducting in the reverse bias direction. The Zener voltage is the voltage at which the depletion region completely vanishes.

The reverse bias applies across the diode increases the intensity of electric field across the depletion region. Thus, it allows the electrons to move from the valence band of P-type material to the conduction band of N-type material. This transferring of valence band electrons to the conduction band reduces the barrier between the p and n-type material. When the depletion region become completely vanish the diode starts conducting in the reverse biased.

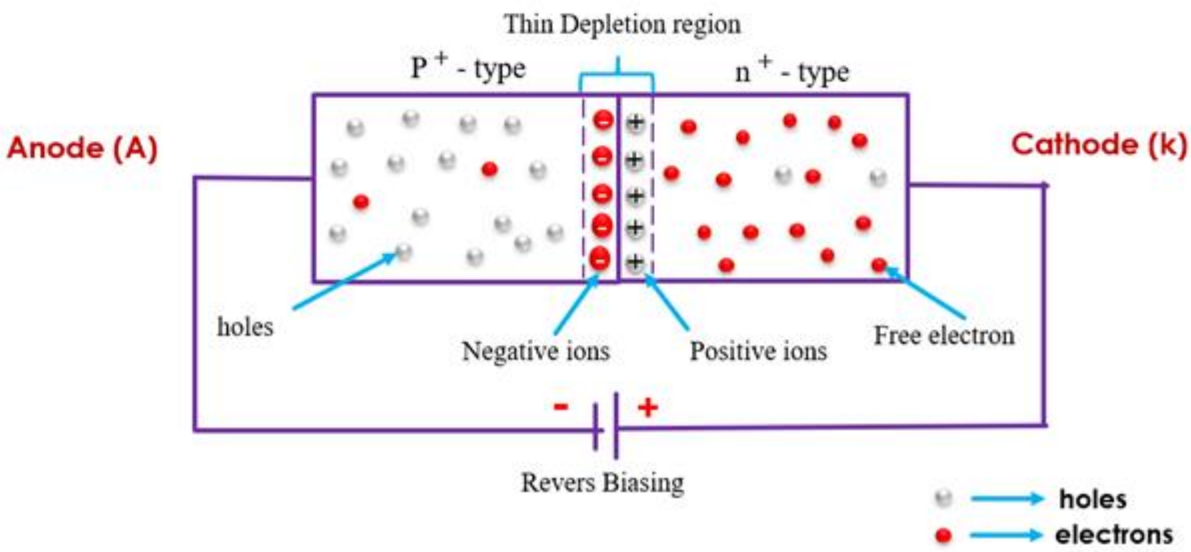


Fig. 3.7 Working of a Zener diode

3.3.3 Characteristics of Zener Diode

The VI characteristic graph of the Zener diode is shown in the figure below. This curve shows that the Zener diode, when connected in forwarding bias, behaves like an ordinary diode. But when the reverse voltage applies across it and the reverse voltage rises beyond the predetermined rating, the Zener breakdown occurs in the diode.

At Zener breakdown voltage the current starts flowing in the reverse direction. The graph of the Zener breakdown is not exactly vertical shown above which shows that the Zener diode has resistance. The voltage across the Zener is represented by the equation shown below.

$$V = V_Z + I_Z R_Z$$

Interesting Information

- Zener is named after American physicist Clarence Zener, who first described the Zener effect in 1934 in his primarily theoretical studies of breakdown of electrical insulator properties. Later, his work led to the Bell Labs implementation of the effect in form of an electronic device, the Zener diode.

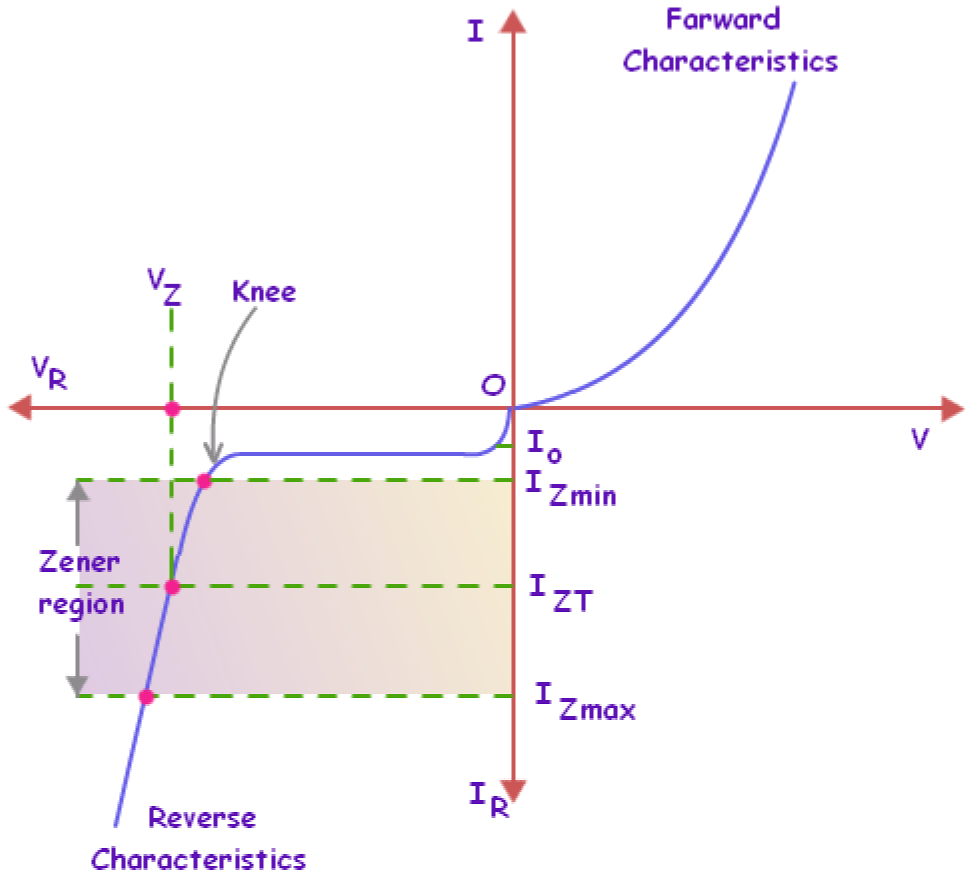


Fig. 3.8 IV Characteristics of a Zener diode

3.4 Bipolar Junction Transistor

A Bipolar Junction Transistor (also known as a BJT or BJT Transistor) is a three-terminal semiconductor device consisting of two p-n junctions which are able to amplify or magnify a signal. It is a current controlled device. The three terminals of the BJT are the base, the collector and the emitter. A BJT is a type of transistor that uses both electrons and holes as charge carriers.

If a signal of small amplitude is applied to the base is available in the amplified form at the collector of the transistor. This is the amplification provided by the BJT. Note that it does require an external source of DC power supply to carry out the amplification process.

There are two types of bipolar junction transistors – NPN transistors and PNP transistors. A diagram of these two types of bipolar junction transistors is given below (Figure 3.9):

Example 3.3

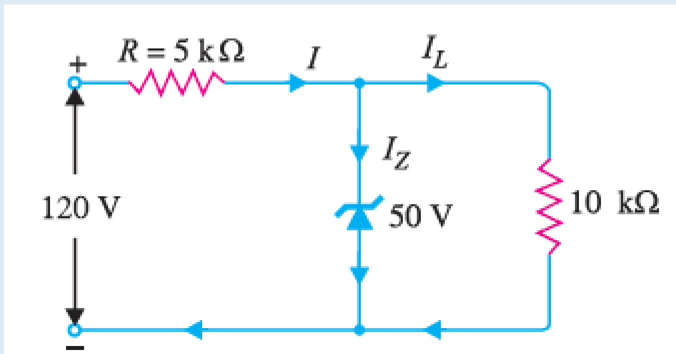
For the circuit shown in Figure

Find:

(i) the output voltage

(ii) the voltage dop across series resistance

(iii) the current through Zener diode.

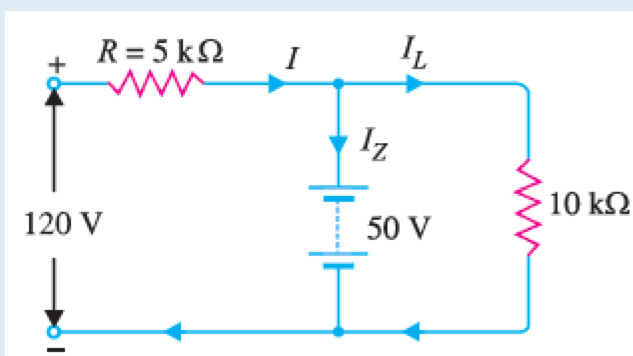


Solution:

If you remove the Zener diode in Figure, the voltage V across the open-circuit is given by:

$$V = \frac{R_L E_i}{R + R_L} = \frac{10 \times 120}{5 + 10} = 80 \text{ V}$$

Since voltage across Zener diode is greater than V_z (= 50 V), the Zener is in the "on" state. It can,therefore, be represented by a battery of 50 V as shown in Figure.



(i) Referring to Figure (ii)

$$\text{Load current, } I_L = V_Z/R_L = 50 \text{ V}/10 \text{ k}\Omega = 5 \text{ mA}$$

$$\text{Current through } R, I = \frac{70 \text{ V}}{5 \text{ k}\Omega} = 14 \text{ mA}$$

$$\text{Voltage across } 5\text{ k}\Omega = 120 - 50 = 70\text{ V}$$

$$\text{Current through } 5\text{ k}\Omega,\ I = \frac{70\text{ V}}{5\text{ k}\Omega} = 14\text{ mA}$$

$$\text{Load current, } I_L = \frac{50\text{ V}}{10\text{ k}\Omega} = 5\text{ mA}$$

$$\text{Applying Kirchhoff's first law, } I = I_L + I_Z$$

$$\therefore \quad \text{Zener current, } I_Z = I - I_L = 14 - 5 = \mathbf{9\text{ mA}}$$

Minimum Zener current:

The Zener will conduct minimum current when the input voltage isminimum i.e. 80 V. Under such conditions, we have,

$$\text{Voltage across } 5\text{ k}\Omega = 80 - 50 = 30\text{ V}$$

$$\text{Current through } 5\text{ k}\Omega,\ I = \frac{30\text{ V}}{5\text{ k}\Omega} = 6\text{ mA}$$

$$\text{Load current, } I_L = 5\text{ mA}$$

$$\therefore \quad \text{Zener current, } I_Z = I - I_L = 6 - 5 = \mathbf{1\text{ mA}}$$

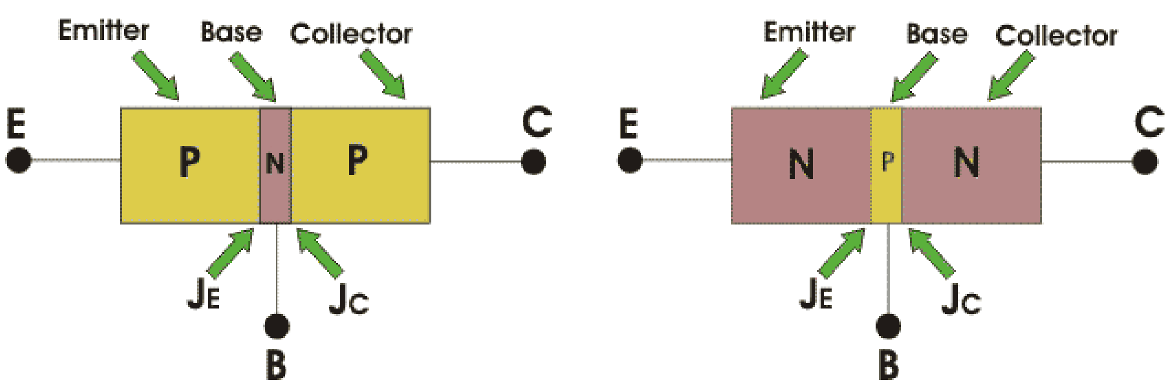


Fig. 3.9 IV Construction of BJT

From the above figure, we can see that every BJT has three parts named emitter, base and collector. J_E and J_C represent the junction of emitter and junction of collector respectively. Now initially it is sufficient for us to know that emitter-based junction is forward biased and collector-base junctions are reverse biased.

3.4.1 **Applications of BJT**

One common application of a BJT is to drive an LED. An LED driver is shown in Figure 3.10. The driver shown in this figure is used to couple a low current part of the circuit to a relatively high current device (the LED). When the output from the low current circuit is low (0 V), the transistor is in cut-off and the LED is off. When the output from the low current circuit goes high (+3.3 V), the transistor is driven into saturation and the LED lights. The driver is used because the low-current part of the circuit may not have the current capability to supply the 20 mA (typical) required to light the LED to full brightness.

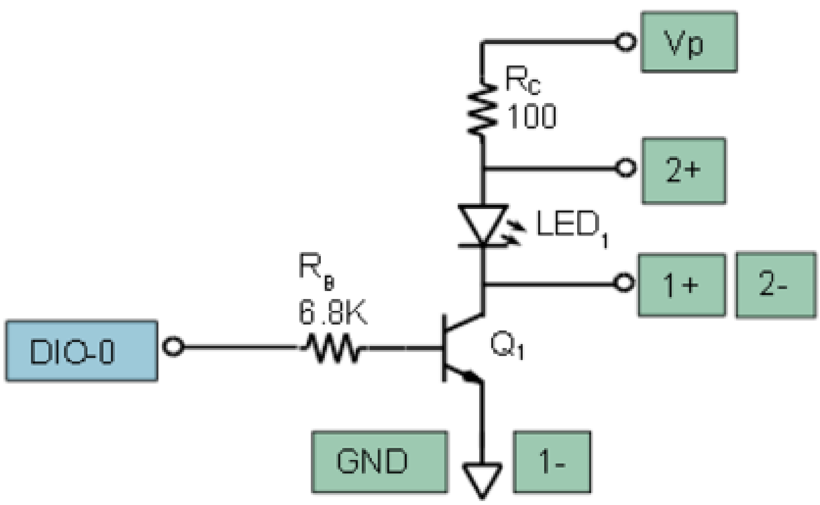


Fig. 3.10 BJT as a Switch

Activity

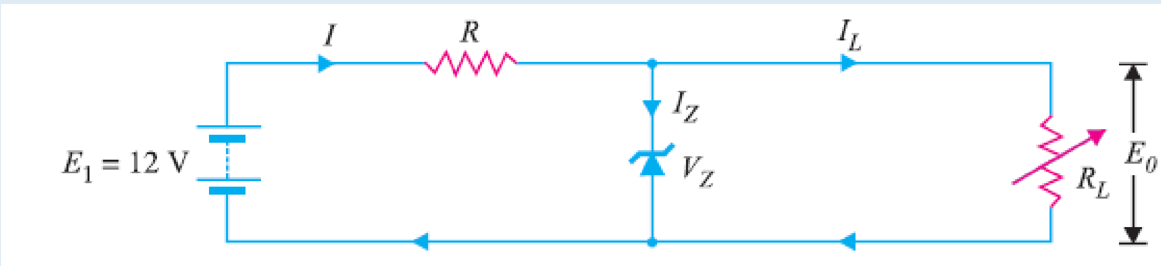
Build the LED switch circuit shown in figure 3.10 on your solder-less breadboard. R_C serves to limit the current that flows in the LED from the +5 V power supply (Vp). The switch is controlled by digital signal DO. Scope channel 1 will display the voltage across the switch transistor Q_1 (V_{CE}) and scope channel 2 will display the voltage across the LED.

Teacher Notes:

- Conduct this activity in Lab. Oscilloscope must be used to plot voltages.

Example 3.4

A 7.2 V Zener is used in the circuit shown in Fig. 3 and the load current is to vary from 12 to 100 mA. Find the value of series resistance R to maintain a voltage of 7.2 V across the load. The input voltage is constant at 12V and the minimum Zener current is 10mA.



Solution:

$$E_i = 12\text{ V}; \quad V_Z = 7.2\text{ V}$$

$$R = \frac{E_i - E_0}{I_Z + I_L}$$

The voltage across R is to remain constant at 12 − 7.2 = 4.8 V as the load current changes from 12 to 100 mA. The minimum Zener current will occur when the load current is maximum.

$$\therefore \quad R = \frac{E_i - E_0}{(I_Z)_{min} + (I_L)_{max}} = \frac{12\text{ V} - 7.2\text{ V}}{(10 + 100)\text{ mA}} = \frac{4.8\text{ V}}{110\text{ mA}} = 43.5\ \Omega$$

If R = 43.5 Ω is inserted in the circuit, the output voltage will remain constant over the regulating range. As the load current IL decreases, the Zener current IZ will increase to such a value that IZ + IL = 110 mA.

Note that if load resistance is open-circuited, then IL = 0 and Zener current becomes

Key Points

- A p-n junction is a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor.
- The p-side or the positive side of the semiconductor has an excess of holes and the n-side or the negative side has an excess of electrons.
- A diode only conducts current in one direction.
- A diode is forward biased if a positive terminal of a source is connected to the p-type side and the negative terminal of the source is connected to the n-type side of the diode.
- A diode is reverse biased if we connect the negative terminal of the voltage source to the p-type side and the positive terminal of the voltage source to the n-type side of the diode.
- Rectifiers are used to convert AC signals to DC signals Flow of charges inside an electric circuit is called electric current.
- In a half-wave rectifier, one half of each AC input cycle is rectified.
- Full-wave rectifier circuits are used for producing an output voltage or output current which is purely DC.
- Zener diode is a heavily doped semiconductor diode which is designed to operate in reverse direction.
- Zener diode is commonly used for load regulation.

Exercise

Select the most appropriate option

1. ____ allows uni-directional flow of current.

   a. Resistance b. Capacitor c. Diode d. None of these

2. ____ is used for load regulation.

   a. Resistance b. Zener Diode c. Capacitor d. None of these

3. _____ can be used as a switch.

   a. BJT b. Capacitor c. BJT d. None of these

4. There are _____ p-n junctions in a BJT

   a. 1 b. 2 c. 3 d. Can be (a) and (c)

5. _______ is always used in reverse bias.

   a. Resistance b. Diode c. Zener diode d. BJT

Give short answer of the following

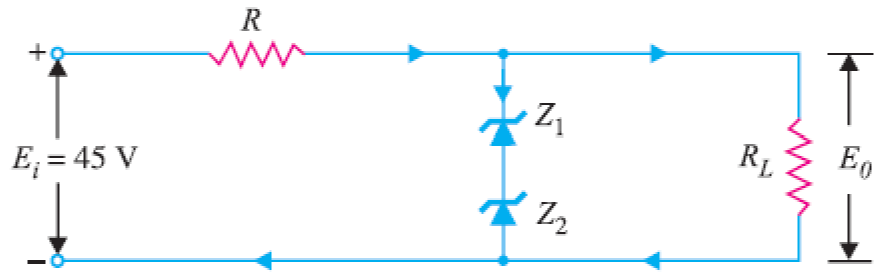
1. Define Diode.
2. What are the applications of diode?
3. Describe the formation of PN junction diode.
4. Define rectification.
5. Describe Half Wave rectifier.
6. Describe Full Wave rectifer.
7. Define Zener diode.

Answer the following question in detail

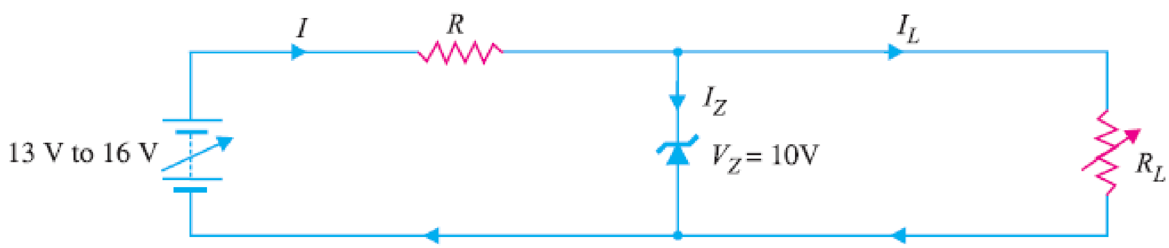
1. Describe the formation of zener diode.
2. Define load regulation and how zener diode can be used for load regulation.
3. What is the difference between Silicon and germinium based diodes.

Solve the Following

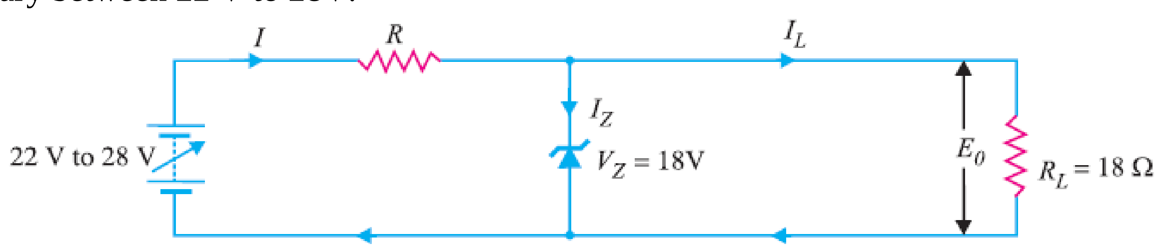
1. The circuit of Figure uses two Zener diodes, each rated at 15 V, 200 mA. If the circuit is connected to a 45-volt unregulated supply, determine :(i) The regulated output voltage (ii) The value of series resistance R.



2. A 10-V Zener diode is used to regulate the voltage across a variable load resistor. The input voltage varies between 13 V and 16 V and the load current varies between 10 mA and 85 mA. The minimum Zener current is 15 mA. Calculate the value of series resistance R.



3. The Zener diode shown in Figure has VZ = 18 V. The voltage across the load stays at 18 V as long as IZ is maintained between 200 mA and 2 A. Find the value of series resistance R so that E0 remains 18 V while input voltage Ei is free to vary between 22 V to 28V.



Chapter 4

Electronics for Internet of Things

After Studying this chapter, you will be able to:

- define FET.
- understand the power rating of FET and its datasheet.
- understand working principle of FET.
- compare JFETs and MOSFETs.
- construct JFETs and MOSFETs.
- identify symbols used for JFET and MOSFETs.
- use multimeter/ datasheet to identify the Gate Source & Drain of FET.
- understand biasing of FET (JFET, MOSFET).
- draw characteristic curve of FET.
- define Thyristor.
- introduce UJT.
- understand construction of UJT.
- understand the biasing of UJT.
- understand characteristic curve of UJT.
- comprehend intrinsic stand-off ratio & RC time constant.

Chapter 4

4.1 Field Effect Transistor

The FET (Field Effect Transistor) is a three-terminal electronic device used to control the flow of current by the voltage applied to its gate terminal. The three terminals in this device are named drain, source, and gate. Figure 4.1 shows the construction of a FET.

- **Source:** It is a terminal through which charge carriers enter the channel.
- **Drain:** It is a terminal through which charge carriers leave the channel.
- **Gate:** This terminal controls the conductivity between the source and the drain terminals.

FETs are also known as unipolar transistors as opposed to BJTs that are bipolar transistors. In FETs, either holes or electrons are used for the conduction process. Whereas, conduction process doesn’t involve both charge carriers simultaneously. FETs usually come with high input impedance at lower frequencies. They are robust and cheap and are used in many electrical circuits. The low power consumption and low power dissipation make this device an ideal fit for integrated circuits.

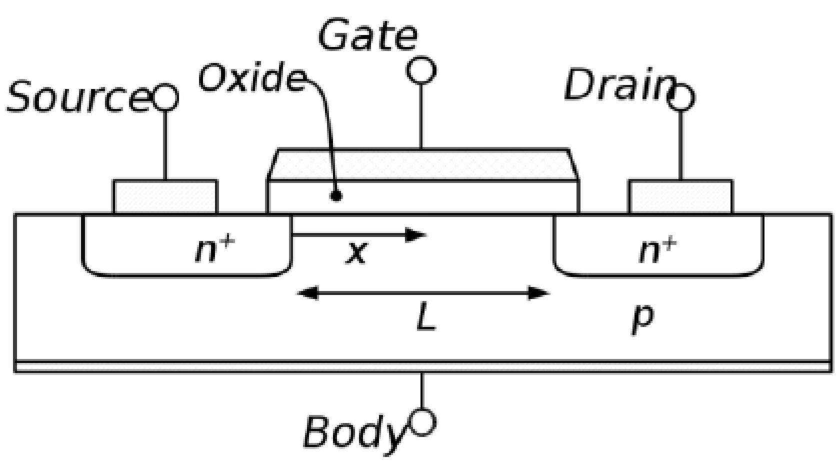


Fig. 4.1 Construction of FET

4.1.1 **Working**

The FET is an electronic device that contains charge carriers, either electrons or holes that flow from source to drain terminals through the active channel. The conductivity process is controlled by applying the input voltage at the gate terminal.

The current-carrying path that exists between the source and drain terminals is known as "channel" which can be composed of either N-type or P-type semiconductor material. Refer to Figure 4.2 for working of FET.

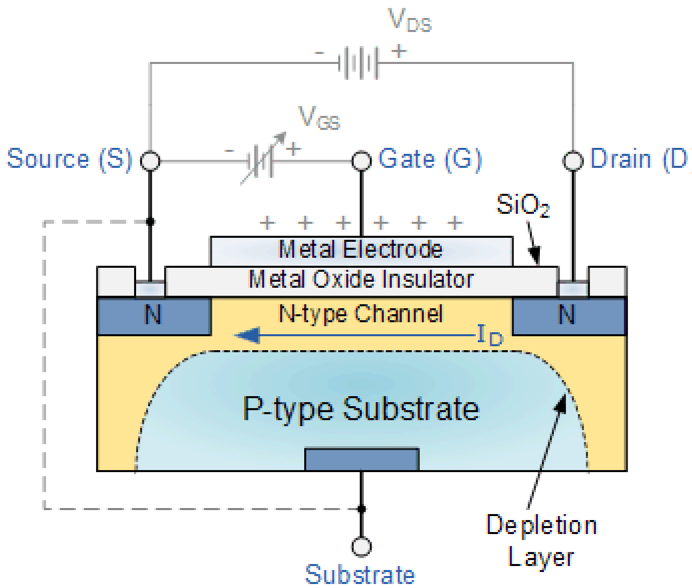


Fig. 4.2 Working of FET

4.1.2 FET Datasheet Specifications & Parameters

FET datasheets contain different parameters and specifications which define the performance of the particular FET type.When developing a new circuit or replacing an existing FET it is important to understand the different parameters and specifications that appear in the datasheets so that the correct device can be chosen and used. All the specifications and parameters are important in different applications.

> **Interesting Information**
>
> The concept of a field-effect transistor (FET) was first patented by Austro-Hungarian physicist Julius Edgar Lilienfeld in 1925and by Oskar Heil in 1934, but they were unable to build a working practical semiconducting device based on the concept.

Some of the mainspecifications of FET are defined below. These specifications are always provided in datasheets. Some of the parameters are particularly important for different types of FET, e.g., JFET, while others may be more applicable to the MOSFETs etc.

- **Gate source voltage, V_{GS}:** The FET parameter V_{GS} is the rating for the maximum voltage that can be tolerated between the gate and source terminals. The purpose for including this parameter in the datasheet is to prevent damage of the gate oxide. The actual gate oxide withstand voltage is typically much higher than this but it varies as a result of the tolerances that exist in the manufacturing processes. It is advisable to remain well within this rating so that the reliability of the device is maintained.
- **Drain-Source Voltage, V_{DSS}:**This is a rating for the maximum drain-source voltage that can be applied without causing avalanche breakdown. The parameter is normally stated for the case where the gate is shorted to the source.While designing a circuit, it is always best to leave a significant margin between the maximum voltage to be experienced and the V_{DSS} specification.
- **Gate Reverse Leakage Current, I_{gss}:** The current which flows in the reverse bias.It is the leakage current between the gate and source at $V_{DS} = 0$ and is defined by applying the maximum rating V_{GSS} between the gate and source.
- **Threshold voltage $V_{GS(TH)}$:** The threshold voltage $V_{GS(TH)}$ is the minimum gate voltage that can form a conducting channel between the source and the drain.
- **Drain current at zero gate voltage, I_{dss}:** This FET parameter is the maximum continuous current the device can carry with the device fully on. Normally it is specified for a particular temperature, typically 25°C.This FET specification is based on the junction-to-case thermal resistance rating and the case temperature.This FET parameter is of particular interest for power MOSFETs and when determining the maximum current parameter, no switching losses are accounted for. Also holding the case at 25°C is not feasible in practice. As a result, the actual switching current should be limited to less than half of the I_{dss} at TC = 25°C rating in a hard switched application.

- **Gate source cut-off voltage, $V_{GS(off)}$:** The gate source cut-off voltage is a turn-off specification. It defines the threshold voltage for a given residual current, so the device is basically off but on the edge of turning on. The threshold voltage has a negative temperature coefficient, i.e., it decreases with increasing temperature. This temperature coefficient also affects turn-on and turn-off delay times.
- **Forward transconductance, G_{fs}:** Forward transconductance (G_{fs}) represents the signal gain (drain current divided by gate voltage) of a MOSFET.
- **Input capacitance, C_{iss}:** The input capacitance parameter for a FET is the capacitance that is measured between the gate and source terminals with the drain shorted to the source for AC signals. In other words, this is the capacitance between the gate and channel. C_{iss} is made up of the gate to drain capacitance C_{gd} in parallel with the gate to source capacitance Cgs. This can be expressed as:

$$C_{iss}=C_{gs}+C_{gd}$$

- **Drain-source on resistance, $R_{ds(on)}$:** With the FET turned hard on, this is the resistance in ohms exhibited across the channel between the drain and source. It is particularly important in switching applications from logic to power switching as well as in RF switching (in radios and televisions), including applications in mixers. FETs typically are able to provide a good performance for switching and have a relatively low $R_{ds(on)}$ value.

FET datasheets contain different parameters and specifications to define the performance of the FET. These are all provided in datasheets that enable the correct choice of FET to be made.

4.2 JFET

The junction-gate field-effect transistor (JFET) is one of the simplest types of field-effect transistor. Figure 4.3 shows the basic form of construction of a practical n-channel and p-channel JFET. A p-channel JFET can be made by transposing the p and n materials as shown in Figure 4.3. All JFETs operate in the depletion mode.

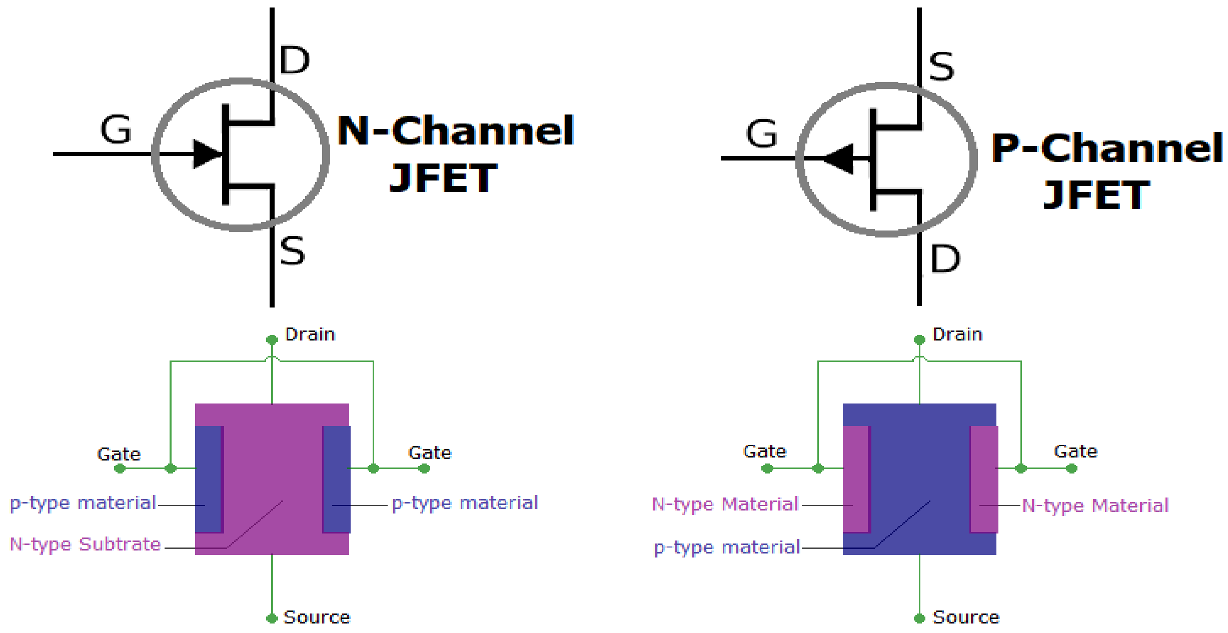


Fig. 4.3 Construction of JFET

Figure 4.4 shows typical transfer characteristics of a low-power n-channel JFET, and illustrates some important features of this type of device. These dopings make a P-N junction in the middle part of the block. We can also form a P-N junction by joining a p-type semiconductor and n-type semiconductor together with a special fabrication technique. The terminal connected to the p-type is the anode. The terminal connected to the n-type side is the cathode.

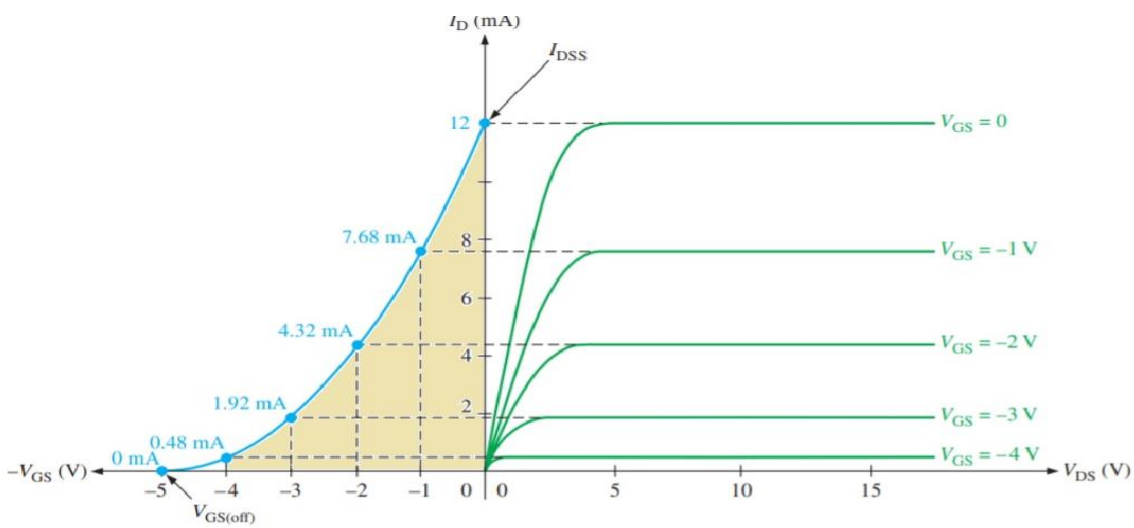


Fig. 4.4 Transfer Characteristics of JFET

The most important characteristics of the JFET are as follows:

- When a JFET is connected to a supply with the polarity shown in Figure 4.2 (drain +ve for an n-channel FET, -ve for a p-channel FET), a drain current (I_D) flows and can be controlled via a gate-to-source bias voltage V_{GS}.
- I_D is maximum when $V_{GS} = 0$, and is reduced by applying a reverse bias to the gate (negative bias in an n-channel device, positive bias in a p-type). The magnitude of V_{GS} needed to reduce I_D to zero is called the 'pinch-off' voltage, V_P, and typically has a value between 2 and 10 volts. The magnitude of I_D when $V_{GS} = 0$ is denoted I_{DSS}, and typically has a value in the range 2 to 20mA.
- The JFET's gate-to-source junction has the characteristics of a silicon diode. When reverse-biased, gate leakage currents (I_{GSS}) are only a couple of nA (1nA = .001µA) at room temperature. Actual gate signal currents are only a fraction of annA, and the input impedance of the gate is typically thousands of mega ohms at lower frequencies.
- If the JFET's gate-to-source junction is forward-biased, it conducts like a normal silicon diode. If it is excessively reverse-biased, it avalanches like a Zener diode. In both cases, the JFET suffers no damage if gate currents are limited to a few milli amperes.
- Note in Figure 4.4 that, for each V_{GS} value, drain current I_D rises linearly from zero as the drain-to-source voltage (V_{DS}) is increased from zero up to some value at which a 'knee' occurs on each curve, and that I_D then remains constant as V_{DS} is increased beyond the knee value. Thus, when V_{DS} is below the JFET's knee value, the drain-to-source terminals act as a resistor.
- R_{DS} can be varied from a few hundred ohms (at $V_{GS} = 0$) to thousands of mega ohms (at $V_{GS} = V_P$), enabling the JFET to be used as a voltage-controlled switch or as an efficient 'chopper' that does not suffer from offset-voltage or saturation-voltage problems.

- Note in Figure 4.4 that when V_{DS} is above the knee value, the I_D value is controlled by the V_{GS} value and is almost independent of V_{DS}, i.e., the JFET acts as a voltage-controlled current generator. The JFET can be used as a fixed-value current generator by either tying the gate to the source, or by applying a fixed negative bias to the gate. Alternatively, it can (when suitably biased) be used as a voltage-to-current signal amplifier.
- FET 'gain' is specified as transconductance, gm, and denotes the magnitude of change of drain current with gate voltage, i.e., a gm of 5mA/V signifies that a VGS variation of one volt produces a 5mA change in ID. Note that the form I/V is the inverse of the ohms formula, so gm measurements are often expressed in 'mho' units. Usually, gm is specified in FET data sheets in terms of mmhos (milli-mhos) or µmhos (micro-mhos).
- In most practical applications, the JFET is biased into the linear region and used as a voltage amplifier. N-channel JFET can be used as a common source amplifier (corresponding to the bipolar npn common emitter amplifier).

4.3 MOSFET

The second and most important family of FETs are IGFET or MOSFET. In these FETs, the gate terminal is insulated from the semiconductor body by a very thin layer of silicon dioxide, hence the title 'Insulated Gate Field Effect Transistor,' or IGFET. The devices generally use a 'Metal-Oxide Silicon' semiconductor material in their construction, hence the alternative title of MOSFET.

Figure 4.5 shows the basic construction and the standard symbol of the n-channel depletion-mode FET. It resembles the JFET, except that its gate is fully insulated from the body of the FET (as indicated by the Figure 4.6) but, in fact, operates on a slightly different principle to the JFET.

It has a normally-open n-type channel between drain and source, but the channel width is controlled by the electrostatic field of the gate bias. The channel can be closed by applying suitable negative bias, or can be increased by applying positive bias.

In practice, the FET substrate may be externally available, making a four-terminal device, or may be internally connected to the source, making a three-terminal device. An important point about the IGFET/MOSFET is that it is also available as an enhancement-mode device, in which its conduction channel is normally closed but can be opened by applying forward bias to its gate.

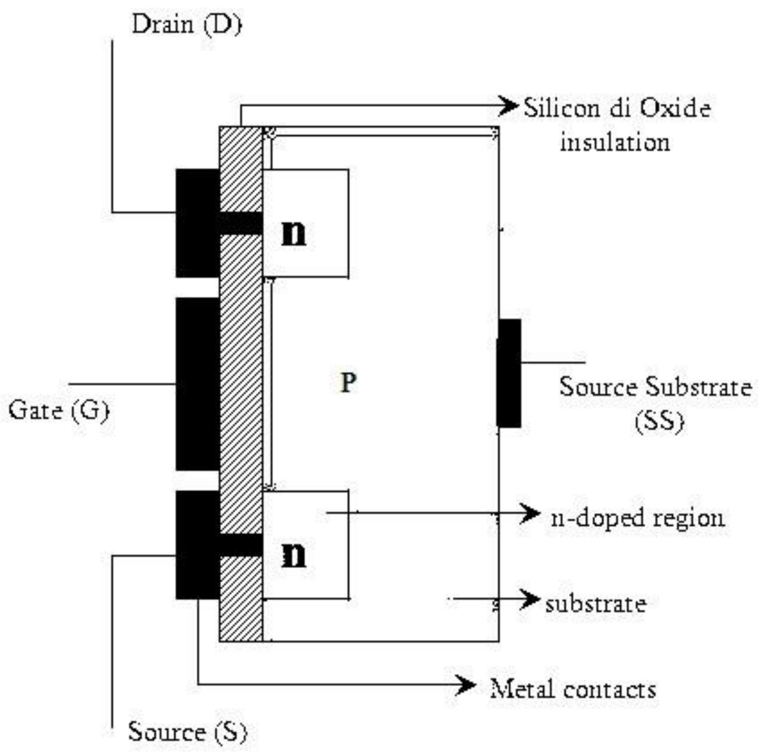


Fig. 4.5 Construction of MOSFET

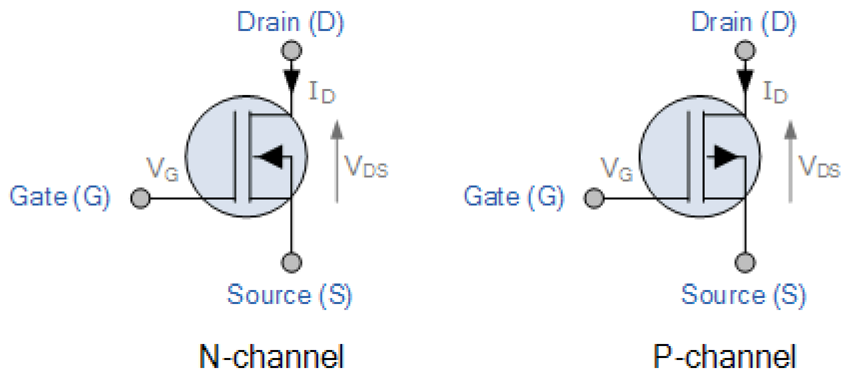


Fig. 4.6 Symbol of MOSFET

To turn the device on, significant positive gate bias is needed, and when this is of sufficient magnitude, it starts to convert the p-type substrate material under the gate into an n-channel, enabling conduction to take place.

Figure 4.7 shows the typical transfer characteristics of an n-channel enhancement-mode IGFET/MOSFET, and the VGS/ID curves of the same device. Note that no ID current flows until the gate voltage reaches a 'threshold' (VTH) value of a few volts, but that beyond this value, the drain current rises in a non-linear fashion.

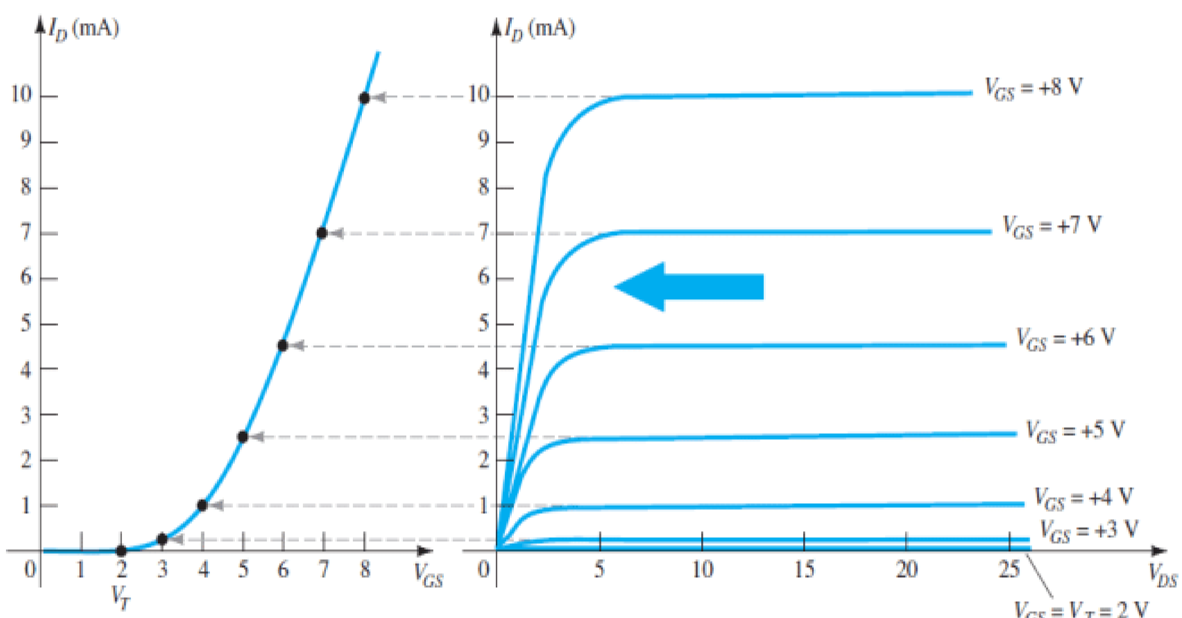


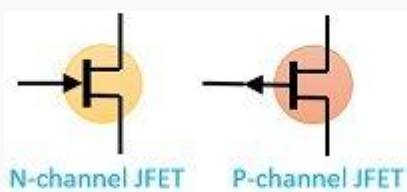
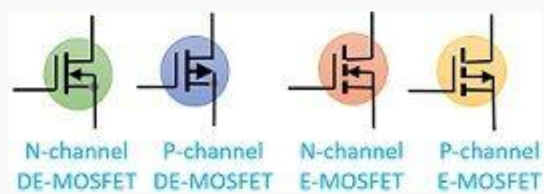
Fig. 4.7 Transfer Characteristics of MOSFET

Note that the transfer graph is divided into two characteristic regions, as indicated (in Figure 4.7) by the dotted line.These are the ‘triode’ region and the ‘saturated’ regions respectively. In the triode region, the device acts like a voltage-controlled resistor.In the saturated region, it acts like a voltage-controlled constant-current generator.

The basic n-channel MOSFETs can be converted to p-channel devices by simply transposing their p and n materials, in which case their symbols must be changed by reversing the directions of their substrate arrows.

Note that the very high gate impedance of MOSFET devices makes them liable to damage from electrostatic discharges and, for this reason, they are often provided with internal protection via integral diodes or Zener diodes.

Comparison Table of JFET and MOSFET

PARAMETERS	JFET	MOSFET
Mode of operation	It operates only in depletion mode.	It can be operated in either depletion or enhancement mode.
Symbol		
Input impedance	JFET have much smaller input impedance mainly of the order of 10^8 Ω.	MOSFETs have much higher input impedance of about 10^{10} to 10^{15} Ω due to small leakage current.
Characteristic curve	As JFET has higher drain resistance, the characteristic curve is flatter.	The characteristic curve is less flat than those of JFET.

PARAMETERS	JFET	MOSFET
Drain resistance	JFET has drain resistance of the order of 10^5 to 10^6 Ω	Drain resistance in case of MOSFETs is of the order of 1 to 50 K Ω.
Fabrication	Fabrication process of JFET is more difficult than MOSFET.	MOSFET can be easily fabricated thus it is more widely used.
Cost	Manufacturing of JFET is cheaper as compared to MOSFET.	MOSFETs are slightly expensive as compared to JFET.
Susceptibility to damage	It does not require special handling.	These are more susceptible to overload voltage and requires special handling.

4.4 Thyristors

Thyristors are also switching devices similar to the transistors. Transistors can be used as amplifying and switching device but they cannot handle higher current. So, to handlehigher currents, thyristors are used.

Thyristor includes many types of switches, some of them are SCR (Silicon Controlled Rectifier), GTO (Gate Turn OFF), and IGBT (Insulated Gate Controlled Bipolar Transistor) etc. SCR is the most widely used device, so the word Thyristor become synonymous to SCR.

SCR or Thyristor is a four-layered, three-junction semiconductor switching device. It has three terminals: anode, cathode, and gate. Thyristor is also a unidirectional device like a diode, which means it allows current only in one direction. It consists of three P-N junctions in series as it is of four layers. Gate terminal is used to trigger the SCR by providing small voltage to this terminal, which is called gate triggering method to turn ON the SCR.

Difference betweenThyristorand MOSFET

Thyristor and MOSFET both are electrical switches and are most commonly used. The basic difference between both of them is that MOSFET switches are voltage-controlled devices and can only switch DC current while Thyristors switches are current controlled device and can switch both DC and AC current. There are some more differences between Thyristor and MOSFET which are given below in the table:

Property	**Thyristor**	**MOSFET**
Thermal Run away	Yes	No
Temperature sensitivity	less	high
Type	High voltage high current device	High voltage medium current device
Turning off	Separate switching circuit is required	Not required
Turning On	Single pulse required	No continuous supply is required except during turning On and Off
Switching speed	Low	high
Resistive input impedance	Low	high
Controlling	Current controlled device	Voltage controlled device

4.5 UJT

UJT stands for UniJunction Transistor. It is a three terminal semiconductor switching device. The Unijunction Transistor is a simple device that consists of a bar of n-type silicon material with a non-rectifying contact at either end (base 1 and base 2), and with a rectifying contact (emitter) alloyed into the bar part along its length, to form the only junction within the device (hence the name 'Unijunction').

The Unijunction Transistor is also known as Double Base Diode. The unique switching characteristics of UJT makes it different from conventional BJT's and FET's by acting as switching transistor instead of amplifying the signals. It exhibits negative resistance in its characteristics which employs it as relaxation oscillators in variety of applications.

4.5.1 Symbol and Construction of Unijunction Transistor (UJT):

In Unijunction Transistor, the P-N Junction is formed by lightly doped N-type silicon bar with heavily doped P-type material on one side. The ohmic contact on either ends of the silicon bar is termed as Base 1 (B_1) and Base 2 (B_2) and P-type terminal is named as emitter.

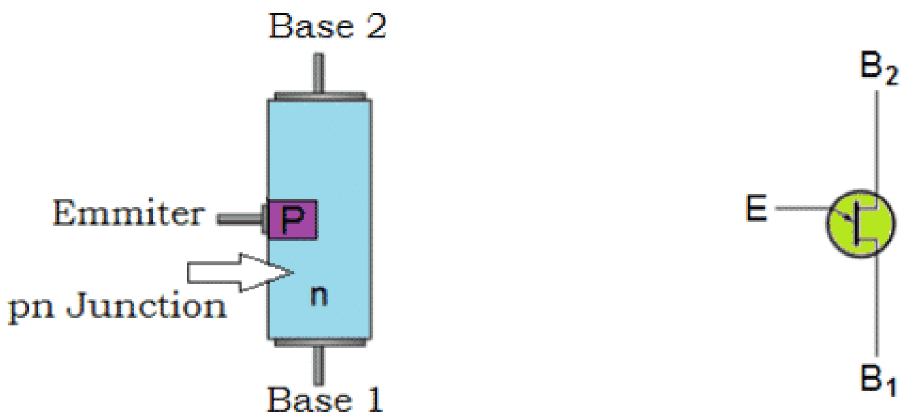


Fig. 4.8 Basic Construction & Symbol of Unijunction Transistor (UJT)

The emitter junction is placed such that it is closer to terminal Base 2 than Base 1. The symbols of both UJT and JFET resemble the same except the emitter arrowhead represents the direction in which conventional current flow, but they operate differently.

4.5.2 Working of a Unijunction Transistor

The equivalent circuit (Figure 4.9) shows that N-type channel consists of two resistors R_{B2} and R_{B1} in series with an equivalent diode, D representing the PN junction. The emitter PN junction is fixed along the ohmic channel during its manufacturing process.

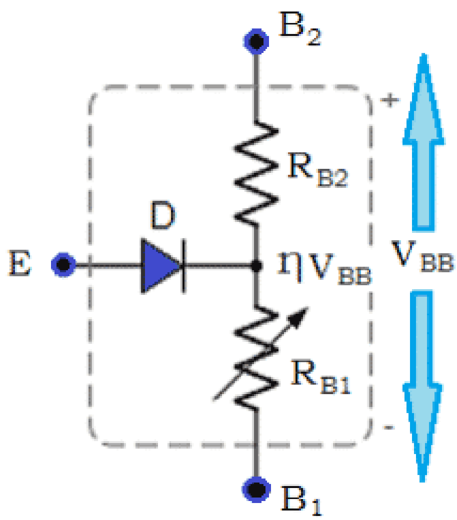


Fig. 4.9 Simplified Equivalent Circuit of Unijunction Transistor

The variable resistance R_{B1} is provided between the terminals Emitter (E) and Base 1 (B_1), the R_{B2} between the terminals Emitter (E) and Base 2 (B_2). Since the PN junction is closer to B_2, the value of R_{B2} will be less than the variable resistance R_{B1}.

A voltage divider network is formed by the series resistances R_{B2} and R_{B1}. When a voltage is applied across the semiconductor device, the potential will be in proportion to the position of base points along the channel. The Emitter (E) will act as input when employed in a circuit, as the terminal B_1 will be grounded. The terminal B_2 will be positive biased to B_1, when a voltage (V_{BB}) applied across the terminals B_1 and B_2. When the emitter input is zero, the voltage across resistance R_{B1} of the voltage divider circuit is calculated by:

$$V_{RB_1} = \frac{R_{B1}}{R_{B1}+R_{B2}}(V_{BB})$$

The important parameter of Unijunction Transistor is 'intrinsic stand-off ratio' (η), which is resistive ratio of R_{B1} to R_{BB}. Most UJT's have η value ranging from 0.5 to 0.8. The P-N junction is reverse biased; when small amount of voltage which is less than voltage developed across resistance R_{B1} (ηV_{BB}) is applied across the terminal emitter (E). Thus, a very high impedance is developed prompting device to move into non-conducting state i.e., it will be switched off and no current flows through it. The UJT begins to conduct when the P-N junction is forward biased.

The forward biased is achieved when voltage applied across emitter terminal is increased and becomes more than V_{RB1}. This results in larger flow of emitter current from emitter region to base region. Increase in emitter current reduces the resistance between emitter and Base 1, resulting in negative resistance at emitter terminal.

The Unijunction Transistor (UJT) will act as voltage breakdown device, when the input applied between emitter and base 1 reduces below breakdown value i.e., R_{B1} increases to a higher value. This shows that R_{B1} depends on the emitter current and it is variable.

4.5.3 Characteristics Curve of Unijunction Transistor (UJT)

The characteristics of Unijunction Transistor (UJT) can be explained by three parameters:

- Cutoff
- Negative Resistance Region
- Saturation

Figure 4.10 shows the detailed characteristics of UJT.

Cutoff

Cutoff region is the area where the Unijunction Transistor (UJT) doesn't get sufficient voltage to turn on. The applied voltage hasn't reached the triggering voltage, thus making transistor to be in off state.

Negative Resistance Region

When the transistor reaches the triggering voltage, V_{TRIG}, Unijunction Transistor (UJT) will turn on. After a certain time, if the applied voltage increases to the emitter lead, it will reach out at V_{PEAK}. The voltage drops from V_{PEAK} to Valley Point even though the current increases (negative resistance).

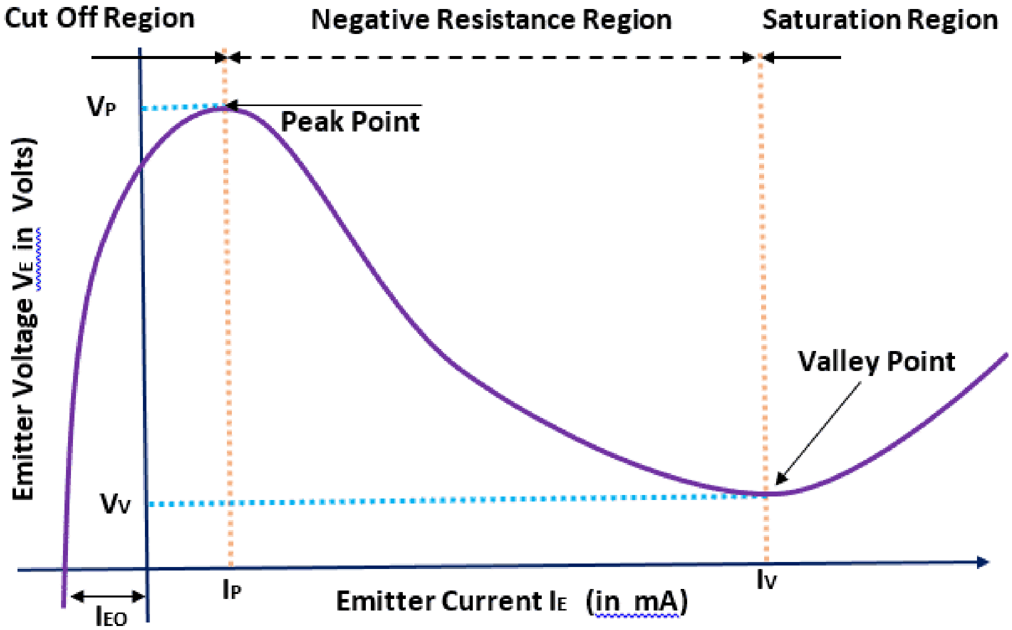


Fig. 4.9 Characteristics of Unijunction Transistor (UJT)

Saturation

In saturation region, current increases with the increase in the applied voltage to emitter terminal.

4.5.4 Applications of Unijunction Transistor (UJT)

The Unijunction Transistor can be employed in variety of applications such as:

- Switching Device
- Triggering Device for Triacs and SCR's
- Timing Circuits
- For phase control
- In sawtooth generators
- In simple relaxation oscillators

Activity

- Implement UJT as a switch on breadboard.

Advantages of Unijunction Transistor (UJT)

The advantages of Unijunction Transistor include

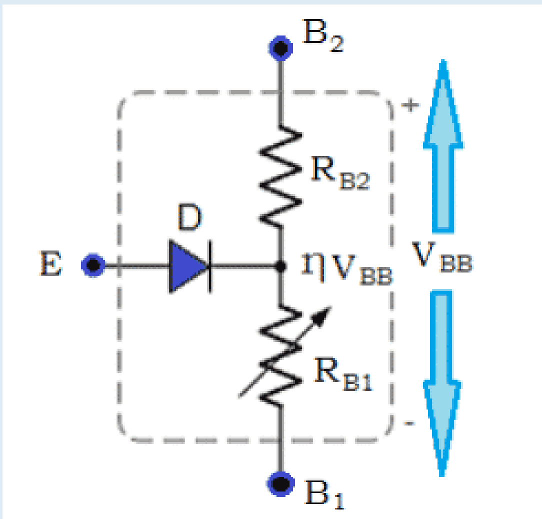
- Low cost
- Negative resistance characteristics
- Requires low value of triggering current.
- A stable triggering voltage
- Low power absorbing device

Disadvantage of Uni junction Transistor (UJT)

The main disadvantage of Unijunction Transistor is its inability to provide appropriate amplification

Example 4.1

The intrinsic stand-off ratio for a UJT is determined to be 0.6. If the inter-base resistance (RBB) is 10kΩ what are the values of RB1 and RB2?



Solution:

Intrinsic stand-off ratio for a UJT is given as

$$\eta = \frac{RB1}{RB1+RB2}$$

$$0.6 = \frac{RB1}{10K}$$

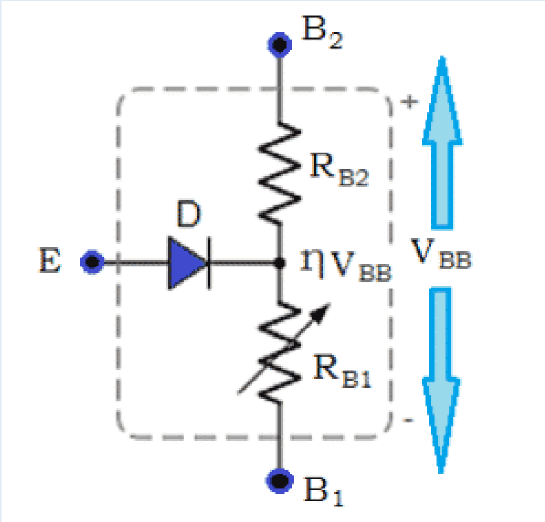
$$R_{B1} = 6K\Omega$$

Teacher Notes

All the topics of this chapter should be taught covering only the basics. Details should be as minimum as possible.

Example 4.2

A UJT has 10V between the bases. If the intrinsic stand-off ratio is 0.65, find the value of stand-off voltage. What will be the peak point voltage if the forward voltage drop in the p-n junction is .7V?



Solution:

V_{BB}=10V, η=0.65, VD =0.7V

Stand-off voltage (V_{RB1}) is given as

$V_{RB1} = \eta V_{BB}$

$V_{RB1} = 0.65 \times 10$

$V_{RB1} = 6.5V$

Peak point Voltage (V_P) is given as

$V_P = \eta V_{BB} + V_D$

After putting values and solving:

$VP = 7.2V$

Key Points

- The FET (Field Effect Transistor) is a three-terminal electronic device used to control the flow of current by the voltage applied to its gate terminal.
- The conductivity process in FET is controlled by applying the input voltage at the gate terminal.
- The junction-gate field-effect transistor (JFET) is one of the simplest types of field-effect transistor.
- All JFETs operate in the depletion mode.
- In MOSFETs, the gate terminal is insulated from the semiconductor body by a very thin layer of silicon dioxide.
- In the triode region, MOSFET acts like a voltage-controlled resistor; in the saturated region, it acts like a voltage-controlled constant-current generator.
- Thyristors are also switching devices similar to the transistors and they are capable of operating in high current conditions.
- The unique switching characteristics of UJT makes it different from conventional BJT's and FET's by acting as switching transistor instead of amplifying the signals.
- The main disadvantage of Unijunction Transistor is its inability to provide appropriate amplification.

Exercise

Select the most appropriate option

1. Which of the following are three terminal electronic devices:

   a. Resistance b. FET c. MOSFET d. Both b and c

2. In MOSFETs,which terminal is insulated from the semiconductor body.

   a. Drainb. Source c. Gate d. None of these

3. _____ are like transistor but can operate in high current conditions.

   a. BJT b. Thyristors c. MOSFETs d. None of these

4. ____ is also known as a double base diode.

   a. UJT b. BJT c. Zener d. JFET

5. _______ are voltage controlled devices

   a. JFET b. MOSFET c. Thyristor d. None of these

Write short answer of the following.

1. Define FET.
2. Define MOSFET?
3. What is the difference between thyristors and MOSFETs.
4. Define UJT.
5. What is the disadvantage of using UJT?

Answer the following question in detail.

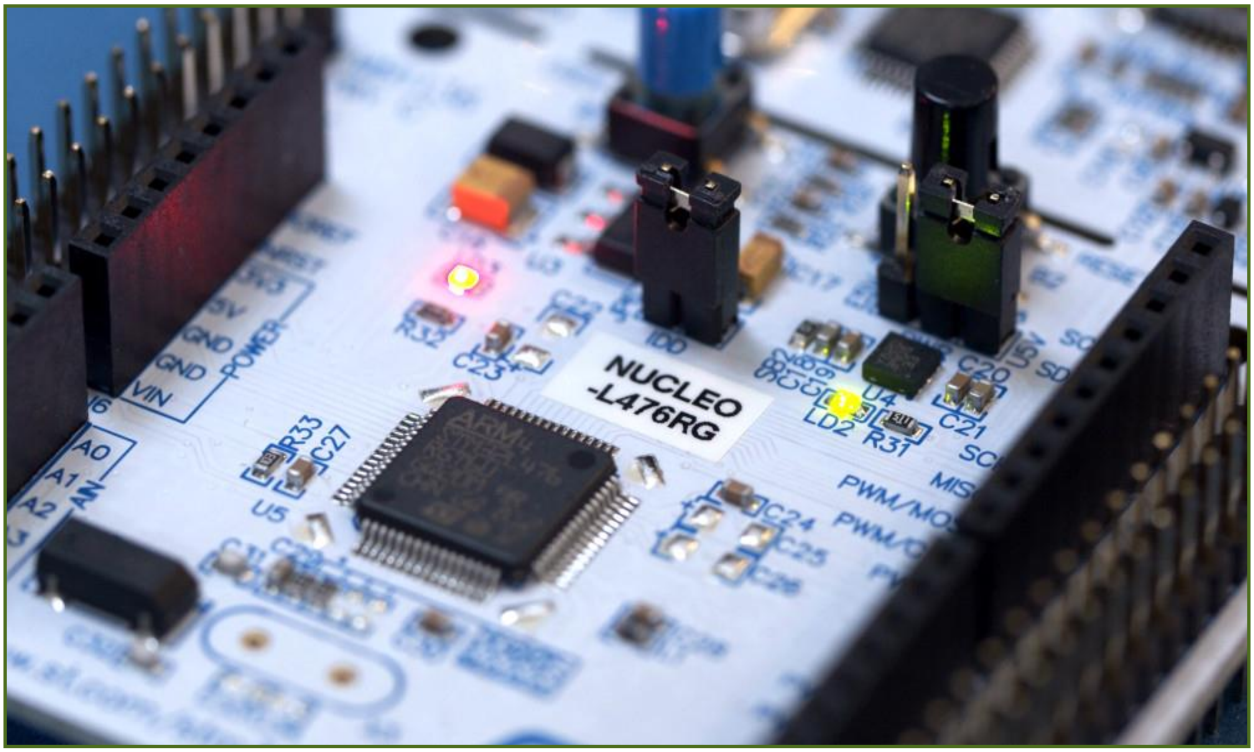
1. Explain the working of MOSFET.
2. Differentiate between UJT and Thyristor.
3. Describe the working of UJT.
4. Enlist Applications of UJT.
5. List down advantages of UJT.

Solve the Following Problems:

1. The intrinsic stand-off ratio for a UJT is determined to be 0.5. If the inter-base resistance (R_{BB}) is 12kΩ what are the values of RB1 and RB2?
2. A UJT has 15V between the bases. If the intrinsic stand-off ratio is 0.75, find the value of stand-off voltage. What will be the peak point voltage if the forward voltage drop in the p-n junction is .7V?
3. Determine the minimum and maximum peak-point voltage for UJT with V_{BB}=24V. Given that UJT has a range of η=0.74 to 0.86.

Chapter 5

Introduction to Microcontrollers



After Studying this chapter, you will be able to:

- define microcontroller.
- describe purpose of microcontroller.
- differentiate microcontroller and microprocessor.
- know common microcontroller.
- name some well-known microcontroller used specifically for IoT application.
- know and understanding of Arduino.
- understand pin configuration of Arduino.
- basic understanding of Arduino IDE.
- process the installation of Arduino IDE.
- know built-in libraries.
- add libraries in Arduino IDE.
- know about USB mini and USB micro.
- process of installing and updating USB to serial driver for Windows.
- select the relevant COM port on Arduino IDE.
- configure required baud rate of COM port in driver.
- select relevant board in Arduino IDE.

Chapter 5

5.1 Microcontrollers

5.1.1 What is a Microcontroller?

A microcontroller is a programmable integrated chip (IC). It has different ports which can be controlled using a program written by the user. These ports control the connected circuitry according to the uploaded program. A typical microcontroller has a microprocessor unit (MPU), memory, and some peripherals.

5.1.2 What Do Microcontrollers Do?

A microcontroller board can sense, monitor and respond to various events, behaviors or input signals that it receives from connected components.

A microcontroller, for example, might be programmed to push a specific type of output signal or behavioral control in response to certain input conditions. This could include the execution of tasks such as:

- Turning ON an LED or OLED display in response to touch-based user demand.
- Playing lights and sounds in temperature-sensing applications or other varieties of alarms and warning systems.
- Responding to the need for a motor to switch on or off in a pump or other mechanical device.
- Adjusting tilt, balance, and velocity in gyroscope or accelerometer-based applications.

5.1.3 Microcontroller vs Microprocessors

A microprocessor does not contain any memory (RAM or ROM) or I/O ports. The instruction set telling a standalone microprocessor how to execute a given function are generally stored externally. In a microcontroller, all these various components - including the simplified processor - are combined into a single self-contained unit.

Performance-wise, microcontrollers and microprocessors are differentiated as:

Microcontroller

- is an entirely self-contained unit that contains a very simple CPU or microprocessor.
- is used for a single specific application, as pre-programmed by the user
- is not especially powerful in performance terms; typically, it only draws a small amount of power and contain little in terms of integrated data storage capacity.
- needs to be programmed by the operator to perform any meaningful role.
- can not operate outside of their specifically programmed code.
- is generally meant for use in specific devices or appliances designed to perform one task repeatedly.

Microprocessor

- is much more complex and versatile in terms of function range, and intended for use in more general computing (as opposed to in specialized one-task devices).
- have much faster processor (clock) speeds than MCUs, often measured in gigahertz (GHz) rather than Hz.
- is challenging and expensive to manufacture, unlike relatively simple and cheap microcontrollers.
- require far more external components (RAM, I/O ports, data storage, EEPROM or flash memory) to operate, none of which are integrated into the microprocessor and must be connected separately.
- have a considerably higher power draw and are subsequently much less cost-effective to run continually.

Chapter 5

Common Microcontrollers

Some commonly used microcontrollers are:

1. 8086 Microcontrollers
2. AVR Microcontrollers
3. Arduino Boards
4. STM
5. ESP
6. Raspberry Pi

Microcontrollers for IoT

Most widely used microcontrollers for development of IoT systems are:

1. ESP8266
2. ESP32
3. Raspberry Pi

5.2 Arduino

Arduino is an open-source embedded systems platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. You need to use the Arduino programming language (based on Wiring), and the Arduino Software (IDE) to start working on Arduino.

5.2.1 Arduino UNO

Arduino UNO is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. Pin configuration of Arduino UNO is shown below:

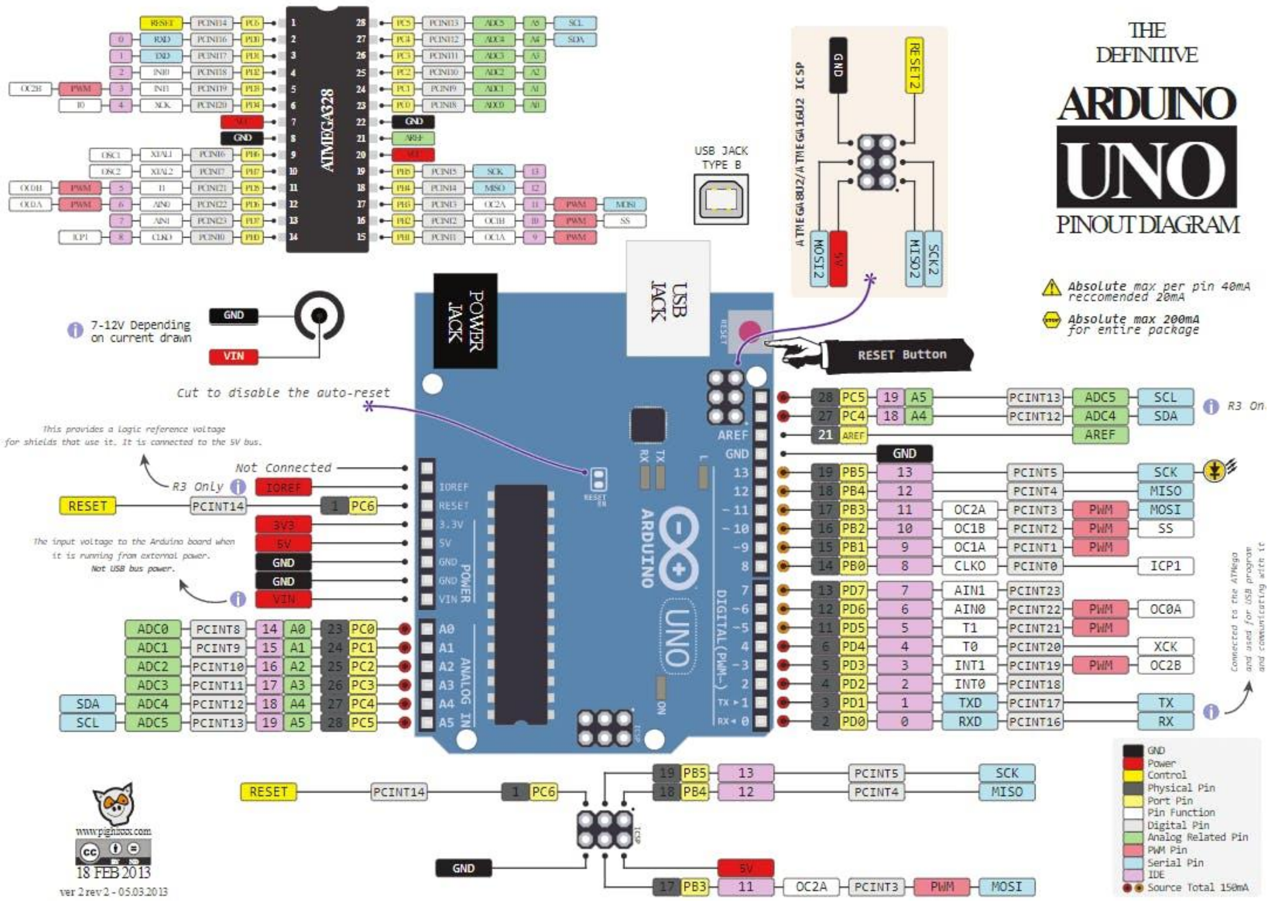


Fig 5.1 Pin Configuration of Arduino UNO

5.3 Arduino IDE

- Arduino IDE is an open-source software, designed by Arduino.cc and mainly used for writing, compiling & uploading code to almost all Arduino Modules.
- It is an official Arduino software, making code compilation easy.
- It is available for all operating systems i.e., MAC, Windows, Linux and runs on the Java Platform that comes with inbuilt functions and commands that play a vital role in debugging, editing and compiling the code.

- A range of Arduino modules are available including Arduino Uno, Arduino Mega, Arduino Leonardo, Arduino Micro and many more.
- Each of them contains a microcontroller on the board that is actually programmed and accepts the information in the form of code.
- The main code, also known as a sketch, created on the IDE platform will ultimately generate a Hex File (executable file containing hex codes) which is then transferred and uploaded in the controller on the board.
- The IDE environment mainly contains two basic parts: Editor and Compiler. The former is used for writing the required code and thelater is used for compiling and uploading the code into the given Arduino Module.
- This environment supports both C and C++ languages.

5.3.1 Installing the Arduino IDE

1. Visit http://www.arduino.cc/en/main/software to download the latest Arduino IDE version for your computer's operating system. There are versions for Windows, Mac, and Linux systems. At the download page, click on the "Windows Installer" option for the installation.
2. Save the .exe file to your hard drive.
3. Open the .exe file.
4. Click the button to agree to the licensing agreement:

Do you know?

Instruction set of every microcontroller is in Assembly language which is converted to machine language instructions while compiling.

Point to Ponder

What is the programming interface of a microcontroller?

Fig 5.2 Arduino setup: License agreement

5. Decide which components to install, then click "Next":

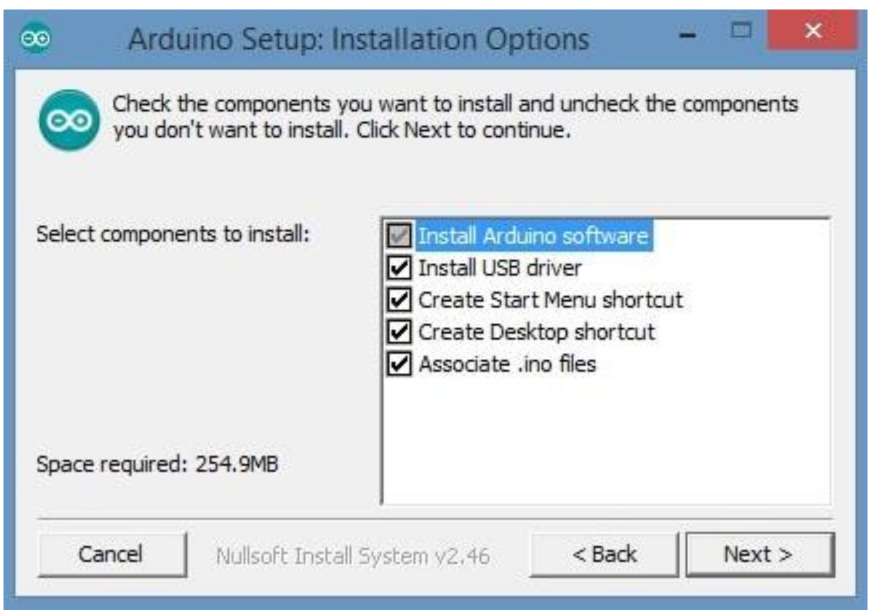


Fig 5.3 Arduino Setup: Installation options

6. Select which folder to install the program to, then click "Install":

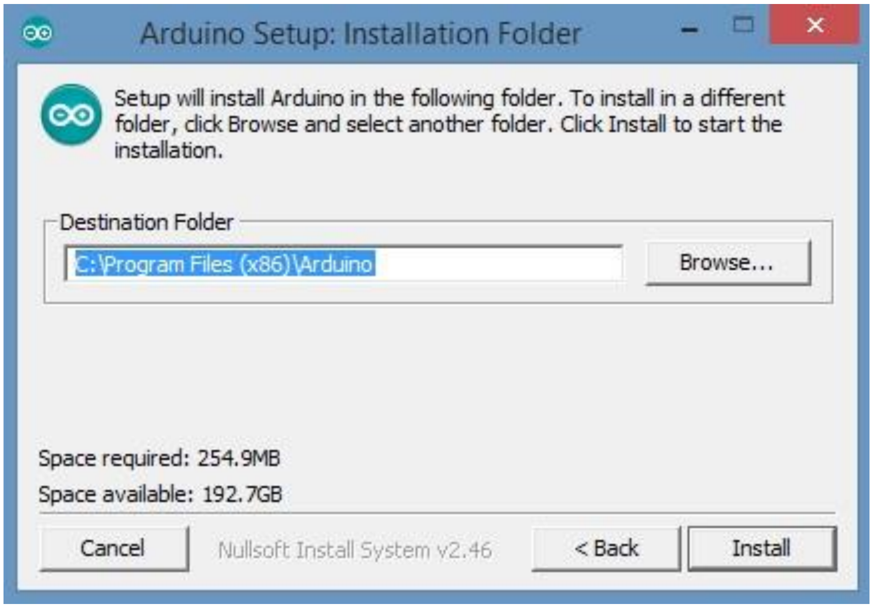


Fig 5.4 Arduino Setup: Installation folder

7. Wait for the program to finish installing, then click "Close".
8. Now find the Arduino shortcut on your Desktop and click on it. The IDE will open up and you'll see the code editor.

Libraries

Libraries are a collection of code that makes it easy for you to connect to a sensor, display, module, etc. For example, the built-in 'LiquidCrystal' library makes it easy to talk to character LCD displays. There are hundreds of additional libraries available on the Internet for download. To use the additional libraries, you will need to install them.

How to Install a Library?

Using the Library Manager

To install a new library into your Arduino IDE you can use the Library Manager (available from IDE version 1.6.2 and above). Open the IDE and click to the "Sketch" menu and then *Include Library > Manage Libraries*:

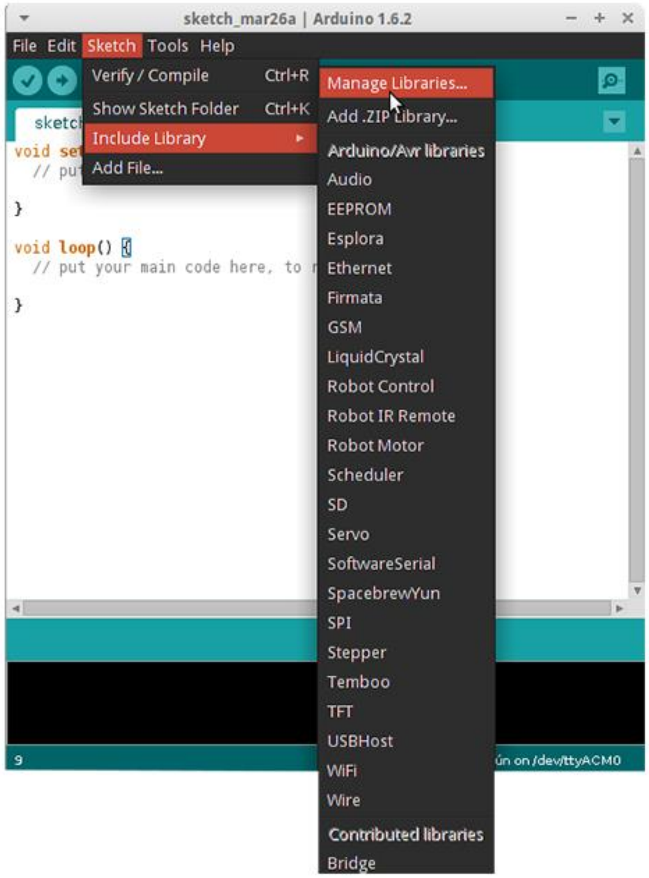


Fig 5.5 Arduino IDE: Include Library

Then the Library Manager will open and you will find a list of libraries that are already installed or ready for installation. In this example we will install the Bridge library. Scroll the list to find it, click on it, then select the version of the library you want to install. Sometimes only one version of the library is available:

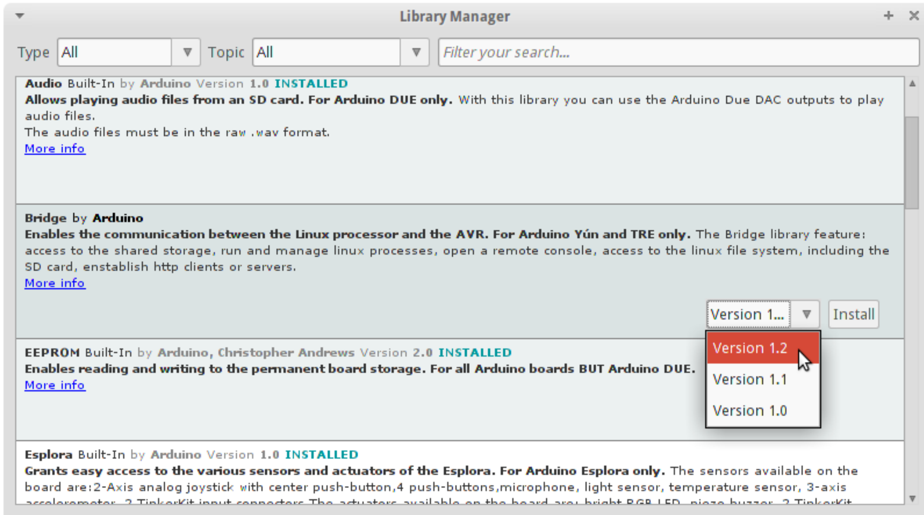
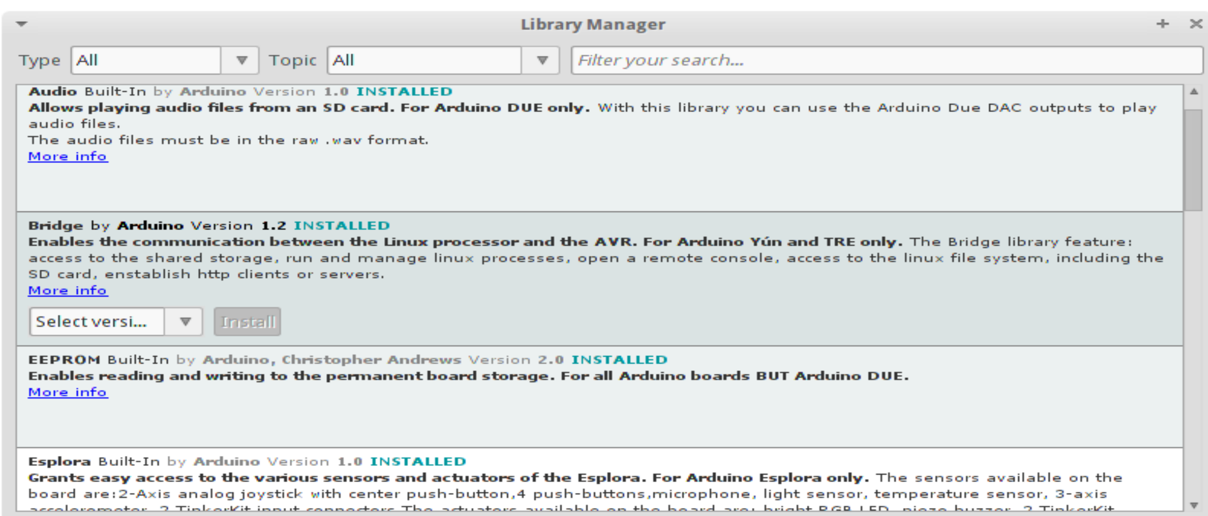


Fig 5.6 Arduino Setup: Library Manager

Finally click on install and wait for the IDE to install the new library. Downloading may take time depending on your connection speed. Once it has finished, an *Installed* tag should appear next to the Bridge library. You can close the library manager:



Teacher Notes:

- Tell students about the available interfaces on Arduino UNO.

You can now find the new library available in the *Sketch > Include Library* menu. If you want to add your own library to Library Manager, follow these instructions.

Importing a .zip Library

Libraries are often distributed as a ZIP file or folder. The name of the folder is the name of the library. Inside the folder will be a .cpp file, a .h file and often a keywords.txt file, examples folder, and other files required by the library. Starting with version 1.0.5, you can install 3rd party libraries in the IDE. Do not unzip the downloaded library, leave it as is.

In the Arduino IDE, navigate to *Sketch > Include Library > Add .ZIP Library*. At the top of the drop-down list, select the option to "Add .ZIP Library":

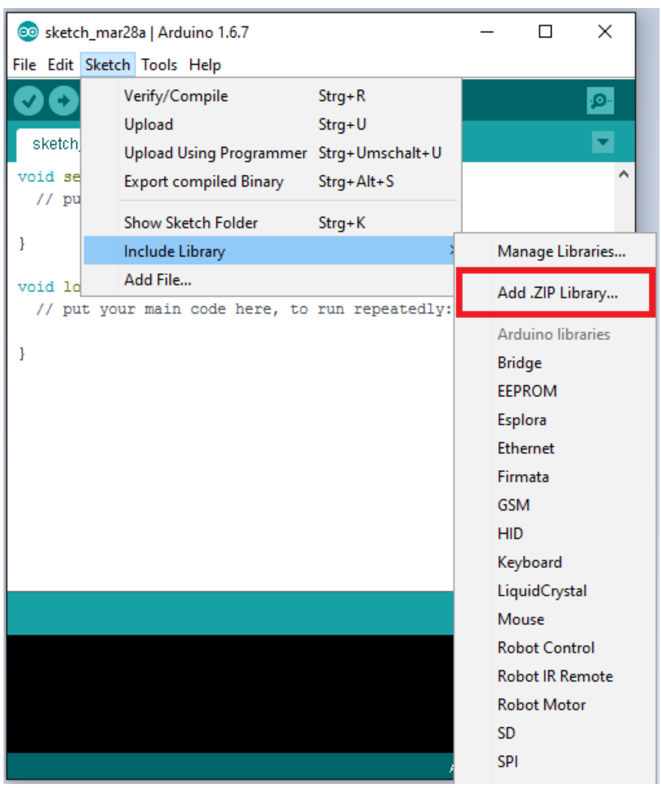


Fig 5.8 Arduino IDE: Adding .zip file of library

You will be prompted to select the library you would like to add. Navigate to the .zip file's location and open it:

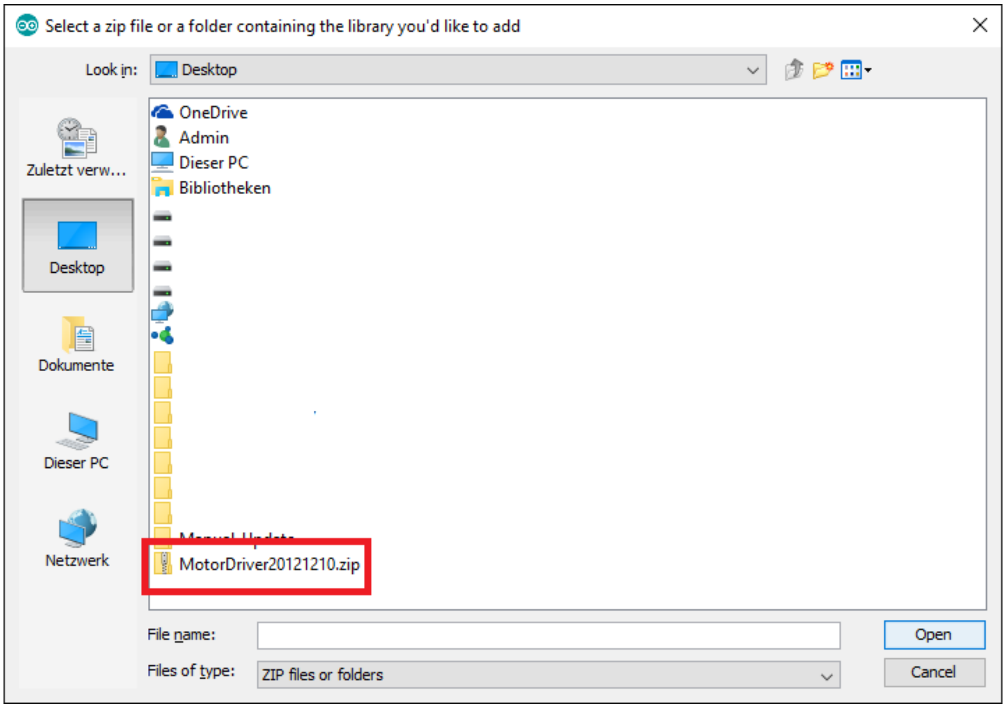


Fig 5.9 Arduino Setup: Selecting .zip file

Return to the *Sketch* > *Include Library menu*. menu. You should now see the library at the bottom of the drop-down menu. It is ready to be used in your sketch. The zip file will have been expanded in the *libraries* folder in your Arduino sketches directory.

5.4 Connecting an Arduino with Computer System

1. Connect Arduino to your computer

USB-Mini cable is used to connect Arduino to your computer. Different types of USB connectors are shown in figure:

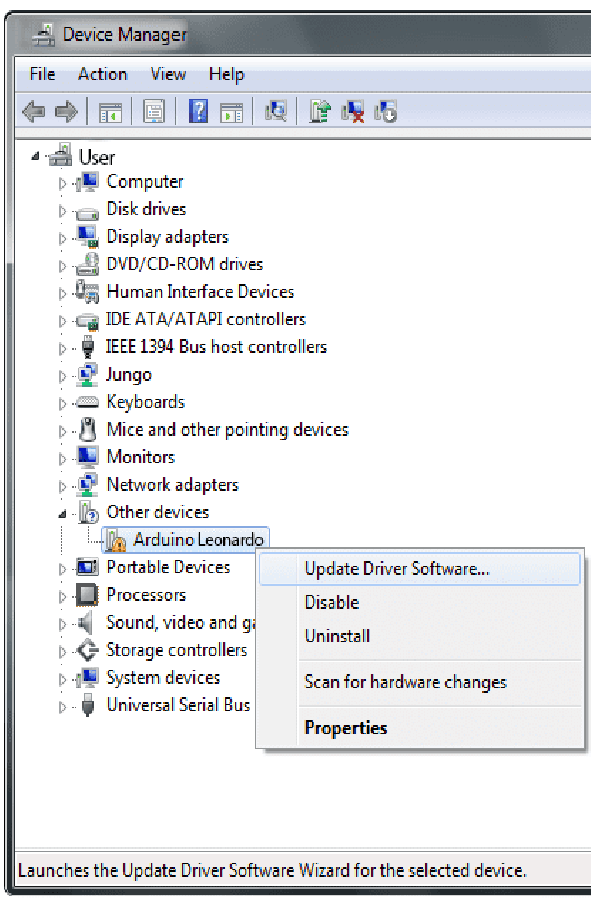
Fig 5.10 USB cables

2. Install/update USB-Serial Driver

The following instructions are for Windows 7, Vista and 10. They are also valid for Windows XP, with small differences in the dialog windows. In the following instruction only the Leonardo board will be mentioned, but the same procedure is valid for all the Arduino boards.

Plug in your board and wait for Windows to begin its driver installation process. If the installer does not launch automatically, navigate to the Windows Device Manager (Start>Control Panel>Hardware) and find the Arduino listing. Right click and choose **Update driver**:

Note: The following figure shows driver for Arduino Leonardo. Process of updating the driver is same for all boards.



Interesting Information

- A device driver is a software component that allows a hardware device to communicate with the operating system of a computer. Drivers allow an operating system to correct interpret and implements the signals that come from the hardware device.

Fig 5.11 Arduino Setup: Device manager: Update Driver

In the next screen, click "Browse my computer for driver software", and click **Next**.

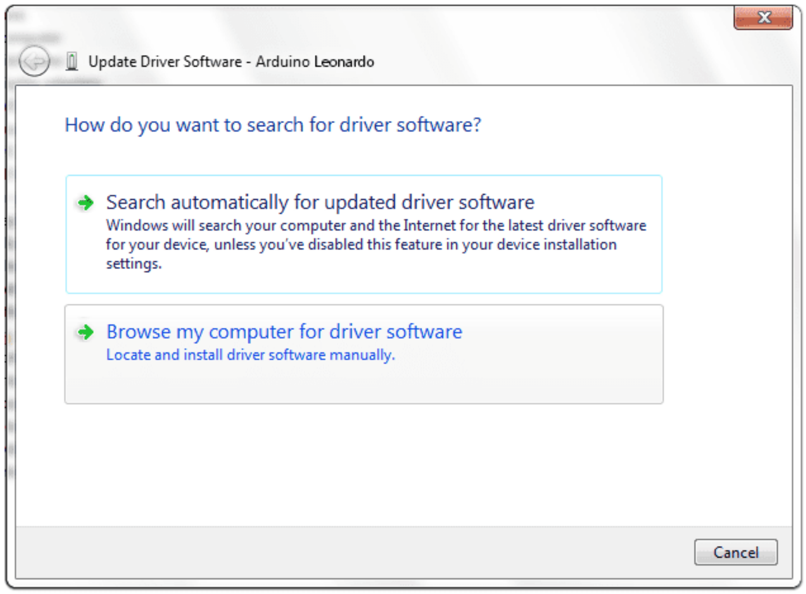


Fig 5.12 Arduino Setup: Update Driver

Click the **Browse** button. Another dialog appears: navigate to the folder with the Arduino software that you just downloaded. Select the **drivers** folder an click **OK**, then click **Next**.

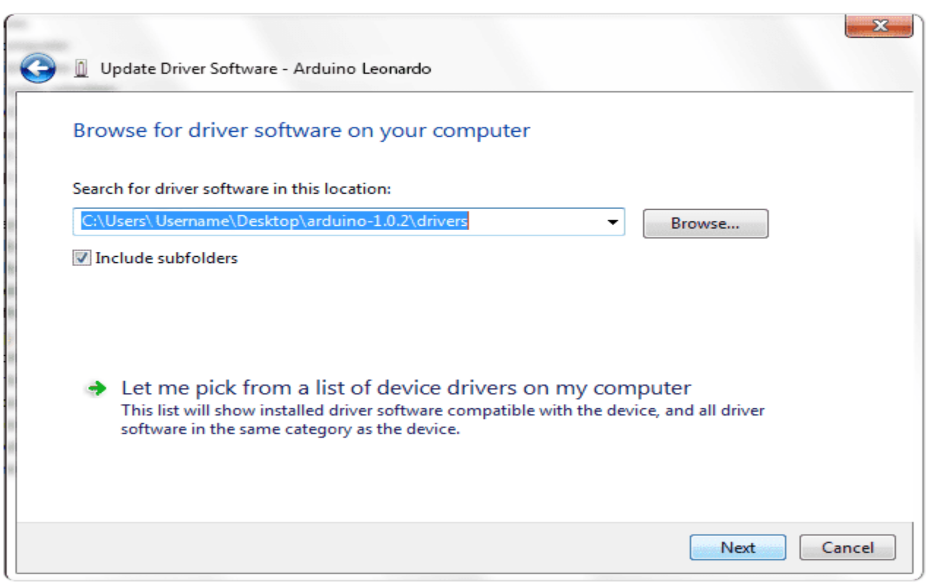


Fig 5.13 Arduino Setup: Select Driver

You will receive a notification that the board has not passed Windows Logo testing. Click on the button **Continue Anyway**.

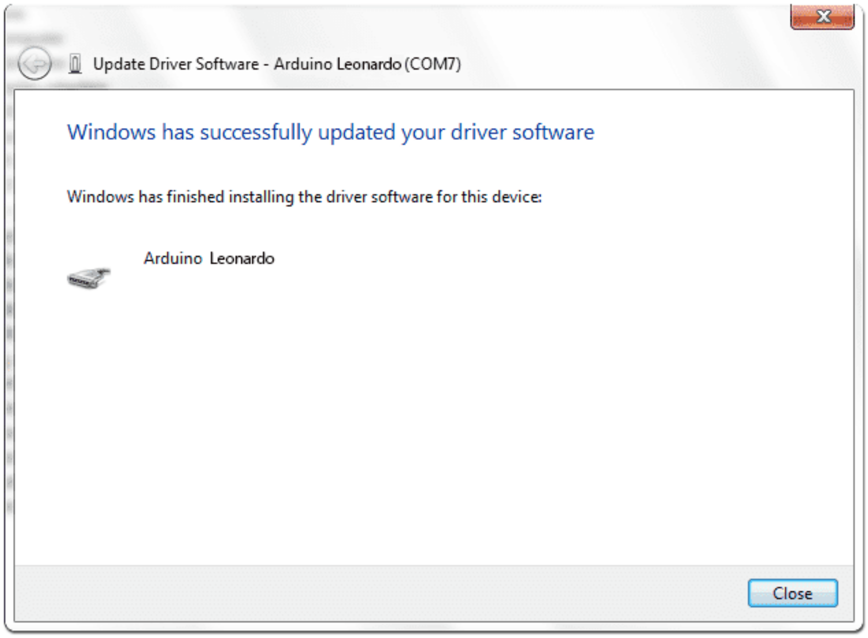


Fig 5.14 Arduino Setup: Driver installed

After a few moments, a window will tell you the wizard has finished installing software for Arduino Leonardo. Press the **Close** button.

5.5 Programming Arduino

Open the LED blink example sketch: File > Examples >01.Basics > Blink.

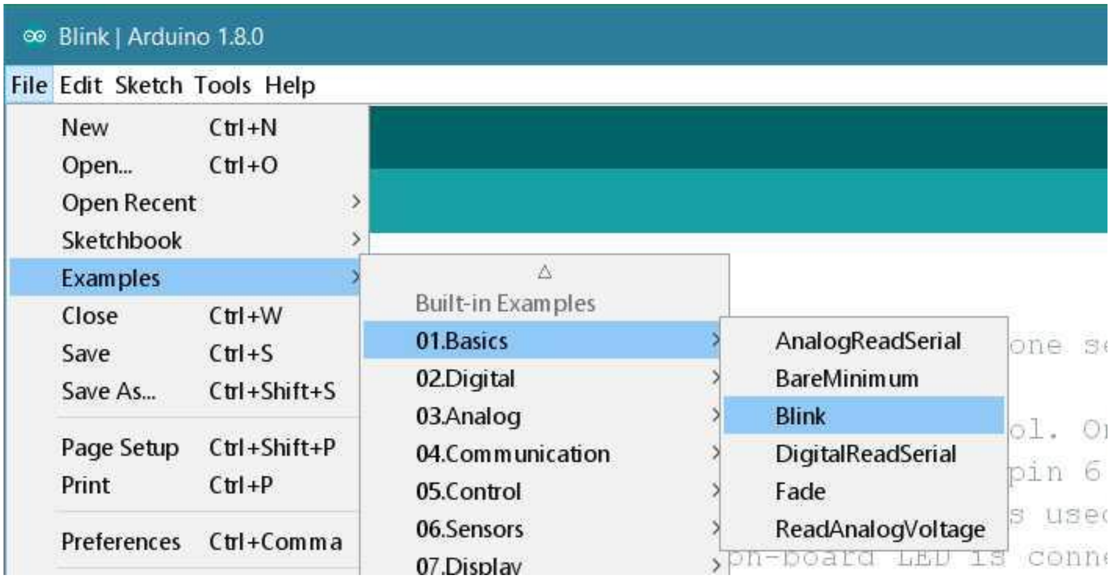


Fig 5.15 Arduino IDE: Blink Example

You'll need to select the entry in the **Tools > Board** menu that corresponds to your Arduino board.

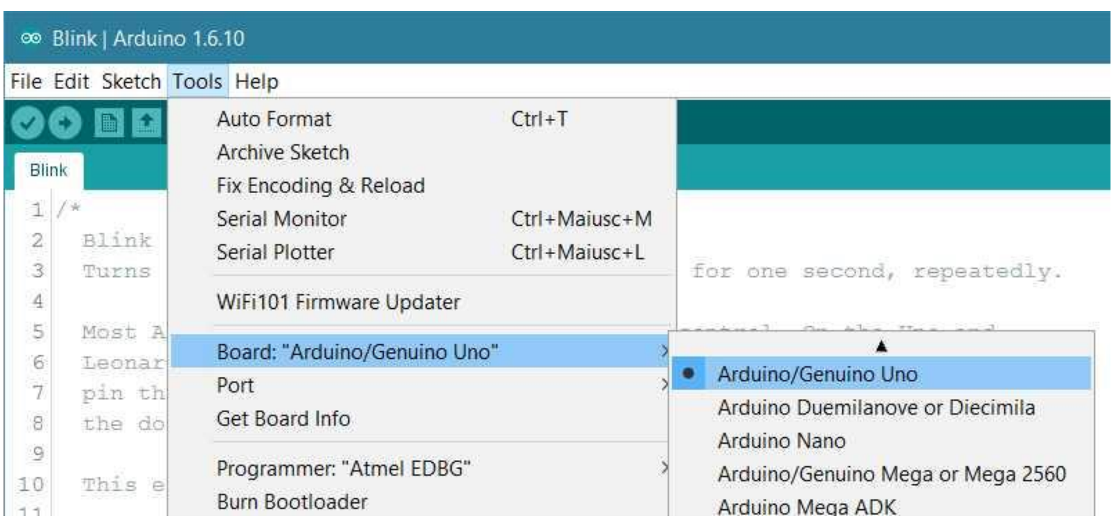


Fig 5.16 Arduino IDE: Select Board

Select the serial device of the board from the Tools | Serial Port menu. This is likely to be **COM3** or higher (**COM1** and **COM2** are usually reserved for hardware serial ports).

To find out, you can disconnect your board and re-open the menu; the entry that disappears should be the Arduino board. Reconnect the board and select that serial port.

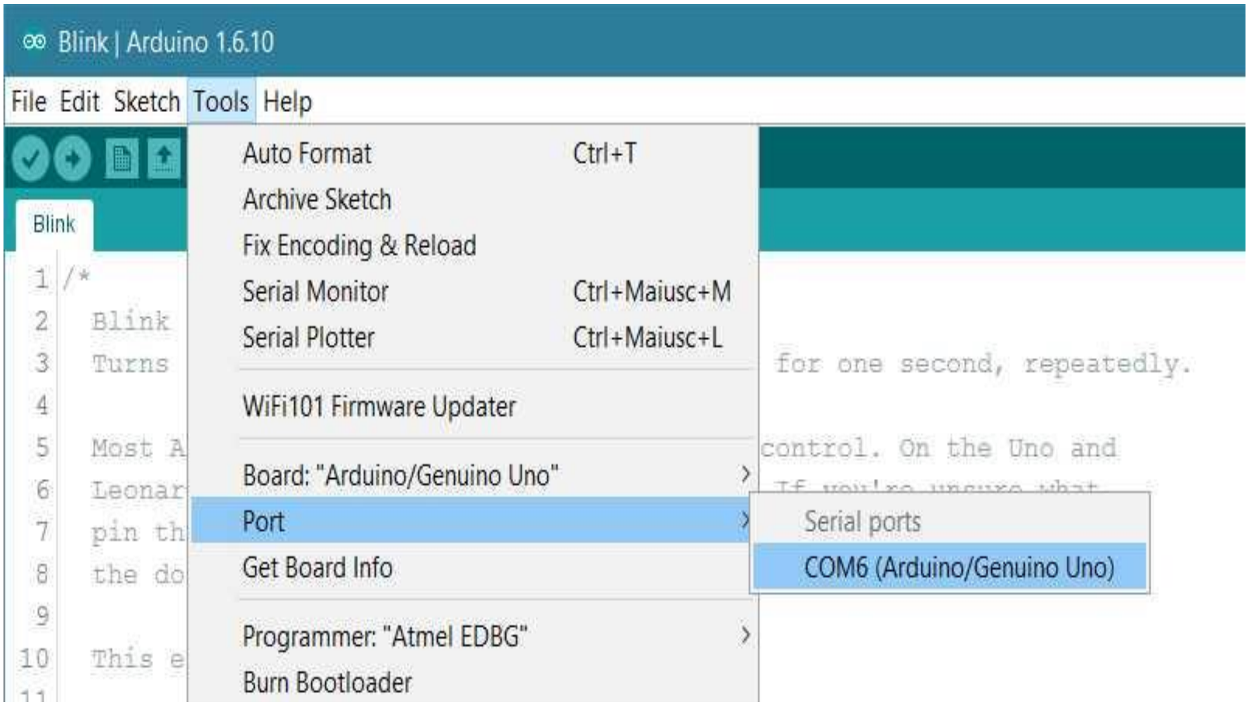


Fig 5.17 Arduino IDE: Select Port

Hardware Setup

Place the LED sensor in the breadboard. Connect a 220-ohm resistor to its anode and connect its pin to GND pin of Arduino. Connect a wire from the resistor to corresponding pin on Arduino (digital pin). Connect the Cathode of LED to GND of Arduino.

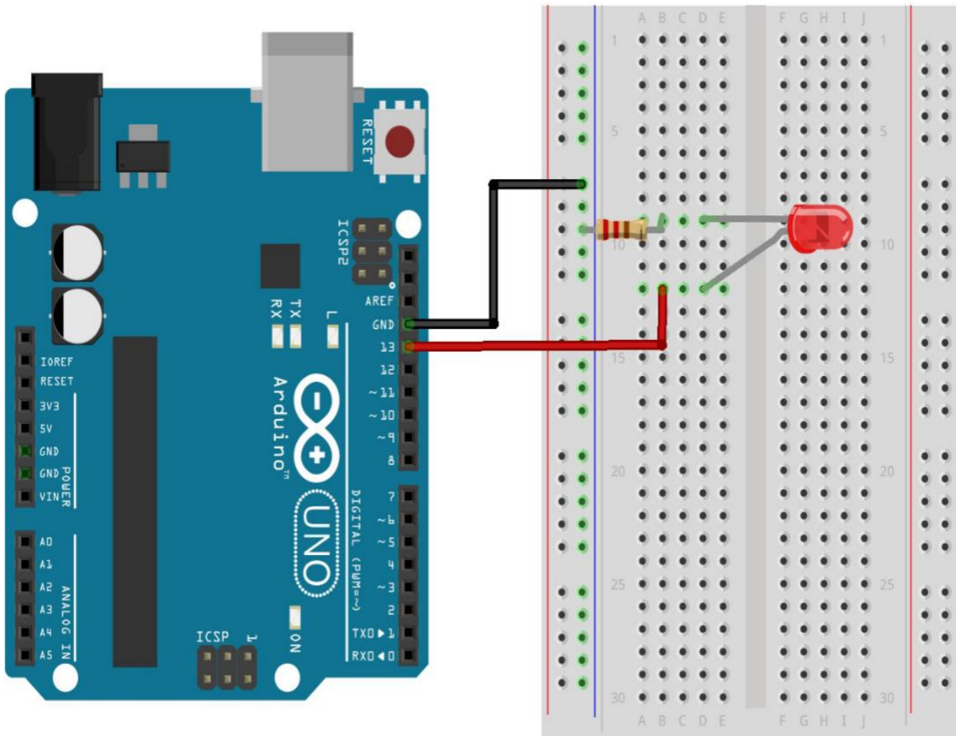


Fig 5.17 Arduino: Hardware Setup for Blink Example

Simply click the "Upload" button in the environment. Wait a few seconds - you should see the RX and TX LEDs on the board flashing. If the upload is successful, the message "Done uploading." will appear in the status bar.

Key Points

- A microcontroller has different ports which can be controlled using a program written by the user.
- Microcontroller contains peripherals i.e. RAM/ROM, I/O ports, EEPROM etc.
- A microprocessor contains no peripherals.
- IDE is used to write a code, compile code, burn the code and debug the program.
- A device driver is necessary to connect arduino with computer.
- Operating voltage of Arduino is 5V.
- Libraries are the ready-made programs/functions which can be added in the existing code according to the need.

Exercise

Multiple Choice Questions

1. A microcontroller contains the following perpherals:
   a. RAM & ROM b. I/O ports c. EEPROM d. All of these

2. Which of the following is not a Arduino board:
   a. Arduino UNO b. Arduino Leaonardo c. Arduino Nano d. None of these

3. Arduino operates at:
   a. 5V b. 3.3 V c. 20V d. Both a and b

4. Which of the following IDE is used for Arduino.
   a. Keil b. Microsoft Visual Studion c. Eclipse d. Arduino IDE

5. Which interfaces are available on Arduino
   a. UART b. SPI c. I2C d. All of these

Write short answer of the following.

1. Define microcontroller.
2. Differentiate between microcontroller and microprocessor.
3. Define IDE.
4. What are libraries and why are they used?
5. Name some arduino based boards.
6. Name some commonly used microcontrollers for IoT.
7. What is a device driver.
8. What do you mean by pin configuration?
9. What are I/O ports?
10. Name some I/O interfaces vailable on Arduino.

Activites.

1. Install Arduino IDE.
2. Install device driver for Arduino.
3. Add any library in Arduino IDE.
4. Connect an LED with Arduino and blink it using an example program.
5. Explore serial port. Print some text on serial monitor of Arduino IDE.

Chapter 6

Work Health and Safety

After Studying this chapter, you will be able to:

- understand basic rules and principles of WHS.
- introduce Ergonomics.
- understand legal obligations and work ethics regarding health and safety.
- identify common workplace hazards.
- manage workplace hazards.
- follow organizational WHS and other relevant policies, procedures andprocesses.
- understand the scope of project.
- identify techniques of the risk profile for all stakeholders.
- identify Clients Health and safety specifications SOPs.
- understand development techniques of health and safety plan.
- implement techniques of health and safety plan.

Chapter 6

6.1 Basics of Work Health and Safety

6.1.1 Safe and healthy work environment

The workspaces and production methods, in a good working environment, have been designed and implemented in such a way that workers can work and move around safely. Workers are familiar with the hazards and risks related to the raw materials used in the work and the substances produced in the work processes. They are well trained to control them efficiently. The machines and tools used in the work suit their purposes. Employees' physical and mental preconditions are taken into account while planning and scaling the work.

Workspaces and Passageways in a Safe Environment

In a safe working environment:

- Structural aspects of the work environment take into account the safety of passageways, workplace lighting, sound environment and indoor air quality.
- Functional factors include the organization of transportation and keeping workspaces and offices organized and neat.

Order and cleanliness

Cleanliness contributes to the safety and health of the workplace.Therefore, it is a top priority. Slipping and tripping caused by the disorder or untidiness of the workplace make up a significant portion of workplace accidents. Special consideration must be paid to the identification and management of physical, chemical and biological health hazards in the workplace. Work machinery, equipment and tools must be in good working order, and they may be used only for the planned work and under the intended conditions. The necessary personal protective equipment and assistive devices must also be in good working order and used only for the planned situation.

Fig 6.1 Example of a good working environment

6.1.2 Rules and Principles of Work Health and Safety

- All people are given the highest level of health and safety protection that is reasonably practicable.
- Those who manage or control activities that give rise, or may give rise, to risks to health or safety are responsible for eliminating or reducing health and safety risks.
- Employers and self-employed people should be proactive and take reasonably practicable measures to ensure health and safety in their business activities.
- Employers and employees should exchange information about risks to health and safety and measures that can be taken to reduce those risks.
- Employees are entitled, and should be encouraged, to be represented on health and safety issues.

6.1.3 Ergonomics

Ergonomics is the process of designing or arranging workplaces, products and systems so that they fit the people who use them. Ergonomics applies to the design of anything that involves people – workspaces, sports and leisure, health and safety. Itis a branch of science that aims to learn about human abilities and limitations, and then apply this learning to improve people's interaction with products, systems and environments.

Ergonomics helps to improve workspaces and environments to minimize risk of injury or harm. Ergonomics should be applied to design amenities of a working environment. As technologies change, so does the need to ensure that the tools we access for work, rest and play are designed for our body's requirements.

Fig 6.1 Ergonomically Designed Chair

6.1.4 Obligations and Ethics towards WHS

Some simple steps to remember when considering ethics in WHS profession are:

- Follow the governmental requirements, laws, guidelines, as well as company principles and policies when conducting WHS related tasks and making decisions.
- Be transparent in communicating data, findings, recommendations to the respective management.
- Follow the code of ethics of the relevant professional association and/or accreditation body and report any incident
- Detach personal judgement, thoughts and ideas from professional setting as much as possible.
- Support and follow WHS values and principles

6.1.5 Common Workplace Hazards

The six main categories of hazards are:

- **Biological**: Biological hazards include viruses, bacteria, insects, animals, etc., that can cause adverse health impacts. For example blood and other bodily fluids, harmful plants, sewage, dust and vermin.
- **Chemical**: Chemical hazards are hazardous substances that can cause harm. These hazards can result in both health and physical impacts, such as skin irritation, respiratory system irritation, blindness, corrosion and explosions.
- **Physical**: Physical hazards are environmental factors that can harm an employee without necessarily touching them, including heights, noise, radiation and pressure.
- **Safety**: These are hazards that create unsafe working conditions. For example, exposed wires or a damaged carpet might result in a tripping hazard. These are sometimes included under the category of physical hazards.

- **Ergonomic**: Ergonomic hazards are a result of physical factors that can result in musculoskeletal injuries. For example, a poor workstation setup in an office, poor posture and manual handling.
- **Psychosocial**: Psychosocial hazards include those that can have an adverse effect on an employee's mental health or wellbeing. For example, sexual harassment, victimization, stress and workplace violence.

6.1.6 Managing Workplace Hazards

If it is not possible to eliminate the hazard.Below are six steps to determine the most effective measures to control workplace hazards and to minimise risk.

Step 1: Design or re-organise to eliminate hazards.

Step 2: Substitute the hazard with something safer.

Step 3: Isolate the hazard from people.

Step 4: Use engineering controls.

Step 5: Use administrative controls.

Step 6: Use Personal Protective Equipment (PPE).

6.1.7 Purpose of Organizational Policies, Procedures and Processes

The purpose of organizational policies, procedures, processes and systems for WHS are to establish the practices and standards that a company will follow in regards to compliance with Work Health & Safety guidelines.

- These company policies and procedures will ensure that the company is in full compliance with the legislative requirements concerning work health & safety for employees
- The policies will create a safe work environment for all employees and will reduce the cost the company has for sending employees to see doctors after accidents, and will reduce the insurance costs of the company because of their safety rating

- The establishment of the policies will create better work relationships between company owners, and their employees. The employees will know that the company is trying to protect them from injury

6.2 WHS in IoT Environments

6.2.1 Understand the Scope of Project

IoT working environments demand extreme precautions while handing IoT equipment. The first and foremost requirement is to understand the scope of the project i.e. to understand the product development cycle. For instance what processes will be involved in designing an IoT product or project. Some IoT projects will be hardware based, some will be software based. So, WHS requirements will vary for different IoT projects.

6.2.2 Risk Profile for different Stakeholders

Different teams are involved in the development of an IoT system i.e., software team, electronics team, PCB team and QA etc. So, WHS requirements will vary for the different teams. For example, WHS principle for software team will be different as compared to that of hardware team.

6.2.3 Client's Health and Safety SOPs

There is always a need to develop SOPs to operate the IoT product or system. These SOPs will be helpful for the client's health and safety. IoT devices have different contexts and require separate SOPs for each application. For example, smart homes and smart cities will require different SOPs for the smooth and safe operation of an IoT system. For instance, an IoT sensor device which is installed in the pantry should have strict SOPs regarding the installation and operation of device. SOPs will be such as: The IoT device installed in the pantry should be at a defineddistance from the hearth, and it should not be installed in the path of smoke etc.

6.2.4 Development Techniques of Health and Safety Plan

Development of health and safety plan in IoT working environment is directly related to the design of IoT devices i.e., what is the maximum temperature the device can bear; Water resistivity of the device; working temperature range of components (sensors and actuators) installed in the device; and operating current and voltage of the device etc. All these design parameters will lead to a successful health and safety plan.

Fig 6.3Example of a good IoT enabled environment

6.2.4 ImplementationTechniques of Health and Safety Plan

Nowadays IoT devices are being used to monitor work health and safety SOPs. To better implement the health and safety plan in an IoT working environment, some IoT devices must be dedicated to sense and report the cases where SOPs are not followed. For instance, tools in an IoT working environment can be synchronized with the personal protective equipment. Tools will not turn on unless the personal protective equipment is worn. Figure 6.1 shows an example of intelligent personal protective equipment.

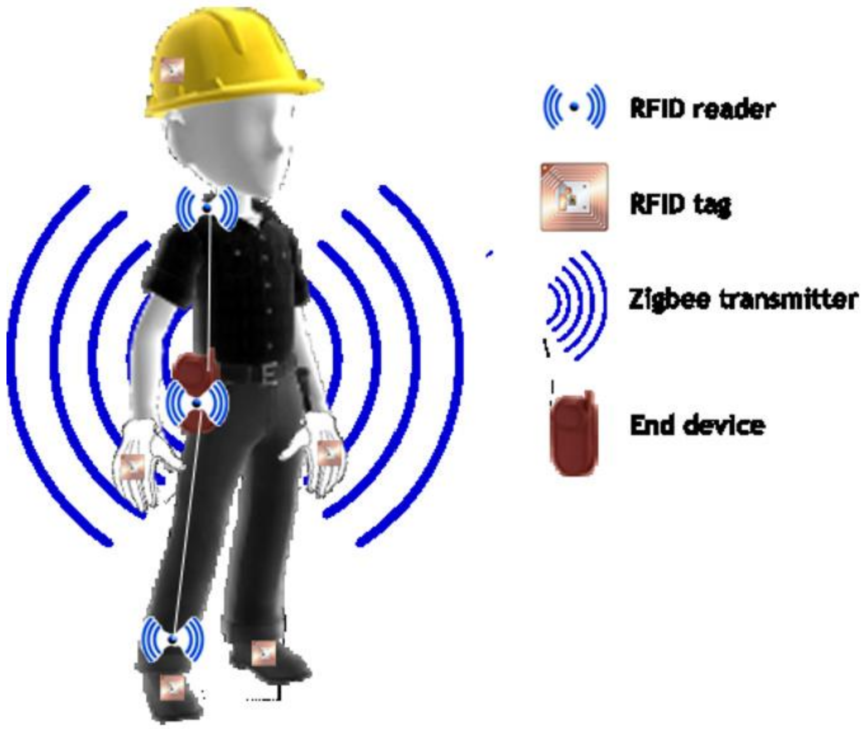


Fig 6.4IoT based protective equipment

Key Points

- Structural aspects of the work environment should take into account the safety of passageways, workplace lighting, sound environment and indoor air quality.
- Functional factors of the work environment must include the organization of transportation and keeping workplaces and offices organized and neat.
- Those who manage or control activities that give rise, or may give rise, to risks to health or safety are responsible for eliminating or reducing health and safety risks.
- Employers and employees should exchange information about risks to health and safety and measures that can be taken to reduce those risks.
- Psychosocial hazards include those that can have an adverse effect on an employee's mental health or wellbeing.

Exercise

Write short answer of the following

1. Define ergonomics.
2. Describe electrical hazards.
3. Enlist hazards involved in an electronics work environment.
4. What are the hazards involved with the handling of IoT devices?

Answer the following question in detail.

1. Describe basic rules and principles of WHS.
2. Describe Ergonomics.
3. What are common workplace hazards?
4. How workplace hazards should be managed?
5. What are the WHS requirements for IoT workplaces?
6. What are the implementation techniques for WHS in IoT environments?

Glossary

Amenities: A desirable or useful feature or facility of a building or place.

Atoms: Atoms are the basic units of matter and the defining structure of elements.

Charge Conservation: In physics, charge conservation is the principle that the total electric charge in an isolated system never changes. The net quantity of electric charge, the amount of positive charge minus the amount of negative charge in the universe, is always conserved.

Clock: A clock signal (historically also known as logic beat) oscillates between a high and a low state and is used like a metronome to coordinate actions of digital circuits.

Closed Loop: A closed loop is a portion of an electric circuit which have a closed path for the flow of current.

Diffusion: Diffusionprocess results from random motion of molecules by which there is a net flow of matter from a region of high concentration to a region of low concentration

Diluted Electrolyte: Electrolytes having low concentration of free ions

Dimension: A measurable extent of a particular kind, such as length, breadth, depth, or height.

EEPROM:EEPROM (electrically erasable programmable read-only memory) is user-modifiable read-only memory (ROM) that allow users to erase and reprogram stored data repeatedly in an application.

Electric Force: The attractive or repulsive interaction between any two charged objects is an electric force.

Electric Grid: An electrical grid is an interconnected network for electricity delivery from producers to consumers.

Electron: The electron is a subatomic particlewhose electric charge is negative one elementary charge.

Electrostatic Force: The electric force between charged bodies at rest is conventionally called electrostatic force.

Generator: Voltage generators are modelled as an ideal voltage source in series with a resistor.

Hazard:A hazard is a source or a situation with the potential for harm in terms of human injury or ill-health, damage to property, damage to the environment, or a combination of these.

Hole: Hole is the lack of an electron at a position where one could exist in an atom.

IC: An integrated circuit or monolithic integrated circuit (also referred to as an IC, a chip, or a microchip) is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material, usually silicon.

Impedance: Impedance is the opposition to alternating current presented by the combined effect of resistance and reactance in a circuit.

Instruction Set: An instruction set is a group of commands for a CPU in machine language.

I/O Port: The input/output port is a memory address used by software to communicate with hardware on your computer.

Kinetic Energy: Kinetic energy, form of energy that an object or a particle has by reason of its motion.

Oxidation-Reduction Reaction: An oxidation-reduction (redox) reaction is a type of chemical reaction that involves a transfer of electrons between two species.

Rating: Ratings are the maximum and minimum values of electrical quantities compatible with a specific component.

Raw Materials: Raw materials are the input goods or inventory that a company needs to manufacture its products.

Risk:A risk is the chance of something happening that will have a negative effect.

Sensitivity: Sensitivity is a measure of how well a test can identify true positives and specificity is a measure of how well a test can identify true negatives.

SOP:A standard operating procedure (SOP) is a set of step-by-step instructions compiled by an organization to help workers carry out routine operations.

Substrate: A substrate is the medium in which a chemical reaction takes place

Unit of measurement:A unit of measurement is a definite magnitude of a quantity, defined and adopted by convention or by law, that is used as a standard for measurement of the same kind of quantity.

Valence Band: The valence band is the band of electron orbitals that electrons can jump out of, moving into the conduction band when excited.

About the Author

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قومی ترانہ

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تو نشانِ عزمِ عالی شان ارضِ پاکستان
مرکزِ یقین شاد باد!

پاک سر زمین کا نظام قوّتِ اُخوّتِ عوام
قوم ، مُلک ، سلطنت پائندہ تابندہ باد!
شاد باد منزلِ مُراد!

پرچمِ سِتارہ و ہلال رہبرِ ترقی و کمال
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