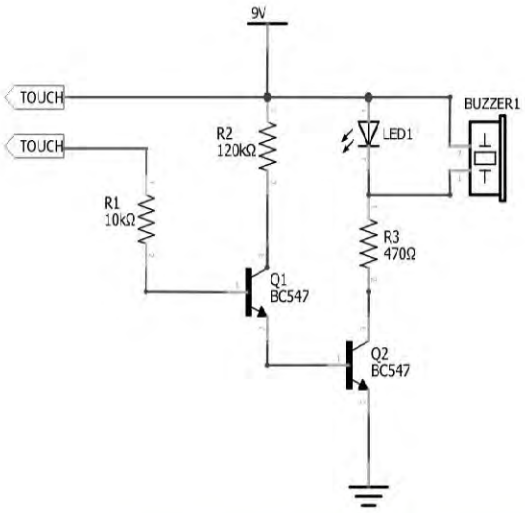
BASIC ELECTRONICS and PROJECT MANUAL

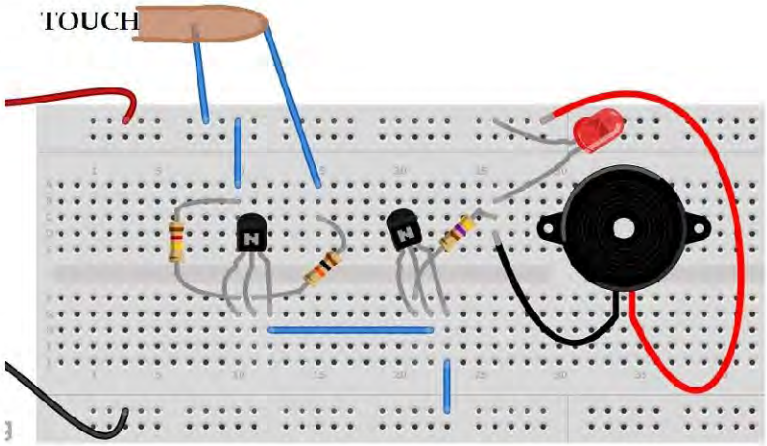
A step-by-step guide to learning electronics

Oluwatayo Somotun
Uchenna Okeke

BASIC ELECTRONICS AND PROJECT MANUAL

A step-by-step guide for anyone to start learning electronics.





CONTAIN EXPERIMENTS THAT WILL OPEN UP YOUR MIND TO TECH CREATIVITY AND INNOVATIONS SUCH AS; LIGHT DISPLAY, FAN WITH CONTROL, TOY CAR MOTION CONTROL, PHONE CHARGER, FLASHING LIGHT, SIMPLE AMPLIFIER, LIGHT CONTROLLED SWITCH AND LOTS MORE

EDUSOD

PROJECT EXODUS

OLUWATAYO SOMOTUN

UCHENNA OKEKE

BASIC ELECTRONICS AND PROJECT MANUAL

A step-by-step guide for anyone to start learning electronics.

By

Oluwatayo Somotun

Uchenna Okeke

EDUSOD Logistics Service

...LEARN, APPLY AND DEVELOP

Basic Electronics and Project Manual
A step-by-step guide for anyone to start learning electronics.
By Oluwatayo Somotun and Uchenna Okeke

DISCLAIMER

While the author has used good faith efforts to ensure that the information and instructions contained in this work are accurate, the author disclaim all responsibility for errors or omissions, including without limitation responsibility for damages resulting from the use of or reliance on this work. Use of the information and instructions contained in this work is at your own risk.

CREDITS

The CAD software for schematic and breadboard design is an open-source initiative called **Fritzing**. For more information about this tool, please visit https://fritzing.org.
Photo credit to the owners of original images and pictures used in this book obtained from the internet.

SAFETY WARNING

This book is suitable for personal and instructional purposes

Not suitable for children under **4 years** of age

Adult supervision is required for younger users

Always observe **safety** precautions at all times - "**Safety First**"

No part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written permission of the author, with the exception that the program listings may be entered, stored, and executed in a computer system, but they may not be reproduced for publication.

© 2018 By EDUSOD Logistics Services. All rights reserved.

For supports, training resources and other services from EDUSOD Logistics Services, contact;

Tel: 08094244576, 07015813133

Email: edusodservices@gmail.com

DEDICATION

This book is dedicated to the Most High God; the Father, the Son and the Holy Ghost.

ACKNOWLEDGEMENT

I, Oluwatayo Somotun appreciate Uchenna Okeke and Tosin Oluwunmi for their contribution and dedication in making these resources available through the EDUSOD Logistics Services. We could not have had this opportunity while growing up but we definitely believe that through our little contributions, we could help someone on the path to fulfilling his/her dreams in life.

My profound gratitude goes to Mr. and Mrs. P.O. Somotun, Mr. and Mrs Okeke, Mr. and Mrs. Oluwunmi, our siblings and relatives.

I also like to appreciate the immerse contributions of Mr. Femi Oluwaferanmi in this work and for setting an example for us through the **Reality Tech Training Centre, Abeokuta**.

To all those who have given brilliant ideas and objective insights for the actualization of this work Pastor Festus Owara, Michael Oyegbola, Victor Choji, Rasheed Sholanke, Tumininu Adeyiga, Michael Adedeji to mention but a few, we say thank you all.

To the Rev. E. K Ajose and other past Priests and members of St. John's Anglican Church Aboru, I appreciate you all.

I will also like to appreciate all the staffs of the Department of Physics, University of Lagos, who have made efforts in adding value to our lives.

Finally, to everyone who sees possibilities in life; everyone who is ready to make trials and learn from mistakes until the goal is achieved; everyone who will not despair; let us know that better days are ahead.

If we believe, with passion and focus, we can achieve the unimaginable!

THANK YOU.

TABLE OF CONTENT

Introduction.....viii
How To Use This book..... ix

SECTION ONE: THEORY

PART 1.....2
Chapter 1.....3
1.0 The breadboard.....3
1.1 Sizes of breadboards.....4
1.2 Other features of the breadboard.....4
1.3 Wires, cables and connectors.....6
1.4 Common breadbord connection mistakes.....7
1.5 Making permanent connection.....7
Chapter 2.....8
2.0 The multimeter.....8
2.1 Types of multimeters.....8
2.2 Parts of a multimeter.....8
Chapter 3.....10
3.0 Cells and Batteries.....10
3.1 How a battery works.....11
3.2 Water analogy of the operation of a battery.....11
3.3 Describing a battery.....12
3.4 DC sources.....12
3.5 Ways of producing dc.....13
3.6 Application of dc.....13
3.7 AC sources.....14
3.8 Application of ac.....14
3.9 Electricity, voltage, current, resistance and ohm's law.....15
3.9.1 Voltage.....17
3.9.2 Current.....17
3.9.3 Resistance.....18
3.9.4 Ohm's law.....18
Chapter 4.....20
4.0 Resistors.....20
4.1 Resistor units.....20
4.2 Resistor types and circuit symbols.....21
4.3 Resistor categories.....21
4.4 Understanding resistor color codes.....22
4.4.1 Four-band colour code.....22
4.5 Resistor power rating.....24

4.6 Basic functions of resistors in a circuit.....24
4.7 Resistance, resistivity and conductance.....25
4.8 Electrical energy, power and current heating effect.....27
4.9 Power consumer and producers.....28
4.9.1 How to calculate power.....28
4.9.2 Power and ohm's law relationship.....29
4.10 Heating element.....30
4.11 Understanding power rating.....30
Chapter 5.....31
5.0 Light Emitting Diode (LED).....31
5.1 What are leds?.....31
5.2 Filament bulb vs led.....31
5.3 Types of led.....32
5.4 How an led works.....32
5.5 Led forward voltage and maximum current.....33
5.6 Understanding electric circuit and schematics.....34
5.6.1 Short circuit.....35
5.6.2 Open circuit.....35
5.7 Understanding circuit schematics.....36
5.8 Tips for proper circuit schematics or diagram drawing.....37
Chapter 6.....39
6.0 Fuses.....39
6.1 How a fuse works.....39
6.2 Types of fuse.....40
6.3 Safety handling tips.....41

PART 2.....**42**
Chapter 7.....43
7.0 Series and Parallel.....43
7.1 Series arrangement.....43
7.2 Parallel arrangement.....44
7.3 Calculating total resistance in series arrangement.....45
7.4 Calculating total resistance in parallel arrangement.....46
7.5 Combining series and parallel connections.....47
7.6 Cells in series and parallel arrangement.....47
Chapter 8.....49
8.0 Variable resistors and voltage divider.....49
8.1 Variable resistors.....49
8.2 Voltage divider.....50
8.3 Voltage divider equation.....51
Chapter 9.....52

9.0 Capacitors.....52
9.1 Unit of a capacitor.....53
9.2 Making a capacitor.....53
9.3 Factors affecting the capacitance of a capacitor.....54
9.4 Internal working of a capacitor.....56
9.5 Charging and discharging of a capacitor.....57
9.6 Energy stored in a capacitor.....58
9.7 Capacitor value calculator.....59
9.8 Capacitor specifications.....60
9.9 Types of capacitors.....60
9.10 Capacitors in series and parallel arrangement.....61
9.10.1 Capacitor in parallel.....62
9.10.2 Capacitors in series.....62
9.11 Basic function of capacitors in a circuit.....62
9.12 Circuit troubleshooting guide.....64

PART 3.....65
Chapter 10.....66
10.0 Switches.....66
10.1 How does a switch works.....66
10.2 Switch characteristics and description.....67
Chapter 11.....69
11.0 Relays.....69
11.1 How an electromagnetic relay works.....69
11.2 Describing a relay.....70
11.3 Types of electromechanical relay packages.....71
11.4 Using relays in circuits.....71
11.5 Introduction to electromagnetism.....72
Chapter 12.....73
12.0 Diode and transistor.....73
12.1 Diodes.....74
12.1.1 How to use a diode.....74
12.1.2 Diode specifications.....76
12.1.3 Diode applications.....78
12.2 Transistors.....79
12.2.1 Bipolar Junction transistors (BJT).....79
12.2.2 Bipolar Junction transistors (BJT) construction and pins.....79
12.2.3 Transistor operation.....80
12.2.4 Different operation modes of a transistor.....81
12.3 Transistor packaging types.....83
12.4 Simple transistor applications.....87

12.4.1 Transistor switch.....87
12.4.2 Transistor as an amplifier.....89
12.4.3 Transistor Configurations.....89
12.5 Other useful Transistor circuits.....92

SECTION TWO: EXPERIMENTS

COMPONENT PARTS LIST.....95
LIST OF EXPERIMENTS.....98
EXPERIMENT 1-30.....99 - 262
APPENDIX.....264

INTRODUCTION

We're living in an age of Information Technology. Electronics is at the very heart of the Information and Computer age. Electronics has made deep impacts in several vital areas such as ICT, Entertainment, Agriculture, Medical diagnosis and treatment, Transportation, Air and space travel etc

It is sometimes unbelievable, how many electronic gadgets we carry these days such as digital wristwatches, calculators, mobile phones, digital cameras, video cameras and so on. There are even other electronic devices we now operate in our homes and offices.

In short, the economic developments of several countries are directly linked to their technological strengths in form of designs, manufacturing and services of various electronic devices. So, apart from learning how to read and write, electronics has become an essential part of a modern society. We therefore need to develop a very good knowledge of electronics in our country so as to favorably compete with other developed nations.

Thus, Electronics has become a "Basic Science". Just as we teach Physics, Chemistry, Biology and Mathematics in our Primary and Secondary schools. It is high time we started teaching our children electronics as a separate subject by itself as this will be important for indigenous technological literacy and development. If one wants to gain a good understanding of electronics, he or she should have a hands-on skill on how to build circuits and solve problems with it.

EDUSOD Logistic Services has therefore organized BASIC ELECTRONICS AND PROJECT MANUAL, for personal and instructional purposes. This manual will be useful for acquiring basic practical knowledge of the characteristics of different electronic devices and hands-on construction of various circuits. This book is focused on providing the knowledge required to have a foundational understanding of electronics.

EDUSOD Logistics Service

...LEARN, APPLY AND DEVELOP

I Hear and I Forget,
I See and I Remember,
I Do and I Understand
...Confucius

HOW TO USE THE BOOK

- **CHAPTER INFORMATION:**

  This book is divided into two parts; **Section One** and **Section Two**. Section One is divided into **three (3) parts** with a total of **twelve (12) chapters**. It forms the introduction to Electrical/Electronic concepts and devices that will we come across in the experiments included in this book and in other related studies.

  Section Two is where we will be involved in setting up a total of **thirty (30) experiments** which have been selected to equip the users with different knowledge of making an electronic circuit on breadboard. Each experiment is a hands-on activity to be done with the kit provided and requires active participation for better understanding.

- **CONTENT INFORMATION:**

  WARNING: Whenever you see warning information, it is very important to strictly observe the instruction given. An example of warning sign and information is shown below.

WARNING: Working with AC current and voltage from wall socket at homes or any other AC source without proper safety...

NOTE: Notes are given to draw attention to and give extra information about a concept or device and possible results for an action taken. An example of a note is shown below

NOTE: Conventional current flows from the positive (+) to the negative (-) electrode while the actual electron flow is from the negative (-) to the positive (+) electrode.

CONNECTION TABLE: the section two contains experiment connection table which contain the information on the type of devices, device images, connection information and the position of components on the breadboard which have well labelled for easy setup. An excerpt of such table is show below.

Component name and value	Component image and label	Connection Description	Breadboard connection	Notes
Battery connector (9V Clip)		Connects to the power rails on the breadboard	Red(+)=> W3 Black(-)=> Y3	1. Power Rail are represented by alphabets W, X, Y and Z starting from the top
Jumper wire 1			J1(A) =>W8 J1(B) =>C9	

SECTION ONE

THEORY

ELECTRONICS: HELLO WORLD!

PART 1

Welcome! This is where we begin our journey into the world of electronics. In this humble beginning, we will be introduced to devices and concepts that will form the foundation for the various applications and developments in electronics.

I encourage you to learn by actively participating in the various activities taught and also get involved in setting up the various experiments in this book for concrete understanding of the devices and concepts.

CHAPTER 1 THE BREADBOARD

Breadboards are one of the most fundamental pieces when learning how to build circuits. It can be a very useful tool for both beginners and advanced electronic hobbyist. Breadboard is a solderless board for setting up temporary circuits and for prototyping (testing and modifying of circuits).

It has array of small sockets arranged vertically and horizontally. The components are inserted into the sockets in order to make connections. In the early years of circuit design, electronic hobbyists used the kitchen breadboard for prototyping and that brought about the name "breadboard".

Figure 1-1 Circuit on Kitchen breadboard

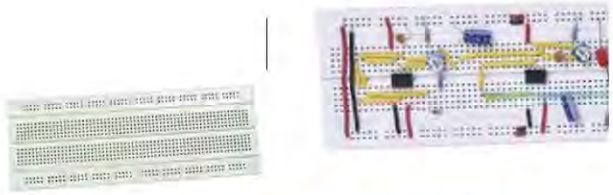


Figure 1-2 Circuit on Electronic breadboard

The major parts of a breadboard are the power rail, terminal strips and the Dual In Line Package (DIP) or Integrated Circuit (IC) support.

- Power Rail: this is the portion where you connect the power supply to power the circuits on the breadboard. One end of the power rail is for the positive power connection while the other end is for negative power connection.

Table 1-1 Breadboard power connections

Positive (+)	Negative (-)
Power	Ground
Red	Black or Blue

- Terminal strips: this is the part of the breadboard where the through-hole components are mounted. It contains vertical strips with alphabets and number labels which are useful for connection guide on the breadboard.

- DIP and IC Support: this is the area that allows easy connection of components with dual in line package and integrated circuit. It is located horizontally at the centre of the breadboard and has a groove that allows the components to be removed easily.

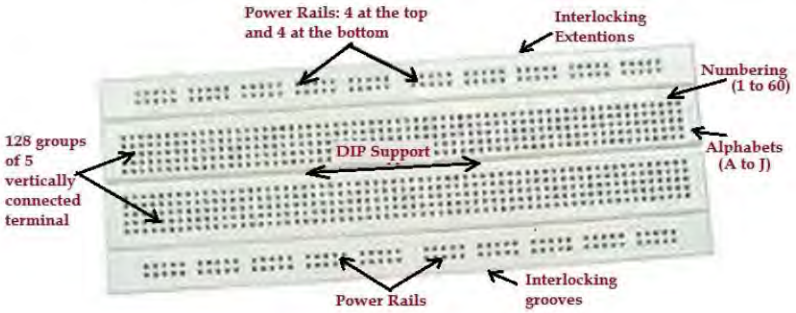


Figure 1-4 Breadboard parts label

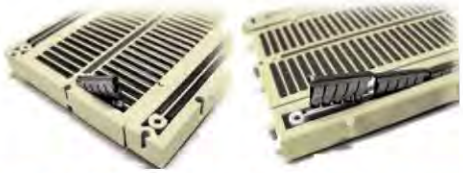
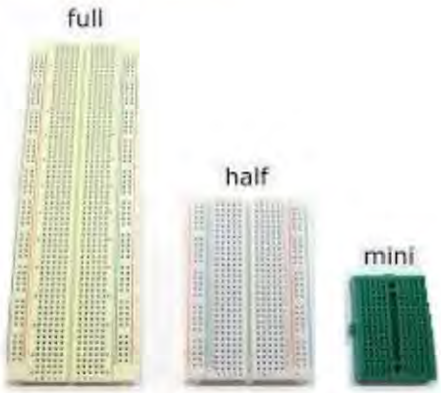


Figure 1-3 Breadboard with back opened

Figure 1-5 Breadboard socket holding a component

1.1 SIZES OF BREADBOARDS



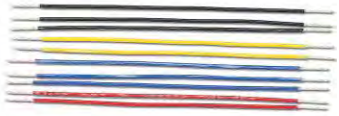
There are different sizes of breadboards available in electronic store namely; the full plus size, full size, half and the mini sizes.

Figure 1-6 Different sizes of breadboard.

1.2 OTHER FEACTURES OF THE BREADBOARD

- Making Connections: Connections are made on the breadboard with the help of jumper wire wires. Jumper wires could be prefabricated (Prefab) or custom made from a piece of solid hook-up wires.

(a)

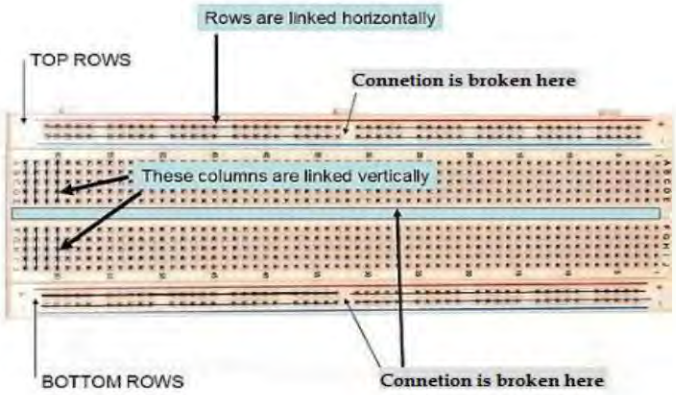


(b)

(c)

Figure 1-7 (a) Prefabricated jumper wire wire with header pins (b) Custom jumper wire wire stripped at both end used for jumper wire (c) Custom jumper wire wires with 90^0 bend

- Separate Power Connection: The power rail of the breadboard has a break half way which is very useful for providing separate power options for the circuits. A jumper wire could be used for bridging the two halves of the power rail as shown in Figure 1-9 (b) below.



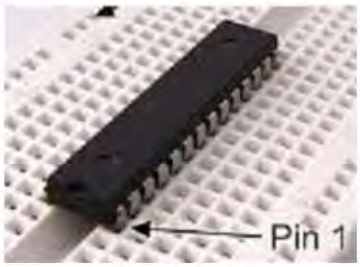


Figure 1-8 (a) Breadboard with connection layout (b) IC placed on a breadboard

- Extending Connection Area: when working on a project that requires a larger area for connection, it can be made possible to extend the area of the breadboard by joining them using the provided attachment extension and groove on its sides.

(a)

(b)

Figure 1-9 (a) Four Small breadboards of different colors joined side-by-side (b) power rail gap linking with a jumper wire on the breadboard

1.3 WIRES, CABLES AND CONNECTORS

Wires and cables are made from conductors which provide low resistance for electric current, that is, allow electric current flow easily through them. The common conductors used inside wires and cables are Copper, Silver and Aluminium.

A wire consists of a solid or stranded core conductor covered by an insulator which includes plastics and rubbers. Cables consist of two or more insulated wires bounded together by another extra insulation usually called a sheath. Solid wire are used in places where the wire will not be move, like on the wall while stranded wires are used when the wire is required to be movable or vibrate. The size of a wire conductor can be measured with the standard wire gauge.

Connectors are components that are attached to the end of wires and cable that allow them to be easily connected to other wires and devices.

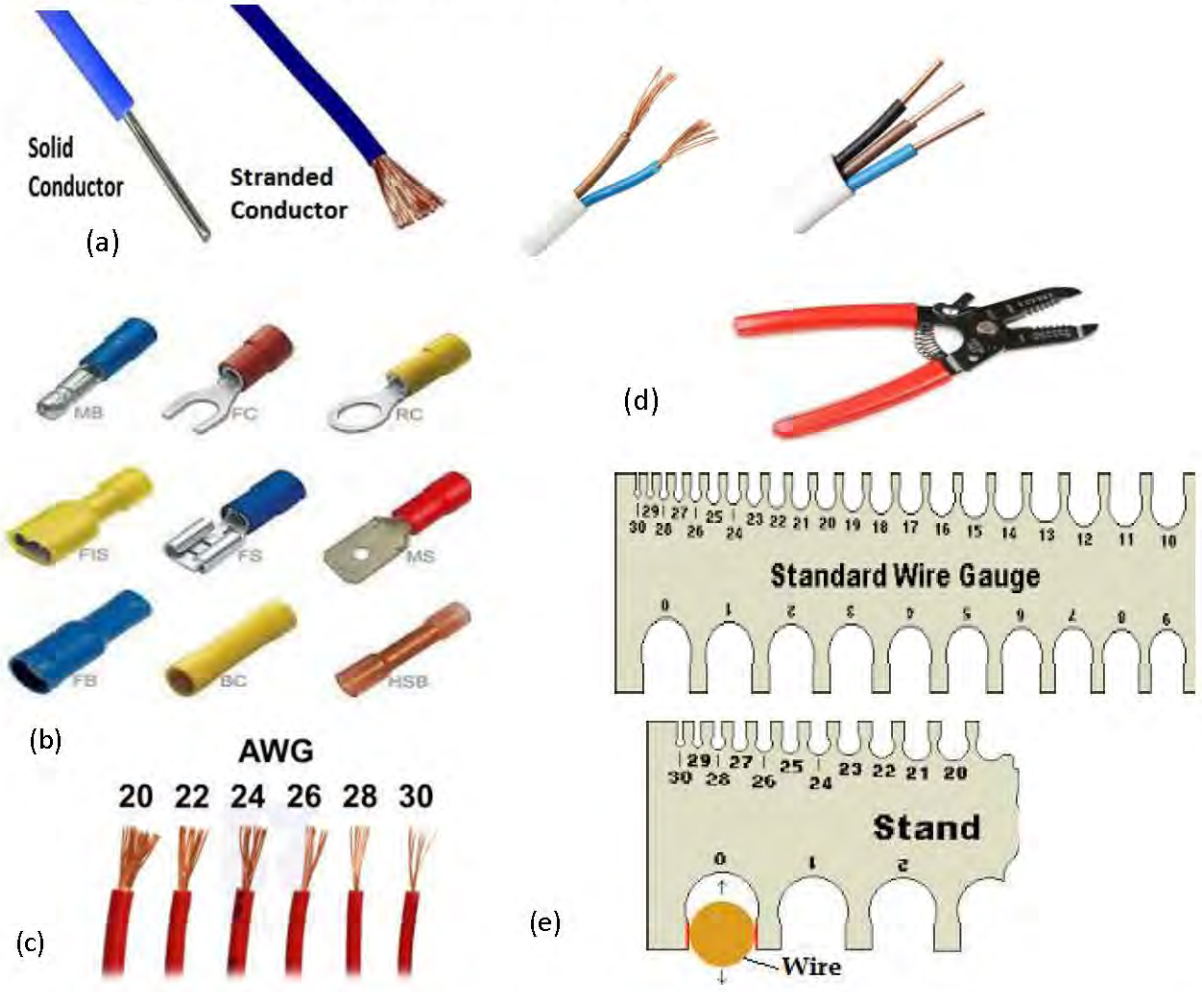


Figure 1-10 (a) Solid and stranded wire and cables (b) Connectors (c) Examples of conductors with gauge number (d) Wire stripper (e) Standard wire gauge

1.4 COMMON BREADBORD CONNECTION MISTAKES

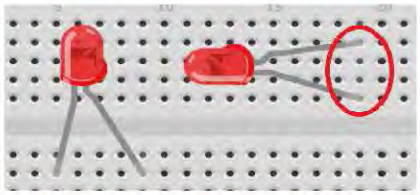


Figure 1-11 Connection to different and the same vertical slots.

Crossing the Leads of Components on the Breadboard: When the lead of components are touching or twisted, Figure 1-12, these could result to a short circuit and may damage some components. Ensure to keep the leads of each component separated from each other and keep the circuit tidy.

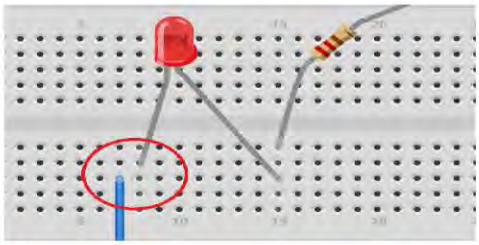


Figure 1-13 Components wrongly connected on the breadboard

Connecting a Component Lead to The Same Vertical Slot: A common connect error is seen when the two leads of a component is placed on the same vertical slot as seen on Figure 1-11, the correct connection of the leads should be on different vertical slot.

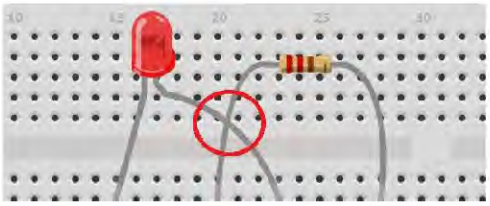


Figure 1-12 Lead of components crossing and touching each other

Disconnection in a Breadboard Connection: When a connection is made in such a way that instead of connecting two components to the same vertical slots, it is placed on different slots as seen image of Figure 1-13. This leads to a break in the circuit and prevent the circuits from functioning. Ensure to check your connections carefully.

1.5 MAKING PERMANENT CONNECTION

After setting up a connection on the breadboard and it works as expected, if you desire to make a permanent connection of such circuits, then you would need to set up the circuit on permanent board type e.g a perforated board, Printed Circuit Board (PCB). In order to do this, the components will be required to be soldered with a soldering lead using a soldering iron.

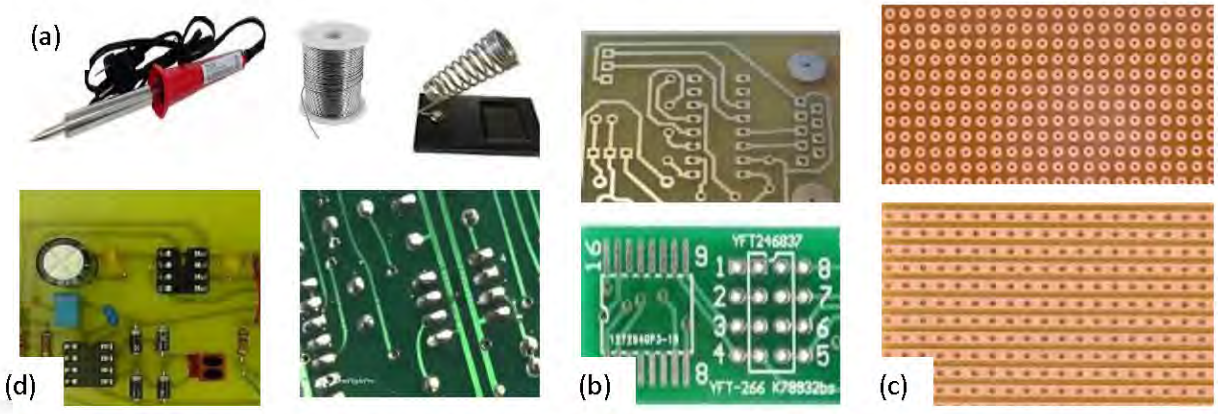


Figure 1-14 (a) Soldering iron and lead with stand (b) Printed Circuit Board (PCB) (c) Perforated Board (d) PCB with components and soldering

CHAPTER 2 THE MULTIMETER

The multimeter is an instrument which can be used for testing and measuring the values of components and different circuit quantities which includes voltage, current and the resistance in a circuit. It is called a multimeter because it combines the voltmeter (measures voltage), ohmmeter (measures resistance) and ammeter (measures current) into one single measuring device.

2.1 TYPES OF MULTIMETERS

Analogue Multimeter: this type of multimeter uses a moving pointer deflection which is placed over a marked scale to indicate the value of what is measured. It is not so precise and difficult to read out the measured values.

Digital Multimeter: this type of multimeter uses electronic circuit to convert the measurements into digital display reading, that is, the measurements will be in numerical form. There are no moving parts and it is very precise. We will be working with digital multimeter throughout this lesson.

Figure 2-1 Digital and Analogue multimeter showing their display formats.

2.2 PARTS OF A MULTIMETER

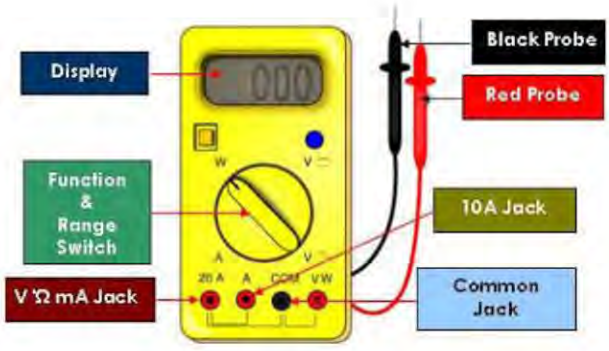


Figure 2-2 Parts of a digital Multimeter

A digital multimeter has a **Digital Display** for showing measured values. It can show up to four digits, indicate negative reading, low battery and other useful information. It also has a **Dial** with a rotary part which has a **Selector** for pointing to the units to be measured.

On the dial, there are different ranges for each units and the selected on depends on the amount of the value to be measured. You may come across some **autorange** multimeter for which you do not need to select the range but it will be done automatically by the processing unit of the multimeter. For example, to measure voltage, the selector will be rotated to the section of the dial indicating direct current voltage (DCV) and the range will be selected.

Another important part of the multimeter is the **Port** for plugging in the leads, which are used for measurement. There are usually three ports present on the multimeter, these are;

- COM
- VΩmA
- 10ADC

The multimeter has a detachable part called the **Leads** which connects the multimeter to the points to be tested in the components or the circuits. The leads are of two colours; Red and Black. One end of the lead has a banana connector for plugging in to the ports while the other end has a steel probe which is the part that is used for touching the circuit.

Figure 2-4 Multimeter leads and different lead attachments for making measurements

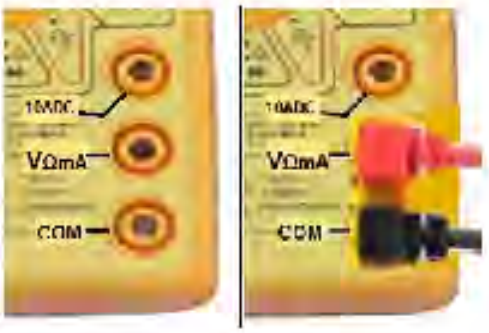


Figure 2-3 Ports on a digital multimeter and the correct lead connection

Figure 2-5 (a) Touching a component with the multimeter probe (b) using an alligator attachment for firmer grip on objects.

CHAPTER 3 CELLS AND BATTERIES

A battery is a source of direct current (DC) voltage.

NOTE: Energy sources can either produce a direct current also called DC or alternating current also called AC. (See the subtopic on DC and AC in the chapter).

Batteries can be used to power electric circuit that uses DC. A battery is made up of two or more cells. A **cell** is made up of two conductors called **electrodes**, the positive(+) and the negative(-) electrodes, separated by a chemical called **electrolyte** that converts chemical energy to electrical energy and causes electrons to flow through a circuit.

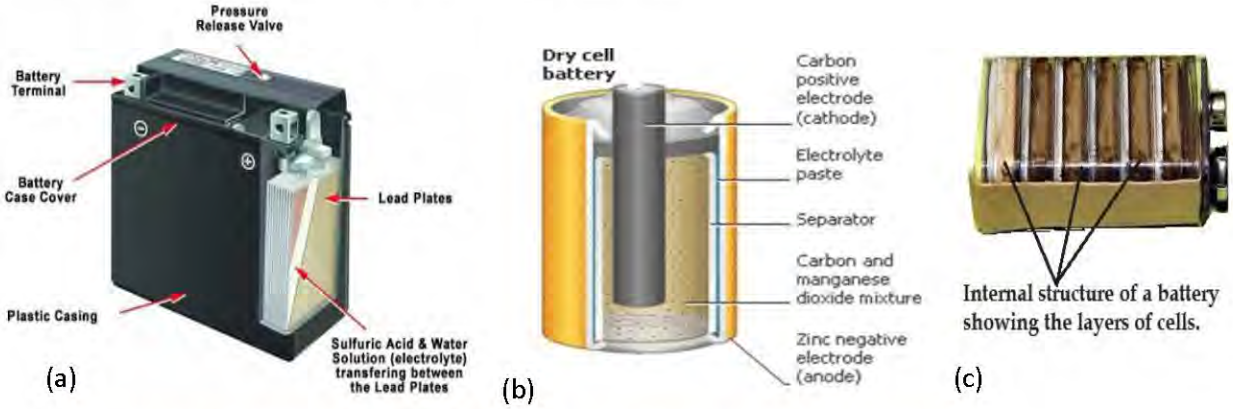


Figure 3-1 (a) A Wet cell (b) A Dry cell (c) Addition of cells in a battery

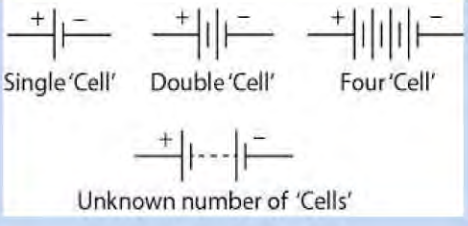


Figure 3-2 Symbols of cells and battery

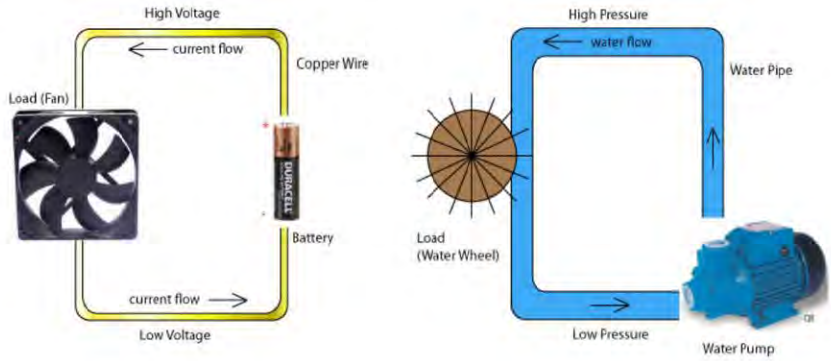
If the electrolyte is a liquid, the cell is called a **wet cell.** If the electrolyte is made from paste-like or gel substance, the cell is called a **dry cell**. Cells that are non-rechargeable (must be thrown away) after the energy of the cell has been used up are called **primary cells** while cells that can be recharged and reused after the cell has been drained are called **secondary cells**.

3.1 HOW A BATTERY WORKS

When a battery positive terminal called **cathode** and the negative terminal called **anode** are connected to an external circuit, there will be a chemical reaction between the anode(-) and the electrolyte which generates electrons making them flow through the circuits and back to the battery through the cathode(+) where another chemical reaction takes place. When the chemical reaction between the electrolyte and the electrode is no longer able to generate electrons to flow in a circuit, then the battery is said to be **drained or dead**.

3.2 WATER ANALOGY OF THE OPERATION OF A BATTERY

Figure 3-3 The water pump pushes the water through the pipe from a higher pressure to a lower pressure while doing work in rotating the wheel. The battery generates the energy to pump current through the conductor from a higher potential to a lower potential to make the fan blades rotate.



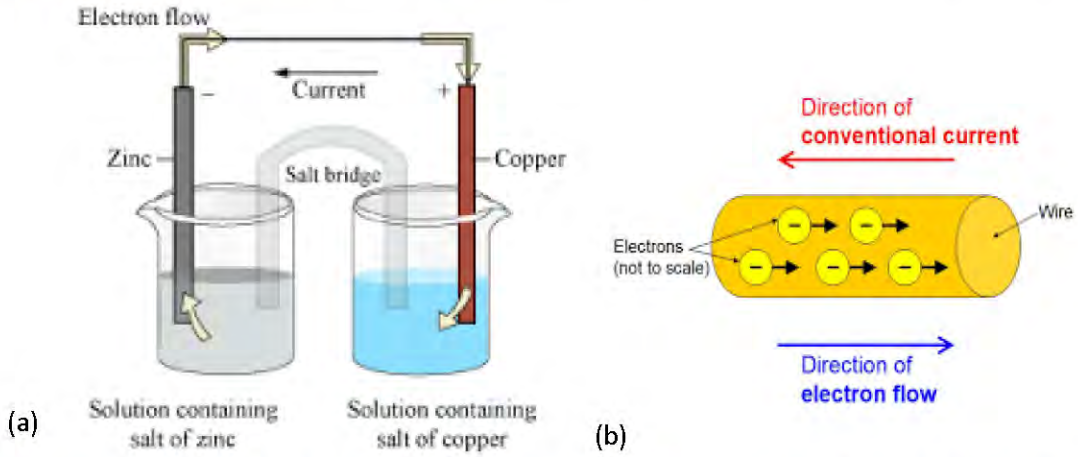


Figure 3-4 (a) The Zinc rod is the anode (-) while the copper rod is the cathode (+). The solutions in the two containers are connected by a salt bridge and the direction of current and electron flow are shown. (b) The conventional current and the actual electron flow are always in opposite direction.

NOTE: Conventional current flows from the positive (+) to the negative (-) electrode while the actual electron flow is from the negative (-) to the positive (+) electrode.

3.3 DESCRIBING A BATTERY

- Nominal Voltage: the nominal voltage of a battery is the voltage stated by the manufacturer. It is usually the voltage of the battery before it is used or discharged.
- Capacity: this is the rating of the battery that indicates how much electrical energy it can deliver over a period of time at a specific voltage. It is usually given in ampere-hour (Ah) and milliampere-hour (mAh). A battery with large capacity will last longer when discharged at the same rate when compared with another with lesser capacity.
- Cell Sizes and Common Names: there are different standard sizes for cells and as well common name for cells depending on the type of electrolyte used as given in the table below.

Figure 3-4 Battery sizes and common names

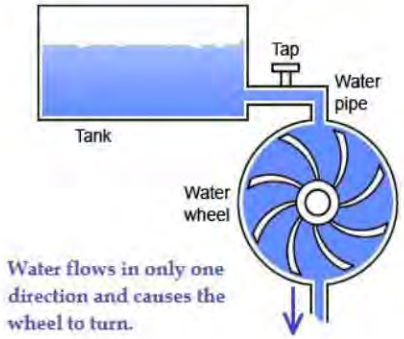
Table 3-1 Battery specifications

Battery Type	Nominal Voltage (V)	Amp/ hour (mAh)	Anode /cathode combination
Alkaline	1.5	2122	Zinc / Manganese dioxide
Zinc-Carbon	1.5	591	Zinc / Manganese dioxide
Lithium - ion	3.6	853	Lithium/ Sulfur-oxygen chlorine

3.4 DC SOURCES

We will be working with **only** direct current (DC) source in this book. A DC voltage or current sources is one that electrons flow in only one direction. When considering DC sources, we talk of **positive** (+) and **negative** (-) terminals.

Figure 3-5 Water Analogy of Direct Current



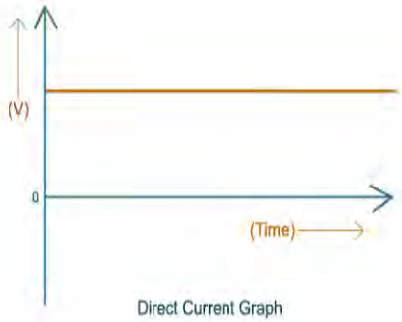


Figure 3-6 Relationship between the current and time for a Direct Current (DC)

3.5 WAYS OF PRODUCING DC

1. Using an alternating current (AC) generator which has a **commutator** (a cylindrical contact with made of multiple segments separated by small gaps) connected to its armature to produce a DC. AC generator converts magnetic energy into electrical energy.
2. Use of a device called a **rectifier** (an electrical device that converts AC to DC) connected to a AC source to convert it to DC.
3. Chemical cells or batteries produce DC by converting chemical energy to electrical energy.
4. Solar Cells also produce DC by converting light energy to electrical energy.

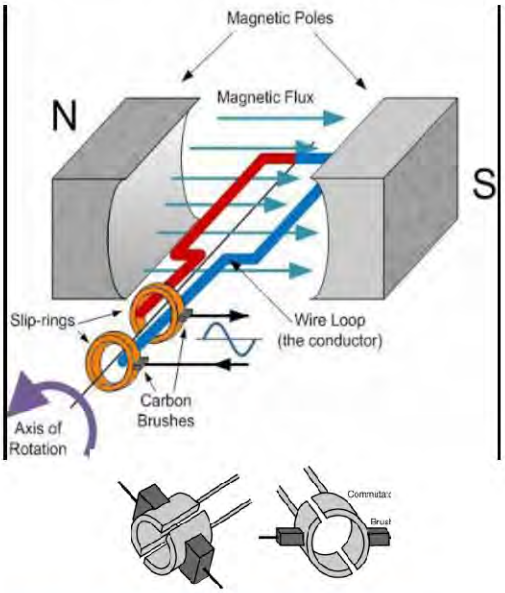


Figure 3-8 Generator for producing AC and the commutator.

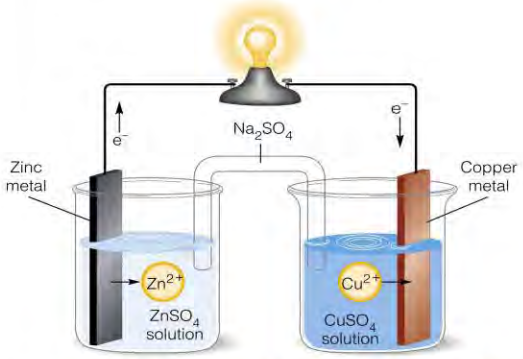


Figure 3-7 Chemical cell for producing a direct current as found in a battery.

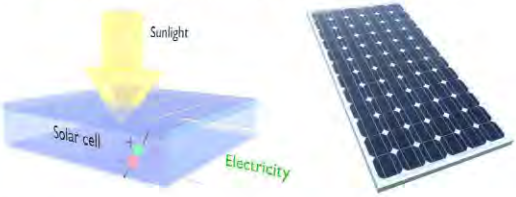


Figure 3-9 Solar cell converts light to electricity.

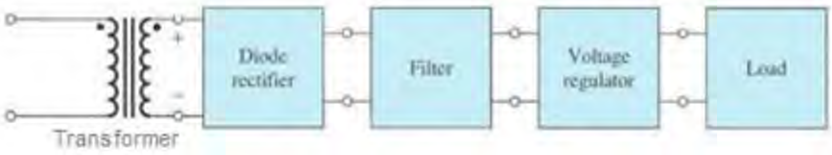


Figure 3-11 Rectification process for producing DC from AC.

3.6 APPLICATION OF DC

Some of the common equipments that operate using DC include;

- Cell phone
- Flashlight
- Electric vehicles
- Any device that uses an AC adaptor (internally or externally)

3.7 AC SOURCES

Alternating Current (AC) is one that the current or voltage changes direction periodically, that is, for a duration of time it has positive value and then sometimes later it changes to negative value. AC is produced using a generator called an **alternator**. In Nigeria, the AC output from the wall socket is about 240 volts.AC terminals a called **Live**(L) , **Neutral**(N) and **Earth**(E) .

WARNING: Working with AC current and voltage from wall socket at homes or any other AC source without proper safety measures, could lead to shock or electrocution. Don't play around with AC sources.

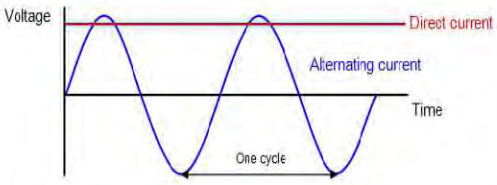


Figure 3-12 AC waveform

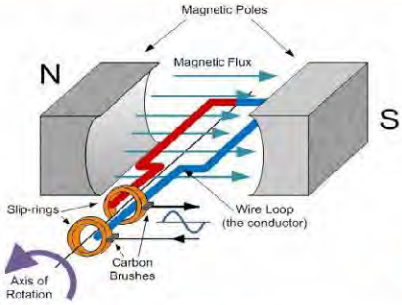


Figure 3-13 AC Generator

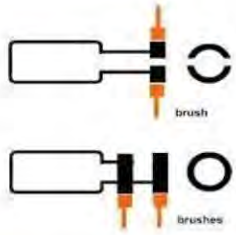


Figure 3-14 Bruch for DC (top) and brushes AC (bottom)

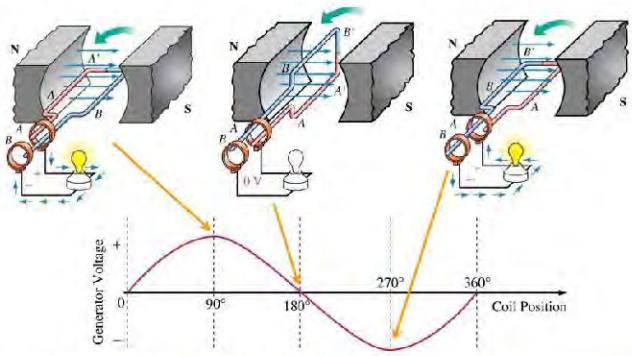


Figure 3-15 Production of AC from a generator connected to a slip ring

Figure 3-16 A wall plug and socket for AC. The Live (L), Neutral N) and Earth (E) are shown with the colour codes.

3.8 APPLICATION OF AC

Some of the common equipments that operate using AC include;

- Home filament bulbs
- Electric iron
- Electric cooker
- Electric motor
- Transformers

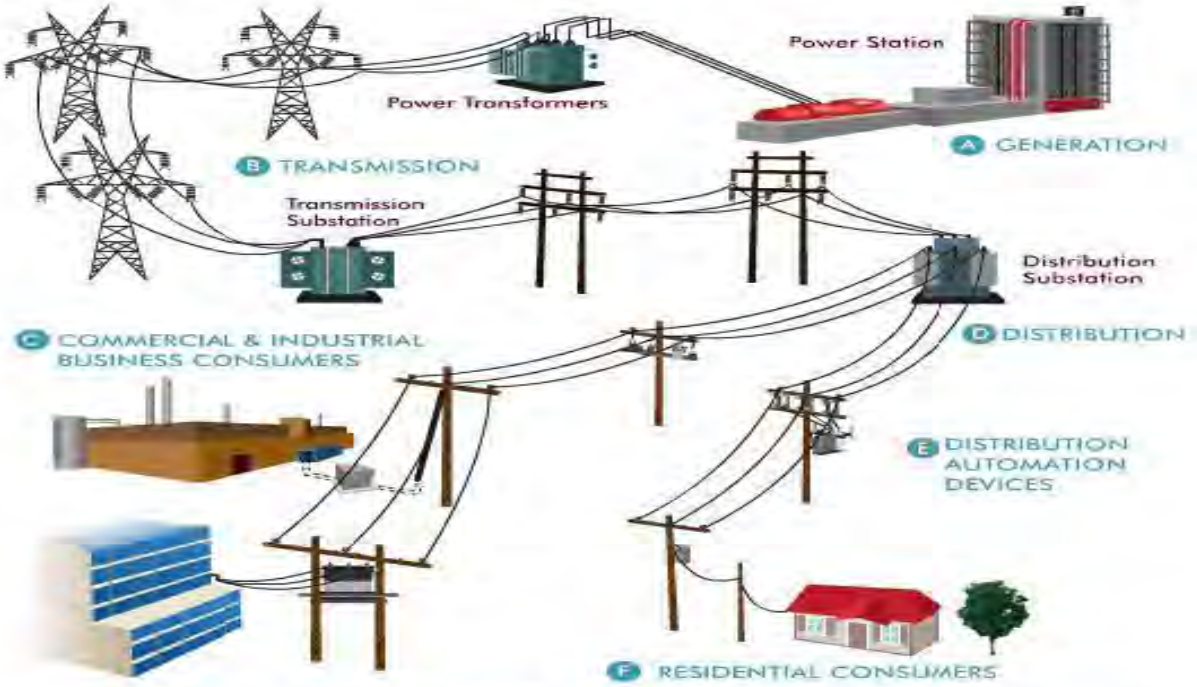


Figure 3-17 Power generation and distribution of AC; the distribution follows the label from A through F.

3.9 ELECTRICITY, VOLTAGE, CURRENT, RESISTANCE AND OHM'S LAW

In here, we are going to have the understanding of voltage, current and resistance. In every circuit you will come across, you will need these knowledge to understand how circuit works and how to change circuit design to your taste. Voltage current and resistance are not visible and cannot be touched but with the aid of measuring tools we can visualize them in a circuit.

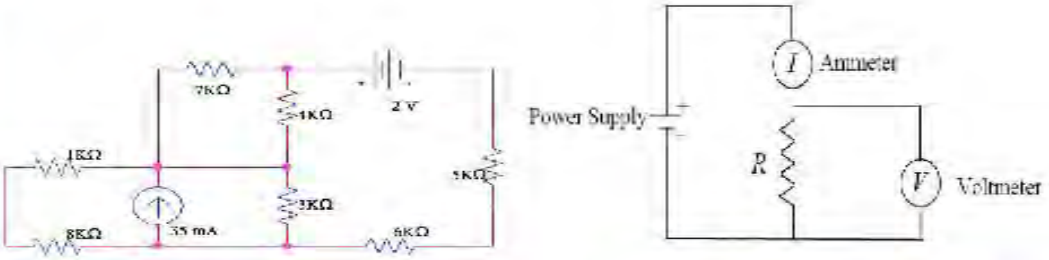


Figure 3-18 Electric circuits and the current, voltage and resistance information given to understand the circuit.

Firstly, let's understand what electricity means. Electricity is the **flow of electric charges**. When charges can flow continuously, it is referred to as **current electricity**. When charges cannot flow continuously, then it is referred to as **static electricity**. There are two types of charges namely; **Positive(+)** and **Negative(-)** charges. The unit of electric charge is the **Coulomb (C).**

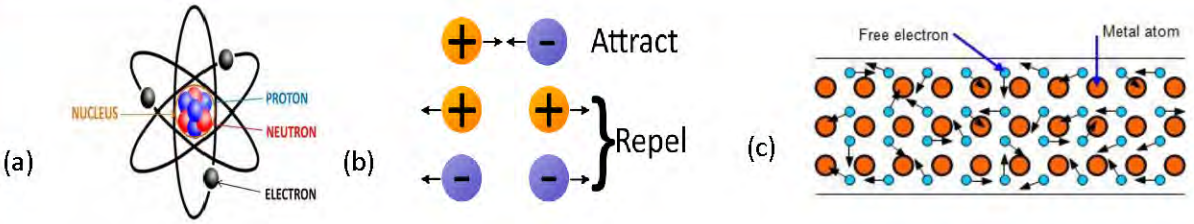


Figure 3-19 (a) The atom and the components (b) Charges and their interactions (c) A conductor having lots of free electrons which allows it to conduct electricity easily.

Electron are mobile negative charges in an atom and therefore majorly responsible for electric current when a force (called electromagnetic force, EMF) is applied on it. Material with lots of mobile or free electrons are called **conductors,** examples of good conductors are copper, silver and aluminum. Materials with immobile electrons are called **insulators** and examples of good insulators are rubber, plastic and glass. The ability of a material to limit the flow of electric charges is called the **resistance** i.e insulator have very high resistance while conductors have very low resistance.

Figure 3-20 (a) Examples of common conductors (c) Example of common insulators

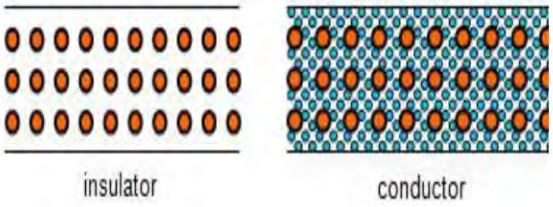


Figure 3-21 Atoms inside Insulator and conductor

The atoms (Orange) inside the conductor are surrounded by lots of free electrons (Blue) as shown in Figure 3-21. In the insulator, there are no free electrons to allow for electricity conduction. Insulators are very useful to preventing electricity flow in any desired place.

Since we now know that charges can attract or repel each other when placed near each other, we say a charge has a **potential energy** in its field (surrounding), and this means that a charge has the ability to do work on another around it by pushing or pulling it. The amount of work done depends on the strength of the two charges interacting.

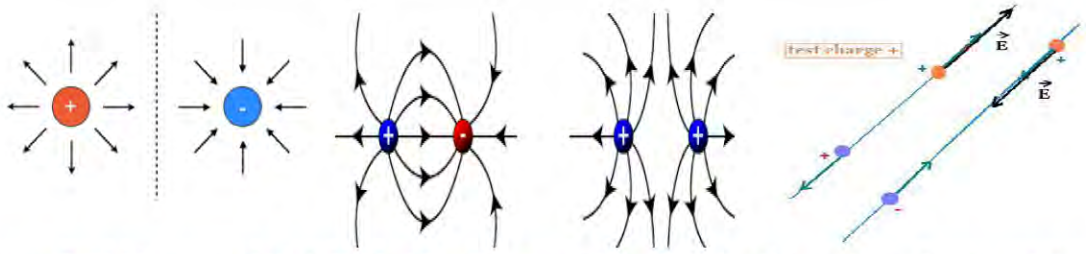
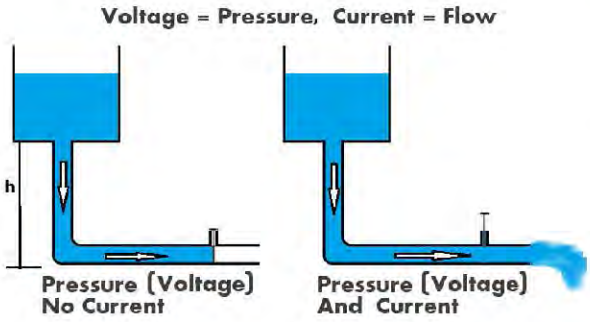


Figure 3-22 Charge and their fields. The direction of the field for the positive charge points outward while that of the negative charge points inward.

3.9.1 VOLTAGE

The kind of work done in moving a charge from one point to another in an electric field is called **electric potential energy** measured in joule(J) which is the unit of work done. The amount of electric potential energy at a point divided by the number of charges at that point is called the **electric potential**. Now, the difference in electric potential between two points in a field is called the **voltage or potential difference.** The unit of voltage is the **volt (V)**. When a voltage or potential difference is placed across a conductor, it gives free electrons within the conductor a push known as the **electromotive force (e.m.f)**.

Figure 3-23 Water analogy of voltage



The voltage is compared to the water pressure in Figure 3-23. The higher the tank is from the ground, the more the pressure and therefore more water flows through the pipe. Likewise, a battery with higher voltage will cause more current to flow through a load when compared with another battery with a lower voltage.

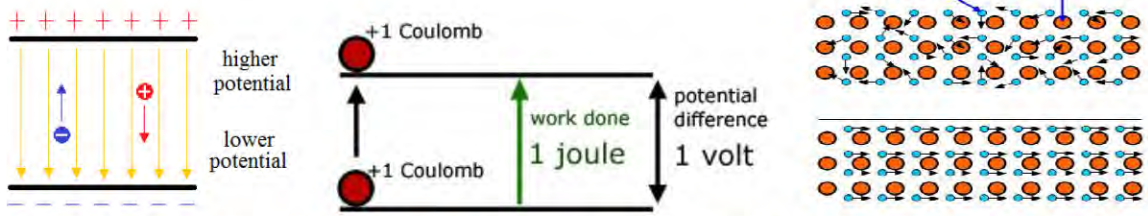
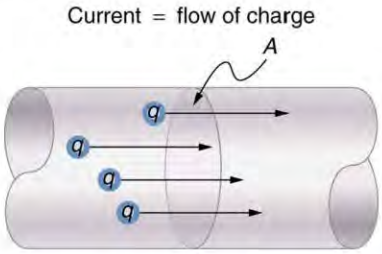


Figure 3-24 Positive charges are at higher potential while negatives charges are at lower potential (Left). The work done in moving a positive charge from one point to another in a field (Middle). Electrons moving in the same direction under the influence of an e.m.f (Right)

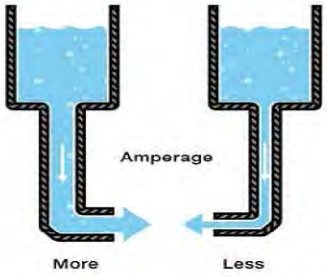
3.9.2 CURRENT

Current is the amount of charges flowing through a point in the circuit within a period of time. Current is measured in **amperes (A).** When 6.02×10^{18} electrons pass through a point in a circuit in one second, this means one ampere (1A) of current flow through that point.



In the figure 3-25, the current flowing through the section of the conductor is determined by measuring the amount of charges (electron charge, q) flowing pass the cross-sectional area (A) of the conductor. For one ampere to flow, then 6.02×10^{18} electrons must have crossed the area, A, of the conductor in one second.

Figure 3-25 Charges flowing through an area of a conductor.



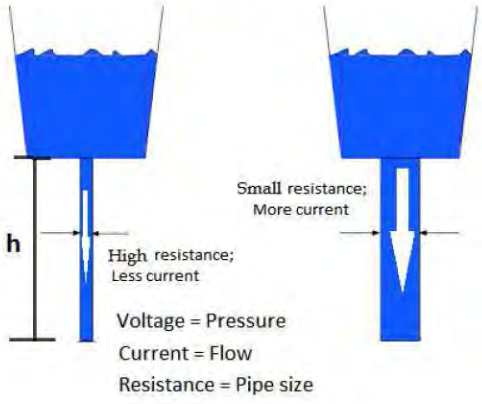
The water flowing through the tank represents the current. When we consider two tanks of the same size and same height from the ground, the amount of water that will flow through the pipe will be determined by the size of the pipes connected to the tanks, as seen in figure 3-26. The wider pipe allows lots of water to flow out while the thinner one allows less water to flow out.

Figure 3-26 Water analogy of the amount of current flow

3.9.3 RESISTANCE

The resistance is the ability of a material to hinder the amount of charges that can flow through it. The higher the resistance, the lower the current that will flow and vice versa. The unit of resistance is the **Ohm**. The Ohm is represented by the Greek alphabet **Omega (Ω).** One Ohm is the resistance that will cause 6.02×10^{18} electrons to flow between two points when a voltage or potential difference between the two points equals one volt (1V).

Figure 3-27 Water analogy of resistance



The pipes in the figure 3-27 are similar to resistances. The smaller pipe represents large resistance while the larger pipe represents small resistance. The smaller pipe allow very small amount of water to flow as a large resistance allows very small amount of current to flow. An example of a small resistance is 10Ω while a large resistance is 1,000,000Ω. A smaller resistance will make a battery to quickly run down because more current will flow out of the battery.

3.9.4 OHM'S LAW

The Ohm's law show the relationship between the voltage, current and resistance in a circuit by an equation given as;

$$V = I \times R$$ --Ohm's Law

Where V - Voltage in volt

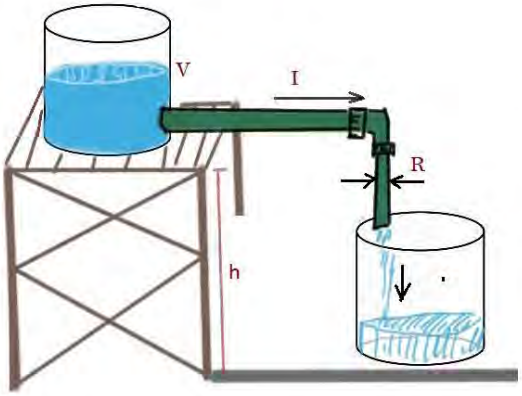
I - Current in ampere

R - Resistance in Ohm

When the value of two of the quantities in the Ohm's law is known, the third quantity can be obtained by rearranging the Ohm's law as;

$$V = I \times R \quad \text{or} \quad I = \left(\frac{V}{R}\right) \quad \text{or} \quad R = \left(\frac{V}{I}\right)$$ Ohm's law

Figure 3-28 Water analogy of Ohm's law



The tank at a height (h) represents the voltage, the pipe represents the resistance and the water flowing through the pipe represents the current as seen in figure 3-28. When the tank is raised higher, more water flows; when the tank is lowered, less water flows. When the tank is at the same height, the pipe size can be changed by opening or closing the tap. When the tap is opened, more water flows while when the tap is closed less water flows. By using the Ohm's law, the changes in voltage, resistance and current can be calculated so easily.

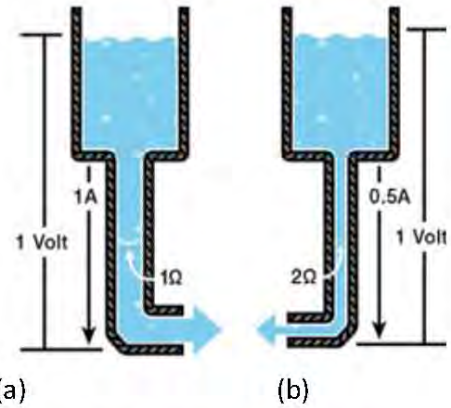


Figure 3-29 Ohm's law calculation

Example 1: Use the diagram in Figure 3-29 to calculate the current in each case and confirm Ohm's law.

Solution

(a) Voltage = 1V, Resistance = 1Ω, using $I = \left(\frac{V}{R}\right)$, then

Current, $I = \left(\frac{1}{1}\right)$ =1A

(b) Voltage = 1V, Resistance = 2Ω, using $I = \left(\frac{V}{R}\right)$, then

Current, $I = \left(\frac{1}{2}\right)$ = 0.5A

For the (b) part we can confirm that Ohm's law holds by using the equation, $V = I \times R$; where Resistance = 2Ω and Current = 0.5A. therefore, Voltage, $V = 0.5 \times 2$ = 1V. This is the same for as the value given in part (b) above.

CHAPTER 4 RESISTORS

Resistors are one of the common components you will usually see in an electric circuit and we will also work with resistor in the lesson. A resistor is an electrical device that limits the flow of electrons through circuit. Resistors are an example of **passive elements** (components that can only consume power but cannot generate it, the opposite of passive elements is **active elements**).

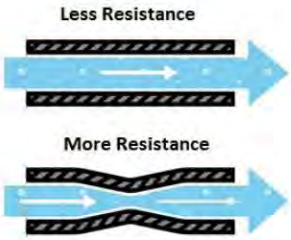


Figure 4-1 Resistor uses definition

Resistors are devices which are specifically designed to be used in an electric circuit to make more current or less current flow. Resistors have resistance values which are determined by the manufacturer by using different resistive materials.

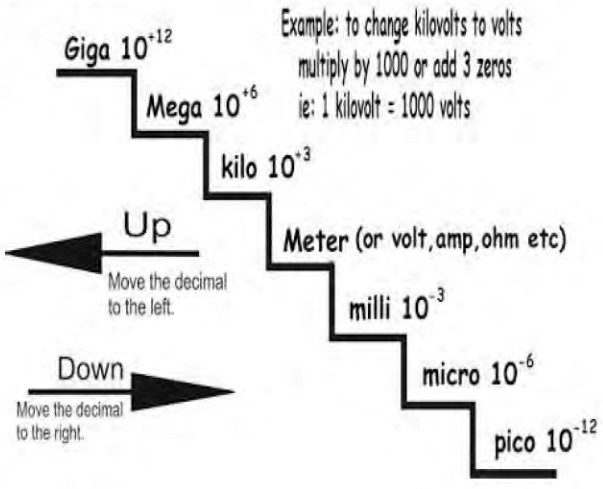
4.1 RESISTOR UNITS

The unit used to express the amount of electrical resistance of a resistor is called the Ohm (Ω). The symbol of the Ohm is a Greek alphabet called Omega. The metric conversion table below is used for writing a short hand form of values of units by eliminating the multiples of zero represented by alphabets.

Table 4-1 Metric conversion

From	In words	Multiply by	Factor
nano (n)	Billionth	1/1000000000	$1*10^{-9}$
micro (μ)	Millionth	1/1000000	$1*10^{-6}$
milli (m)	Thousandth	1/1000	$1*10^{-3}$
centi (c)	Hundredth	1/100	$1*10^{-2}$
deci (d)	Tenth	1/10	$1*10^{-1}$
		1	
deca (da)	Ten	10	$1*10^{1}$
hecto (h)	Hundred	100	$1*10^{2}$
kilo (k)	Thousand	1000	$1*10^{3}$
mega (M)	Million	1000000	$1*10^{6}$
giga (G)	billion	1000000000	$1*10^{9}$

Example 1:



4.2 RESISTOR TYPES AND CIRCUIT SYMBOLS

The examples of different resistor types and their symbols are shown in figure 4-2. In a circuit with one than one resistors, you will represent each resistor by a capital **R** followed by the number to identify it.

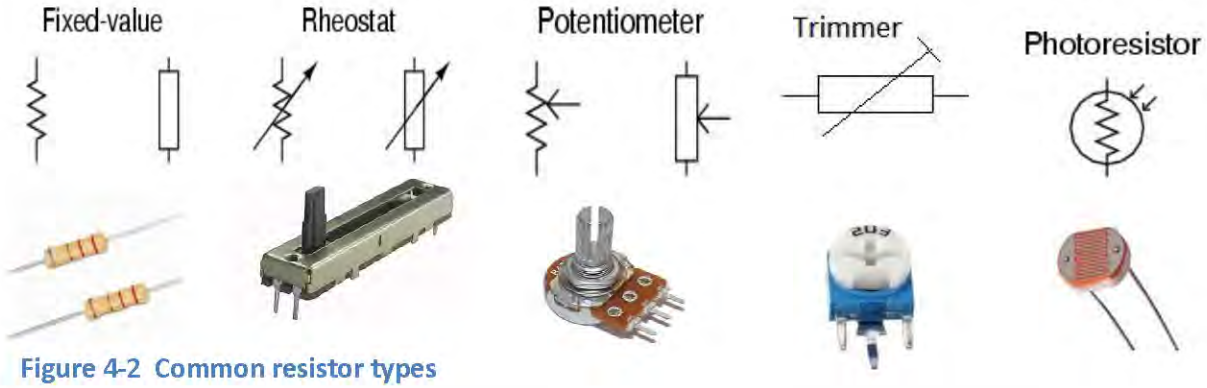


Figure 4-2 Common resistor types

WHAT IS INSIDE A RESISTOR

There are different material that could be used for making a resistor which includes Carbon, metals and metal-oxide. The mode of achieving the resistance value depends on the material property and its geometry.

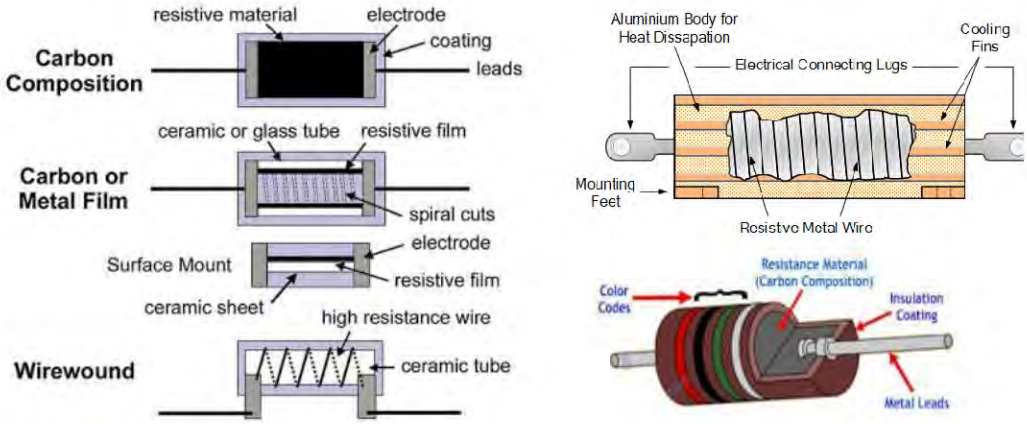


Figure 4-3 Composition of resistors

4.3 RESISTOR CATEGORIES

There are different ways of categorizing a resistor, which are;

1. Mounting: the types of mountings are through-hole or surface mount. The through –hole requires that a hole be made to the surface which the resistor is to be placed while the surface mount does not require making hole.

Figure 4-4 Through-hole and surface mount resistors

2. Fixed or Variable Values: the resistance value of a resistor could be made to be fixed or variable. The resistance of variable resistors can be adjusted to the desired resistance value.

3. Packaging: resistor can either be made as a standalone or in a package containing one than one resistor in single package.

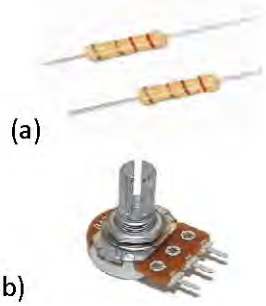


Figure 4-5 (a) Fixed resistor (b) Variable resistor

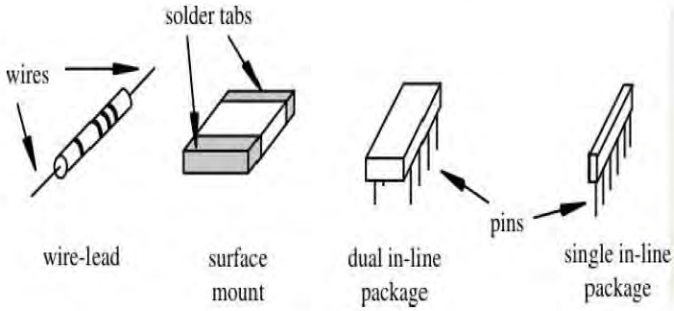


Figure 4-6 Different resistor packages

4.4 UNDERSTANDING RESISTOR COLOR CODES

The colour on axial resistors can be used to determine their resistance. The colour codes are usually of four, five or six bands.

4.4.1 Four-Band Colour Code

If there are only four bands on a resistor, then the first two bands represents the first digits, the second band the second digit, the third band is a multiplier which multiplies the first two digits by a power of ten. The fourth band represents the tolerance value.

Table 4-2 Resistor colour code

Colour	*Value*	*Multiplier*	*Tolerance*
Black	0	1 (10^0)	
Brown	1	10 (10^1)	±1%
Red	2	100 (10^2)	±2%
Orange	3	1,000 (10^3)	
Yellow	4	10,000 (10^4)	
Green	5	100,000 (10^5)	±0.5%
Blue	6	1,000,000 (10^6)	±0.25%
Violet	7	10,000,000 (10^7)	±0.1%
Grey	8		±0.05%
White	9		
Gold		0.1 (10^{-1})	±5%
Silver		0.01 (10^{-2})	±10%
None			±20%

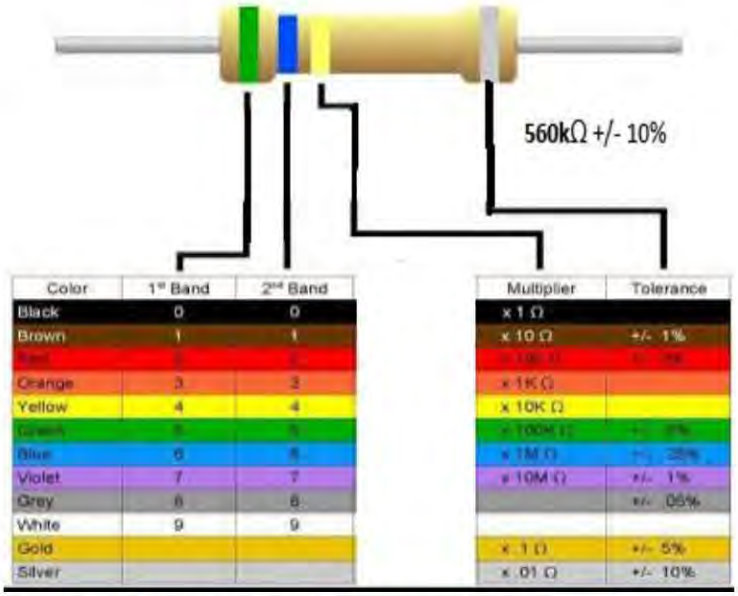


Figure 4-7 Example of resistor with colour code

Let us take an example as we read the resistance value of the resistor shown in figure 4-7 using the colour code.

NOTE: At first, this might seem difficult to read but as you practice more using the colour code chart; you get familiar with the colour values.

Example 2: The colour bands of the 560kΩ resistor are;

1st Band: **Green** (Value =5)

2nd Band: **Blue** (Value = 6)

3rd Band: **Yellow** (Value = 4)

Now, put the first two values together as; **GreenBlue** (value = 56). Next multiply the first two bands by 10 to the power of the value of the third band as;

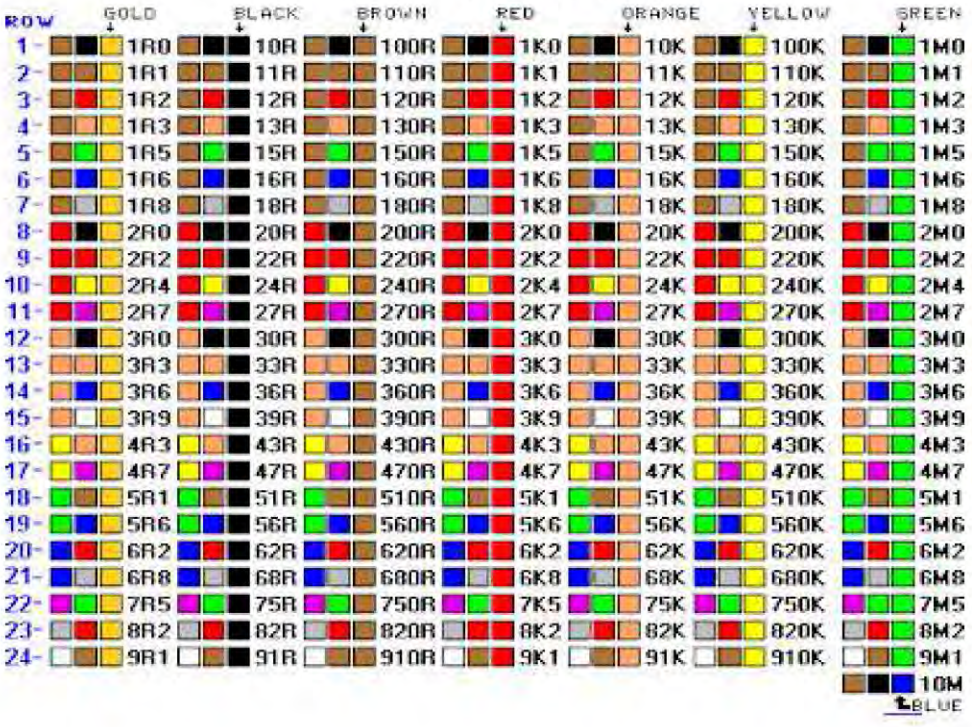
Multiplier value= $10^{(value\ of\ third\ band\ colour)}$

$= 10^4 = 10000$

When we put it all together, we will have;

GreenBlue x 10^{yellow} = 56 x 10^4

= 560000Ω or 560kΩ



Note: **The colour combination represents the three bands for all the standard resistor value. Using this chart will allows you become familiar with the resistor colour code.**

Figure 4-8 Standard colour code with colour combinations.

Standard Resistor Values (±5%)						
1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	2.2M
2.4	24	240	2.4K	24K	240K	2.4M
2.7	27	270	2.7K	27K	270K	2.7M
3.0	30	300	3.0K	30K	300K	3.0M
3.3	33	330	3.3K	33K	330K	3.3M
3.6	36	360	3.6K	36K	360K	3.6M
3.9	39	390	3.9K	39K	390K	3.9M
4.3	43	430	4.3K	43K	430K	4.3M
4.7	47	470	4.7K	47K	470K	4.7M
5.1	51	510	5.1K	51K	510K	5.1M
5.6	56	560	5.6K	56K	560K	5.6M
6.2	62	620	6.2K	62K	620K	6.2M
6.8	68	680	6.8K	68K	680K	6.8M
7.5	75	750	7.5K	75K	750K	7.5M
8.2	82	820	8.2K	82K	820K	8.2M
9.1	91	910	9.1K	91K	910K	9.1M

Table 4-3 Resistor standard value for tolerance of ±5% (Left) and metric conversion for values of Ohms, Kilohms and Megohms (Bottom)

Ohms	Kilohms	Megohms
1Ω	0.001k	0.000001M
10	0.01k	0.00001M
100Ω	0.1k	0.0001M
1000Ω	1k	0.001M
10,000Ω	10k	0.01M
100,000Ω	100k	0.1M
1,000,000Ω	1,000k	1M

4.5 RESISTOR POWER RATING

Usually, the sizes of resistors are an indication of the amount of power that the resistor can handle. The power determines the maximum voltage or current that a resistor can withstand before getting damaged by the heat generated within it. The higher the power of a resistor the higher the current or voltage it can withstand.

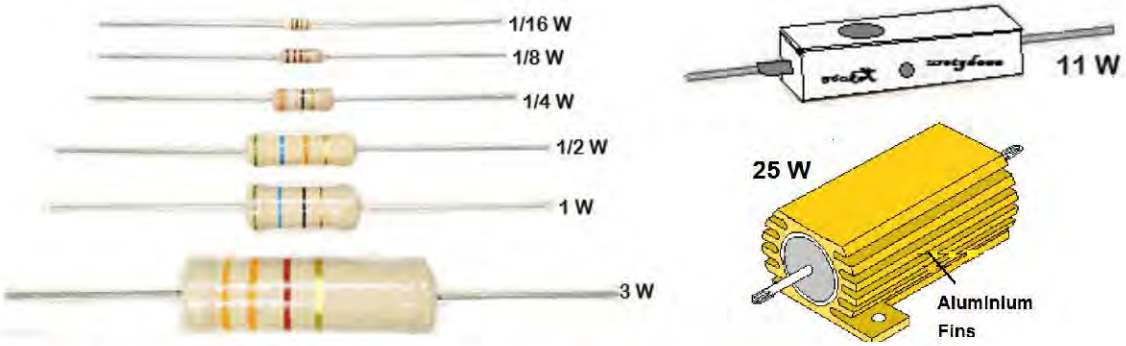


Figure 4-9 Resistors of different sizes and their respective power ratings

Note: The rule of thumb in selecting a resistance value for an application is to ensure that the resistor power rating is at least twice the calculated or expected value.

4.6 BASIC FUNCTIONS OF RESISTORS IN ACIRCUIT

When used in a circuit, the resistor can basically be used to limit current flow and to set voltage level within the circuit;

a. As a Current Limiter: When used as a current limiter, the resistor determines the maximum current that can flow from the source through it to any other component or device on the same circuit path.
b. Voltage Level Setting: when used to set voltage level in a circuit, the resistor is connected into a network that divides the voltage from the power source into smaller voltage output.

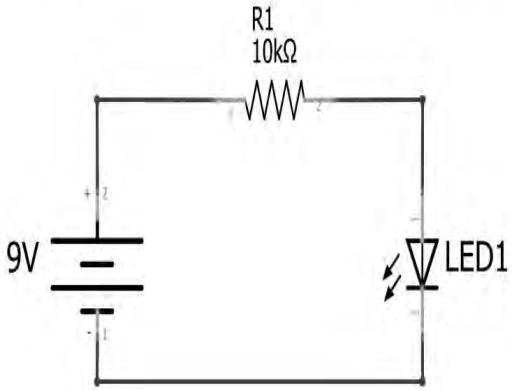
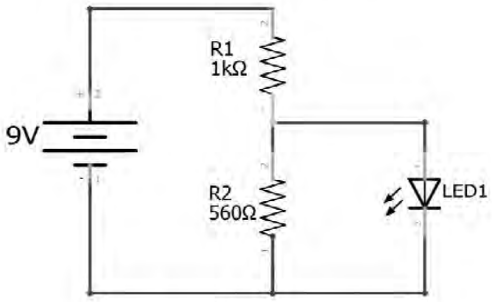


Figure 4-10 Resistor used for setting the maximum current flowing through the LED.



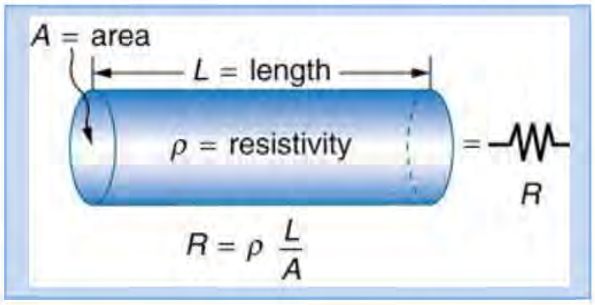
$$V_{R2} = \left(\frac{R_2}{R_1 + R_2}\right) V_{SUPPLY}$$

Figure 4-11 Two resistors placed in series (end-to-end) connection are used to make a voltage divider by applying Ohms law.

4.7 RESISTANCE, RESISTIVITY AND CONDUCTANCE

Let's take a closer look at the resistance of a conductor and the factors that affect it. It has been experimentally proven that the resistance of a wire is related to its cross-sectional area and its length by a relationship given as;

$$\mathbf{R = \rho \frac{l}{A}}$$



R – resistance of the wire(Ω)
ρ - a constant called the **resistivity**(Ωm)
l- length of the wire(m)
A- cross-sectional area of the wire(m^2)

From the above equation, it can be derived that for a piece of wire of the same material;

i. The longer the length of a wire, the higher its resistance
ii. The higher the diameter of a piece of wire, the lower will be the resistance

The resistivity (ρ) is a property of the wire that does not depend on the length or the cross-

sectional area of the wire but on the material the wire is made from. It is unique for each material.

The resistivity can be written as; $\rho = R\frac{A}{l}$

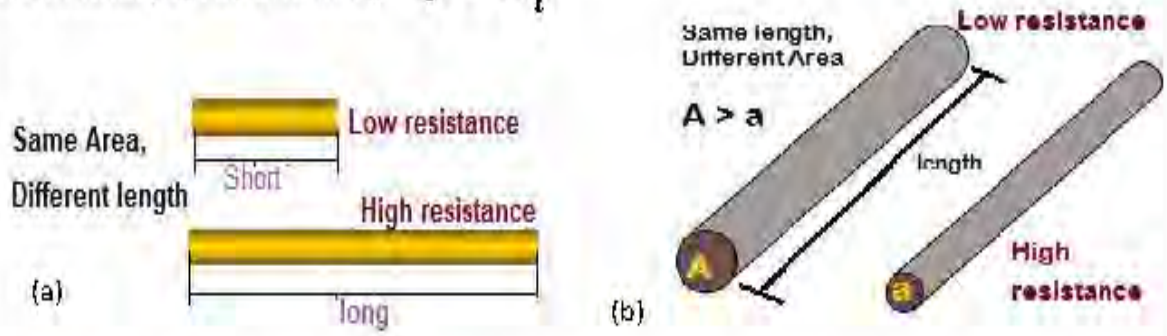


Figure 4-12 (a) Resistance variation with wire length (b) Resistance variation with wire cross-sectional area

The unit of resistivity is the (Ωm) and it tells us how much a conductor will oppose the flow of electrons through it. The opposite of resistivity is the **conductivity**, which tells us how much a conductor will allow electrons to flow through it.

$\sigma = \frac{1}{\rho}$ and $\rho = \frac{1}{\sigma}$ σ - conductivity of the material

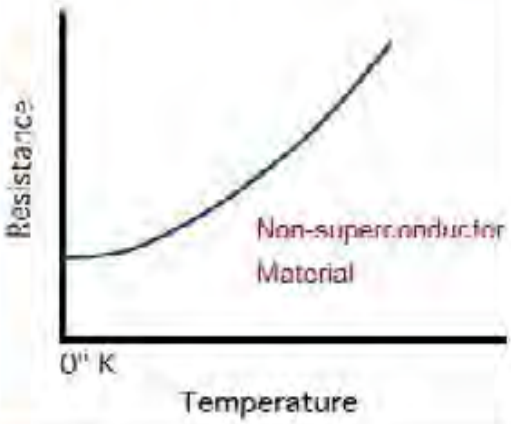
The unit of conductivity is the **Siemen,** ρ - resistivity of the material

Siemen, $S = \frac{1}{(\Omega m)}$ or $(\Omega m)^{-1}$

The resistivity and conductivity of a material can be affected by temperature changes. For most conductors, the resistivity increases as the temperature increases.

Table 4-4 Resistivity of common conductors and effect of temperature on resistance

Conductor Material	Resistivity (Ohm meters @ $20^{o}C$)
Silver	1.64×10^{-8}
Copper	1.72×10^{-8}
Aluminum	2.83×10^{-8}
Tungsten	5.50×10^{-8}
Nickel	7.80×10^{-8}
Iron	12.0×10^{-8}
Constantan	49.0×10^{-8}
Nichrome II	110×10^{-8}



4.8 ELECTRICAL ENERGY, POWER AND CURRENT HEATING EFFECT

It is very important that we understand the concept of power and why engineers want devices and circuits that consume small amount of power but firstly, let's define energy. Energy is the ability to do work, that is, the influence of an object to make another object move from one place to another. There are different forms of energy which include light energy, heat energy, sound energy, chemical energy e.t.c

Energy in one form can be transformed to energy in another form, for example, electrical energy is converted to light energy in a light source and en electric iron converts electric energy to heat energy. Devices that transform a physical quantity to electrical energy or vice versa are called **transducers**. Examples of physical quantities include temperature, pressure, sound, light e.t.c.

The amount of energy produced will always equal the amount of energy used and energy cannot be created nor destroyed.

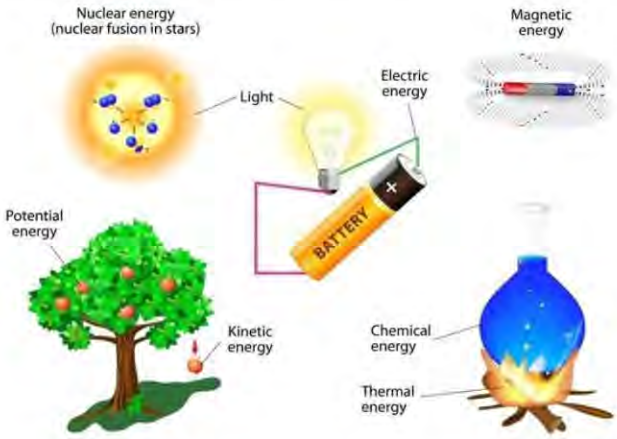


Figure 4-14 Different forms of energy

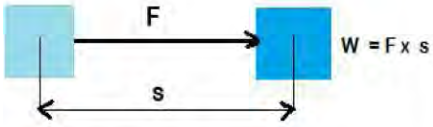
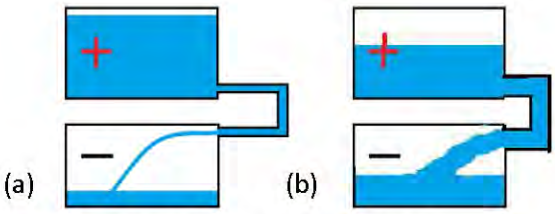


Figure 4-13 Work done in moving an object through a distance

Figure 4-15 Examples of transducers

When we consider power, it tells us how much of energy is generated or consumed within a period of time by a device i.e power is the rate at which energy is transferred (total energy produced or consumed divided by the time taken to produce or consume the energy). The more the power consumed for example by a device, the more the cost of using that device as compared to with another device that can deliver the same result with lower power consumed.



Pipe Size =Resistance; Water flow = Current
Tanks = Energy Source

Figure 4-16 Power consumption represented by different pipe sizes.

The tanks in figure 4-16 (a) has a small pipe connected between them while the tanks in (b) has a large pipe connected to them. Small power consuming devices (or high resistances) represent small pipes; it takes a longer time for the water in the upper tank to be emptied into the lower tank. High power consuming devices (or small resistances) represent large pipes; in this case the water is emptied quickly into the lower tank.

4.9 POWER CONSUMER AND PRODUCERS

A component in a circuit can either produce or consume power. In both cases, energy is transformed from one form to another. For example, a battery which produces power converts chemical energy within it into electrical energy while a LED converts electrical energy into light energy. In this regard, the components that convert another form of energy to electrical energy are a "**producer**" while those that convert electrical energy to other forms of energy are a "**consumer**".

Table 4-5 Power consumers and producers

POWER CONSUMER	POWER PRODUCERS
Resistors, Light Emitting Diode (LED), Radio set, Electric Iron, Television set e.t.c	**Battery, Solar Cell, Wind Turbine, Alternator e.t.c**

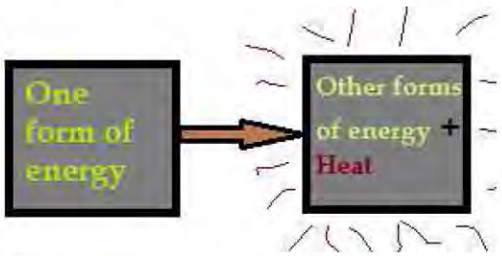


Figure 4-17 Energy conservation

NOTE: The total energy produced in a circuit will always equal the total energy consumed in that same circuit; this is called the **conservation law of energy**.

4.9.1 HOW TO CALCULATE POWER

We now like to know to calculate the power produced by a component or circuit. The generalized power law tell us that if we can determine the current through a device and the voltage across it, then the power used by the device is given as;

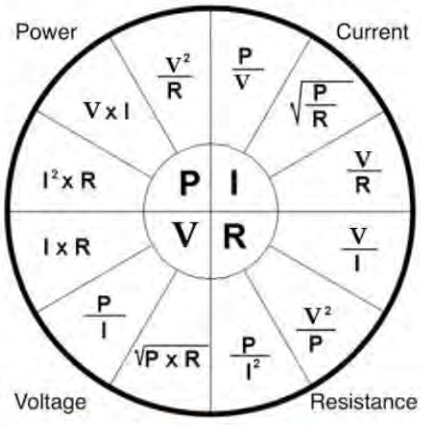
$$P = V \times I$$

Where P - power used

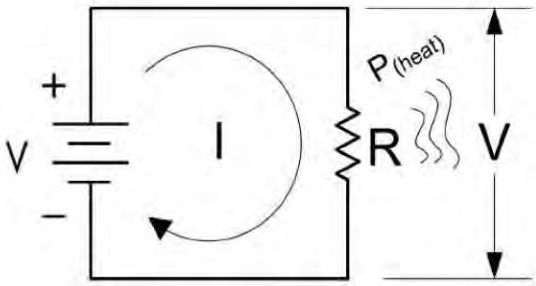
V - voltage across device

I - current through the device

NOTE: Although the power tells us the rate at which the energy is used up, it does not tell us about the forms of energy the electrical energy was transformed to.



(a)



(b)

Figure 4-18 (a) Power Chart (b) Parameters of a resistor connected to supply

4.9.2 POWER AND OHM'S LAW RELATIONSHIP

For any device that obeys the ohm's law, it is observed that the power consumed by such a device is **entirely** converted to only heat energy. For an ohmic device such as a resistor, we can relate the power law and the Ohm's law as;

Where $P = V \times I$ and since $V = I \times R$, we can write

$$P = (I \times R) \times I \qquad \text{and} \qquad P = V \times \left(\frac{V}{R}\right)$$

$$P = V \times I \quad \text{or } P = I^2 \times R \quad \text{or } P = \left(\frac{V^2}{R}\right)$$

Power –Ohmic law

This means that in a circuit, the heat produced is as a result of the ohmic devices or material within it. When components convert one form of energy to another, a part of the energy is converted to heat. For example, a LED will convert electrical energy to light and heat energy as a result of the ohmic property of the material used in fabricating it and this is a source of **power loss**. As we now know that during the cause of energy transfer from one form to another, there exits an "unwanted" energy produced in form of **heat**. For this reason, scientist continue to research for new materials with high energy transfer efficiency , that is, have low heat generation during energy transfer or low power loss. For example, when we compare the LED and a filament bulb which reveals that the LED is a more efficient light source. Also, the more power a device require to operate it, the more it will quickly run down the energy of the power supply connected to it power make it work.

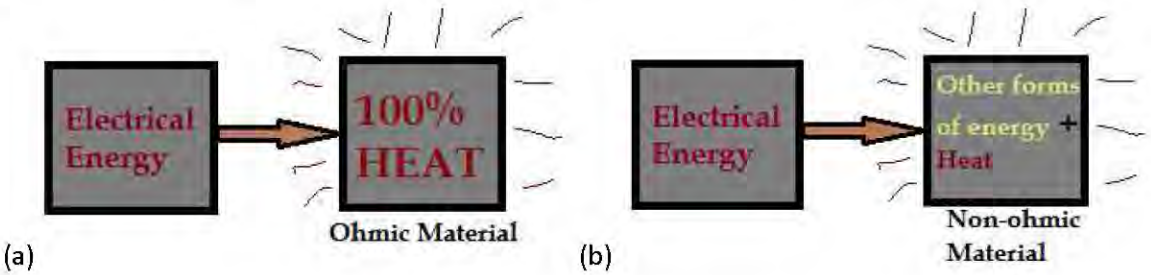


Figure 4-19 Power dissipation for (a) Ohmic materials (b) Non-ohmic materials

Example: If a current flowing through a resistor of 10kΩ is 20mA. What is the heat dissipated in the resistor?

Solution; $R = 10k\Omega, \mathrm{I} = 20\mathrm{mA}$

$P = I^2R = (0.02)^2A \times 10{,}000\Omega$

$\therefore P = 0.0004A \times 10{,}000\Omega = 4W$

Note: A resistor of power rating of less than 4W would be damaged by such amount of current. The rule of thumb in selecting a resistance value is to ensure that the resistor power rating is at least twice the maximum expected value.

4.10 HEATING ELEMENT: The ability of ohmic materials to dissipate large amount of heat when current passes through them has been used for making useful electrical devices such as electric iron, soldering iron and electric cookers e.t.c. The major part of these devices which is responsible for heating is a low resistance wire called **heating element** made from alloys which does not oxide in air when it gets hot. It is usually coiled so as to concentrate the heat.

Figure 4-20 Example of appliances which operate using heating elements.

Figure 4-21 Heating element becomes red hot when connected electricity.

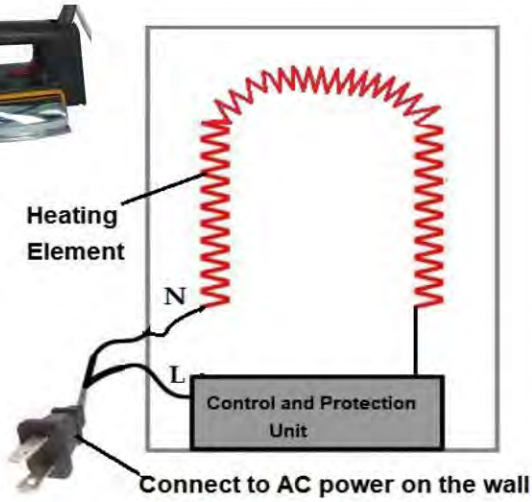


Figure 4-22 The simplified diagram of an electric cooker. The cooker's main part is the heating element which is connected to an AC source. It has a control unit for changing the temperature and protection unit for safety in case it malfunctions.

4.11 UNDERSTANDING POWER RATING

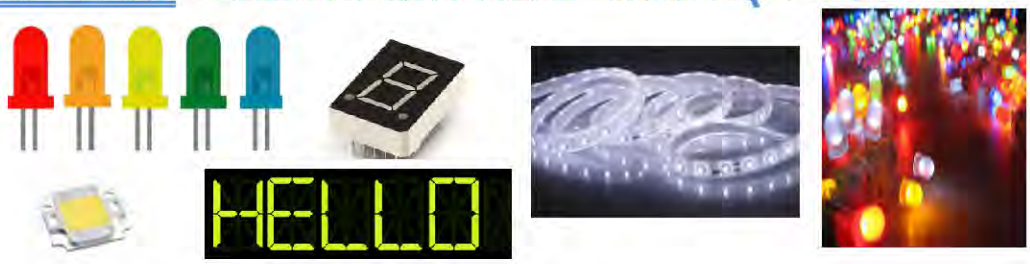
Electrical devices usually have power rating which give the information on how much energy it is able to consume when connected to a power supply. The power rating also gives information on the usage as to know the working voltage and current of the component. If the working voltage or current is exceeded, it could lead to a large dissipation of heat inside it which could damage or totally destroy the device.

Table 4-6 Common appliances and their power ratings

Appliance	Watts
Stereo	200
Table Fan	200
TV-VCR	250
Small Refrigerator	350
Hand Drill - 1/2"	600
Light Bulb - 100 W	100
Clock Radio	7

Appliance	Watts
Microwave - 1000 W	1000
AC (5,000 BTU)	700
Computer	150
Hair Dryer	1000
Coffee Maker	1200
Blender	400
Laptop	75

CHAPTER 5 LIGHT EMITTING DIODE (LED)



Almost all small light sources we can see in our phones, cars, homes and on every other electronic gadget around us are LEDs. (LED is pronounced as ell-ee-dee)

5.1 WHAT ARE LEDS?

The Light Emitting Diode (LED) is a type of diode (Diodes will be discussed in a later chapter) that are designed to produce visible or infrared light. LEDs convert electrical energy to light energy.

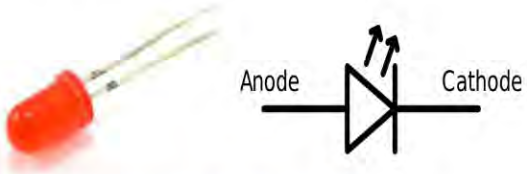


Figure 5-1 LED and the symbol

5.2 FILAMENT BULB VS LED

Filament bulbs were the common light sources available before the discovery of the LEDS. In a filament bulb, the conversion of electrical energy to light energy is made possible by passing sufficient current through a thin wire, so that it heats up and become hot so much that it starts to produce visible light. LEDs on the other hand are made from semiconductor material (semiconductors have both conductor and insulator property).

Table 5-1 comparing an LED and filament bulb

Comparison	LED	Filament Bulb
Life span (Average)	50,000 hours	1,200 hours
Power consumption	6 -8 watts	60 watts
Cost	Very cheap	High
Sensitivity to humidity	No	Some
Durability	Very durable	Not very durable
Sensitivity to low temperature	None	Some
Contribution to CO_2 emission	Very Low	High

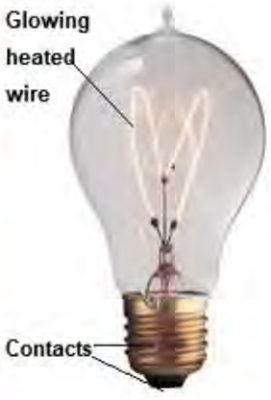


Figure 5-2 Filament Bulb

5.3 TYPES OF LED

1. Visible- Light LED: common colours of visible light LEDs include the green, yellow, orange and red lights.
2. Infrared LEDs: these LEDs emit infrared light. They are the type found on television remotes.
3. Blinking LEDs: these LEDs have internal circuitry that makes it blink or flash when powered. They have uses in light flasher.
4. Multicolour LEDs: can emit more than one kind of light colour depending on the circuit design. For a multi-colour LED with Red-Green-Blue (RGB) combination, it can be made to produce all the rainbow colours by changing the brightness of each colour.

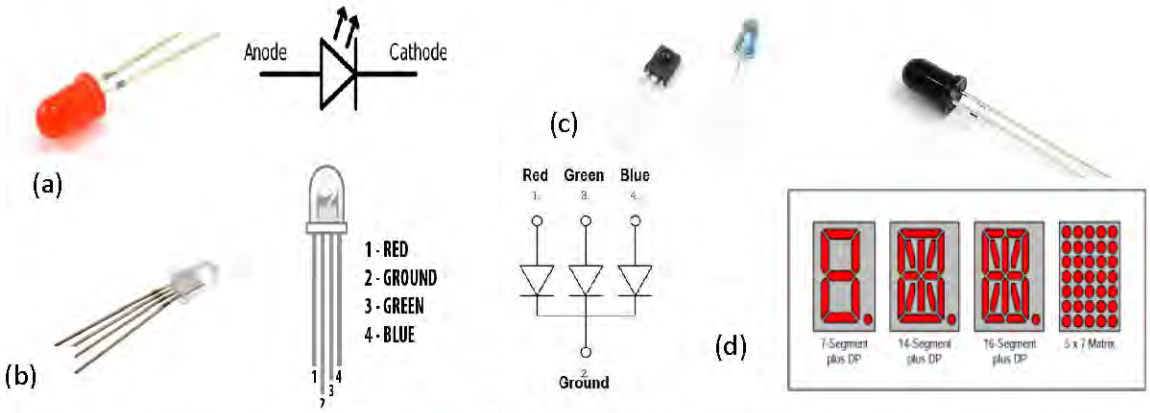


Figure 5-2 (a)Generic Red LED (b) Multicolour LED (C) Infrared LED and receiver (d) 7-Segment, 14-Segment and 5x7 Matrix Display

5.4 HOW AN LED WORKS

The LED is made by joining different types of semiconductor materials. When connected to a battery, it produces light at the point where the two materials join. The kind of light produced depends on the type of materials used and the type of transparent casing used for the LED. The LED behaves like an electronic switch which emits light when current flows in only one direction and will not give light when current flow in the opposite direction. For the LED to give light, the current must flow from only the anode to the cathode. The brightness of the LED can be adjusted by varying the amount of current flowing through it.

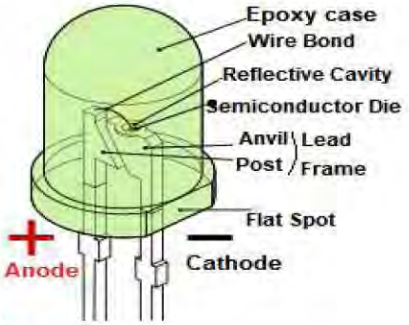


Figure 5-3 Internal structure of an LED

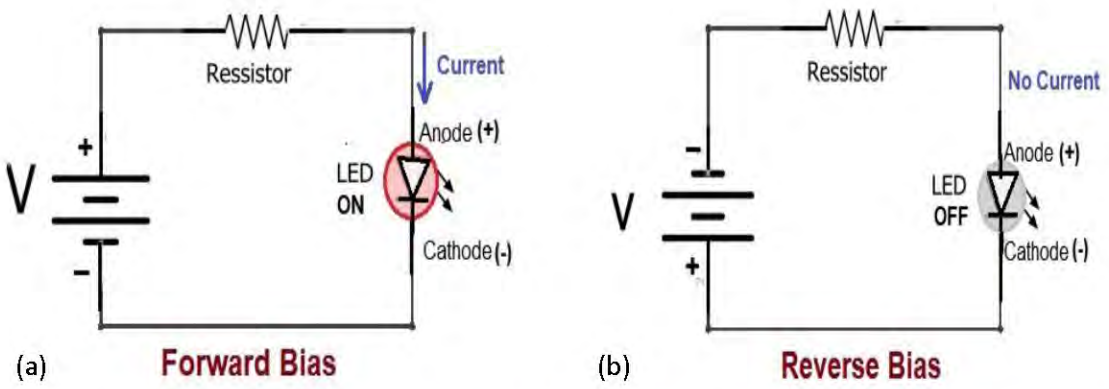


Figure 5-4 (a) LED (glowing) connected in the forward bias mode through a series resistor (b) LED (not glowing) when connected in the reverse bias (battery polarity swapped)

5.5 LED FORWARD VOLTAGE AND MAXIMUM CURRENT

Before an LED will emit light, the voltage across the anode and the cathode terminals must be greater than the forward voltage (V_{LED}). If the current through an LED get too high beyond the maximum current (I_{LED}) the LED can handle, it can result to it being destroyed by the heat generated within it. The current through the LED can be limited by using a resistor.

The forward voltage (V_{LED}) and the maximum current (I_{LED}) depend on the colour and material used for making the LED. These values are usually given by the manufacturer. Typically, for low intensity LEDs the forward voltage (V_{LED}) is about 2V and the maximum current (I_{LED}) is about 20mA.

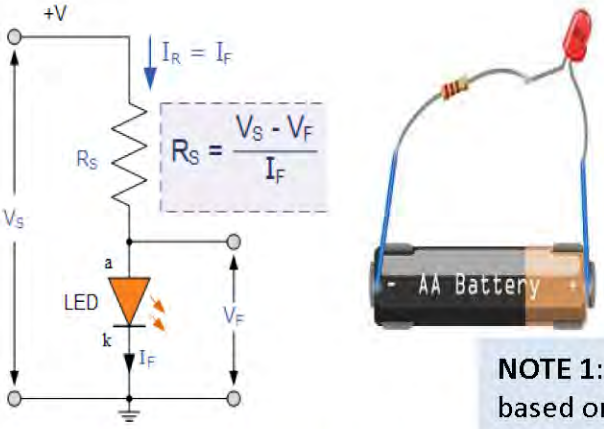


Figure 5-5 LED circuit and the physical connection

Table 5-1 Typical value of V_{LED} and I_{LED}

Lens Colour	Forward Voltage		Forward Current	
	Typical	Maximum	Typical	Maximum
RED	1.6 Volts	2.0 Volts	0.010Amp	0.020Amp
GREEN	2.2 Volts	3.0 Volts	0.010Amp	0.020Amp
YELLOW	2.2 Volts	3.0Volts	0.010Amp	0.020Amp
"Blue" (Note)	3.8 Volts	4.5 Volts	0.020Amp	0.020Amp
WHITE	3.2-3.6 Volts	3.8 Volts	0.010Amp	0.020Amp

NOTE 1: The above Voltage and Current ratings are based on several everyday generic LEDS in the 3mm and 5mm ranges.

NOTE 2: Blue colour LEDS may typically have forward working voltages exceeding those used in the above example. Forward working voltages for some Blue colour LEDS may also fall in the 4.9 to 5.5Volt range.

A light load or high resistance component or devices requires small amount of current to made it work while a heavy load or low resistance component is one that requires very large amount of current to make it work. The higher the current a component from the power supply (in this case a battery) the faster it drains the battery till it is dead.

5.6.1 SHORT CIRCUIT

A short circuit happens when a wire is used to connect the positive side of a power supply (e.g. a battery) to the negative side without any load connected in the path of the current.

WARNING: Short circuit can lead to fatal injuries and should be avoided in a circuit.

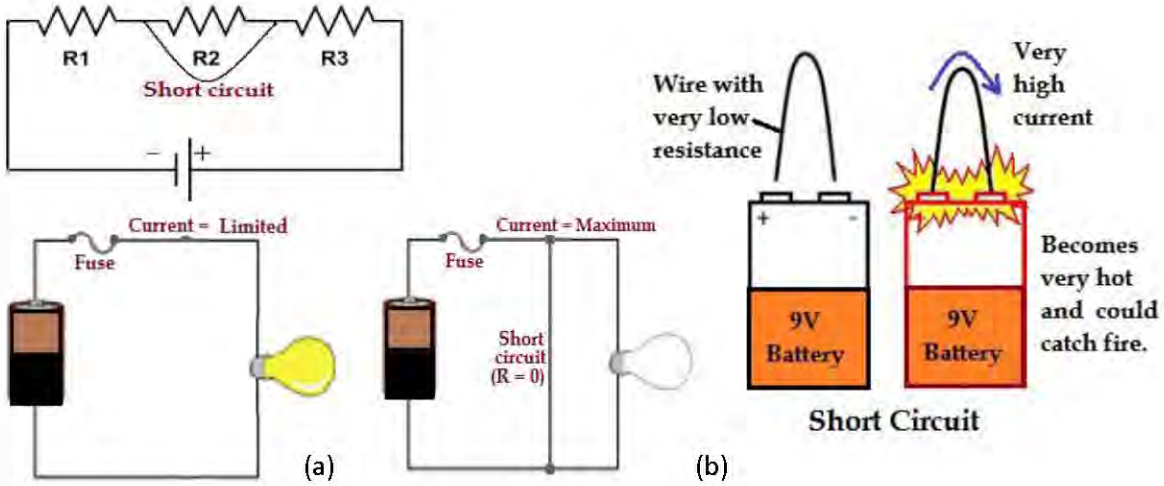


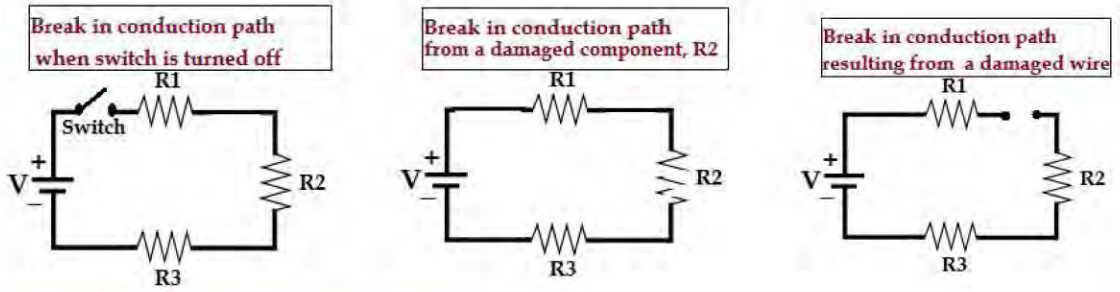
Figure 5-9 (a) Short circuit of a resistor and light bulb (b) Short circuit of a battery

When a short circuit takes place, it will cause a infinite (very large) amount of current flow between the terminals of the battery. Usually, when you have a circuit with a connected load, it will provide a resistance that limits the current flow in the circuit given by the Ohm's law relationship but for a short circuit, there is no connected load (Resistance = 0) and there for will cause an infinite(very high) current flow according to the Ohm's law relationship.

When a power supply (e.g. a battery) is allowed to supply an infinite amount of current, it makes it get hot as well as the connecting wires and damage these cause it to get damage and even lead to a fire outbreak. Short circuit could be cause when the insulation of conductors get peeled and make contacts. A fuse can be used in a circuit to prevent a short circuit by setting a maximum current that will flow.

5.6.2 OPEN CIRCUIT

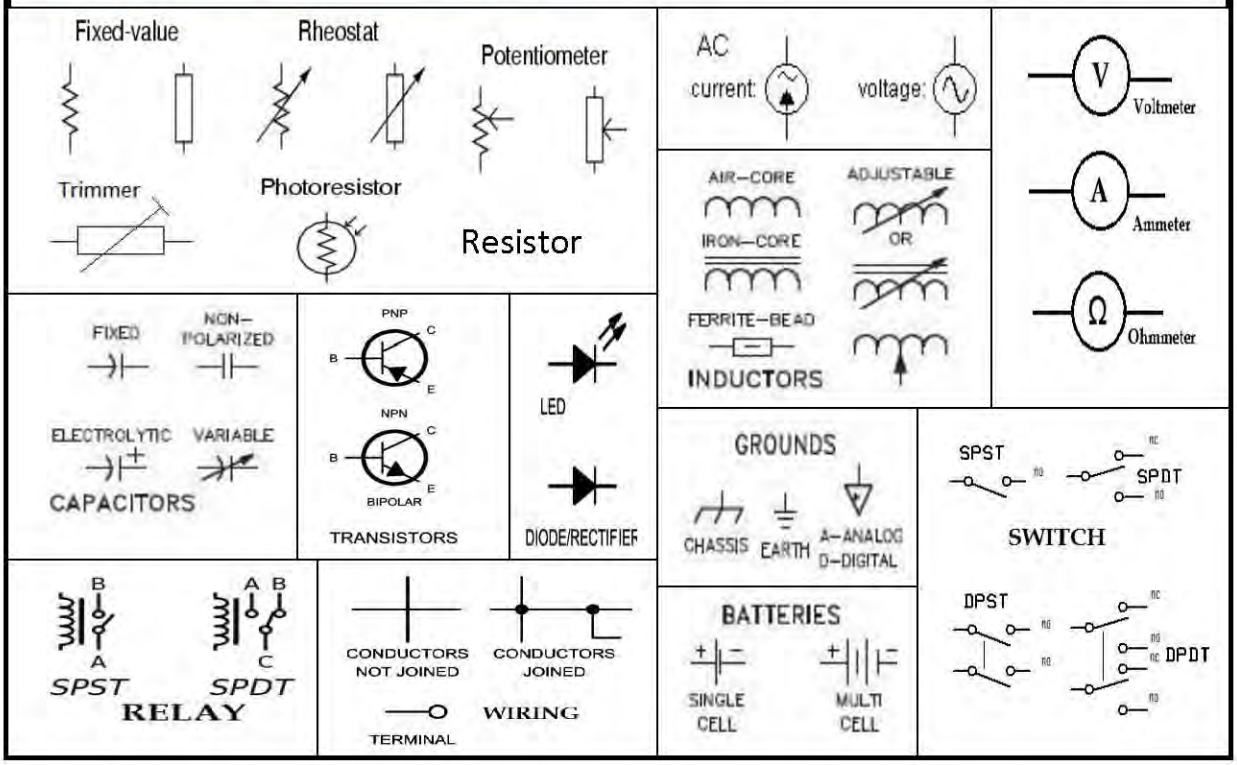
Open circuit is the opposite of a short circuit. An open circuit represents a broken connection in any part of a circuit resulting from a break in a component or wire. An open circuit will result to no current flowing through the circuit because it places an infinite resistance in the path of the current flow. A damage component e.g. a resistor can sometime develop infinite resistance when damaged. A multimeter can be used to check for an open circuit.



5.7 UNDERSTANDING CIRCUIT SCHEMATICS

Communication is an essential part of life as it aids continuity and proper documentation. If one has to describe a circuit in words, then some information may not be captured and language differences may limit knowledge transfer. Electronics designers have therefore come up with a means of communicating their ideas and results by adopting universal signs and symbols which are representatives of circuit elements and concepts. These signs and symbols are called **circuit schematics or circuit symbols**. A diagram of schematics representing an electric circuit is called **schematics or circuit diagram.** Schematics symbols and diagram are like guides to help us design, interpret, troubleshoot (fault finding) and modify electronic circuits. Once you acquire the basic knowledge of circuit schematics, you will be equipped with the skills to interpret circuit diagram and even start drawing your own. Examples of schematic symbols are shown below.

Figure 5-10 Examples of Schematics symbols



5.8 TIPS FOR PROPER CIRCUIT SCHEMATICS OR DIAGRAM DRAWING

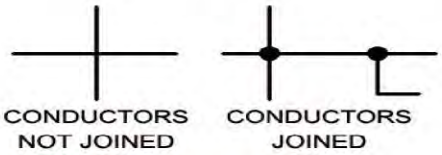
A circuit schematic or diagram must communicate sufficient information for others to understand. Below are some of the things to note when drawing circuit diagrams;

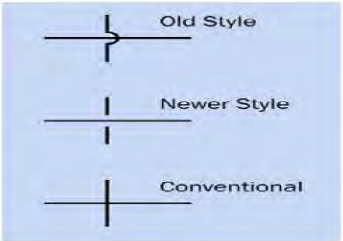
1) Each component symbol in the circuit must have a name and a value to identify it. For example, the names for resistors are represented by **R's** while capacitors are represented by **C's**. The value of the component tells us size or type of the component.

A	separable assembly
AR	amplifier
AT	attenuator; isolator
B	blower, motor
BT	battery
C	capacitor
CB	circuit breaker
CP	connector adapter, coupling
CN	capacitor network
D or CR	diode
D or VR	breakdown diode
DC	directional coupler
DL	delay line
DS	display, lamp
E	terminal
F	fuse
FD*	fiducial
FL	filter
G	generator, oscillator
GN	general network
H	hardware
HY	circulator, directional coupler
J	connector, jack, female
K	contactor, relay
L	coil, inductor, bead, ferrite bead
LS	loudspeaker, buzzer
M	meter
MG	motor-generator
MH*	mounting hole
MK	microphone
MP	mechanical part
P	connector, plug, male
PS	power supply
Q	transistor
R	resistor
RN	resistor network
RT	thermistor
S	switch
T	transformer
TB	terminal board, terminal strip
TC	thermocouple
TP	test point, In-circuit test points
TZ	transzorb
U	inseparable assembly, IC pkg
V	electron tube
VR	voltage regulator
W	wire, cable, cable assembly
X	fuse holder, lamp holder, socket
Y	crystal, magnetostriction oscillator
Z	miscellaneous

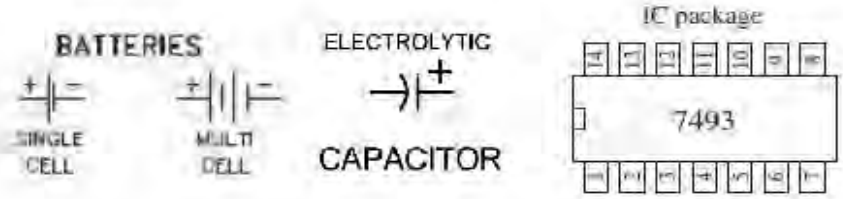
2) If there is more than one component with the same name in a circuit, each similar component should be labelled with a number to identify it. For example you can write R1, R2, C2 e.t.c
3) For large value component labels, the use of abbreviations will keep the schematics tidy.

Prefix	In words	Multiply by	Factor
nano (n)	Billionth	1/1000000000	$1*10^{-9}$
micro (μ)	Millionth	1/1000000	$1*10^{-6}$
milli (m)	Thousandth	1/1000	$1*10^{-3}$
centi (c)	Hundredth	1/100	$1*10^{-2}$
deci (d)	Tenth	1/10	$1*10^{-1}$
		1	
deca (da)	Ten	10	$1*10^{1}$
hecto (h)	Hundred	100	$1*10^{2}$
kilo (k)	Thousand	1000	$1*10^{3}$
mega (M)	Million	1000000	$1*10^{6}$
giga (G)	billion	1000000000	$1*10^{9}$





5) Always ensure to indicate the polarity of the components if any. When representing integrated circuits(IC), the names are written on the inside while the pin numbers are on the outside.

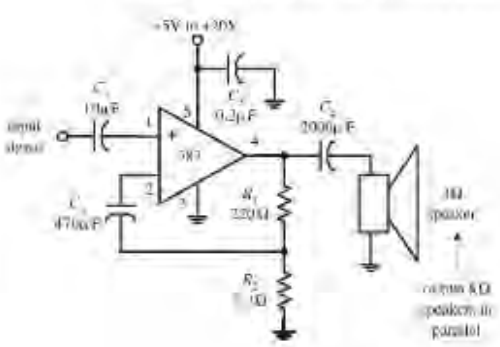


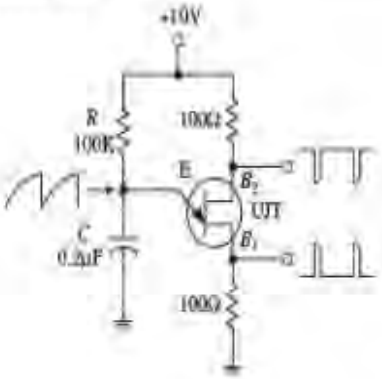
6) When drawing circuit schematics the input is usually placed on the left side while the output will be at the right side. Also, the positive supply will usually be place at the top while the negative (common ground or reference point) will be at the bottom. If there are more than one voltage levels, it should be clearly indicated in the circuit diagram.

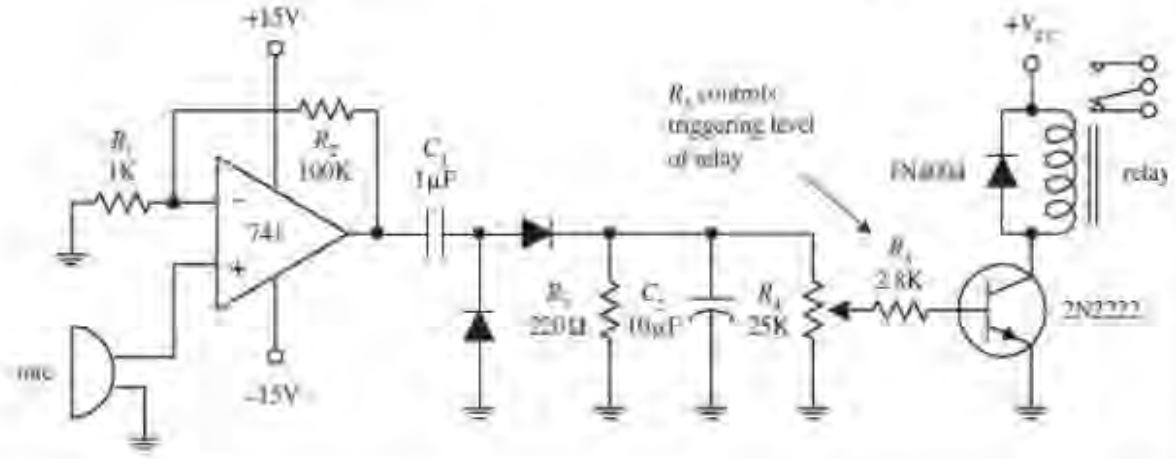
7) Always keep **functional groups** (circuit segments that perform a similar function) such as voltage divider, filters e.t.c separated within the schematics.

8) Whenever the waveform of a signal is to be shown in a circuit, the exact waveform diagram should be placed at the location where the waveform is needed.

9) Finally but not limit to the list in the guide, learn from already drawn schematics from other source such as textbooks and online resources.







CHAPTER 6 FUSES

A fuse is a protective component that is required to cause a break (or open circuit) in circuit connection when the current flowing is more than the limit set by the fuse. The maximum current capable of making a fuse to blow up resulting to an open circuit will usually be known. The major reason for very large current flow is a short circuit or power surge (sudden increase in voltage). The fuse is usually placed on the positive side of the power supply for DC and on the live wire for AC.

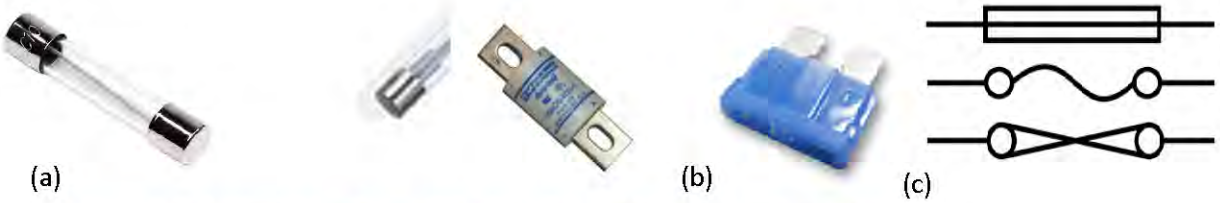
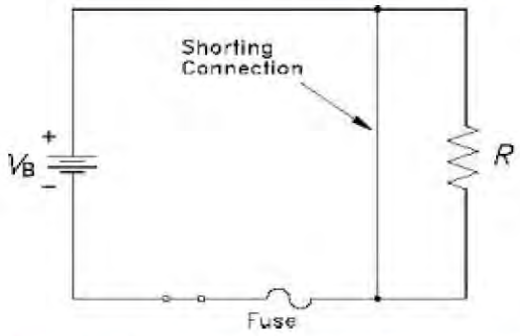


Figure 6-1 (a)Cartridge fuses (b) Blade fuses (c) Fuse circuit symbols



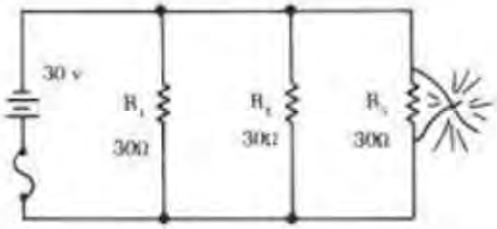


FIGURE 8–154. A shorted component causes the fuse to open.

Figure 6-2 Fuse assist in protecting a circuit from damage during short circuit

6.1 HOW A FUSE WORKS

A fuse consists of a container having electrical contacts on both ends having a piece of bare (un-insulated) conductor or wire strand connecting the terminals. When a certain amount of current is allowed to flow through the fuse, the piece of conductor or wire strand will usually gets heated till it melts and break up the circuit connection. The current amount of current required to melt the fuse will get given by the manufacturer.

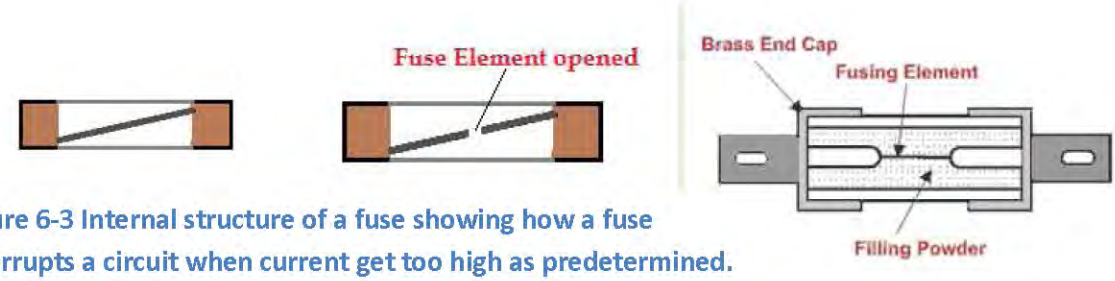


Figure 6-3 Internal structure of a fuse showing how a fuse interrupts a circuit when current get too high as predetermined.

In practice, when selecting a fuse, the fuse current rating should be 50 percent more than the nominal current expected for that circuit path. A blown fuse must always be replaced with another fuse with the same current rating. For example, a 5A fuse should be replaced with another 5A fuse **not** a 10A fuse.

Warning: Do not replace a fuse with another fuse of higher current rating. This may lead to over-current flow leading to damage of devices and fire outbreak. For re-wireable fuses, the same wire gauge of conductor should be used when the fuse blows.

6.2 TYPES OF FUSE

Fuses come in different shapes and sizes and with different current ratings. A fuse is usually house in a **fuse holder** for firm connection to its contacts. Fuses also have colour codes which have standard current rating as shown in the table below.

Figure 6-4 images of different kinds of fuse and their holder which are used for holding the fuse in place when connected in a circuit.

Table 6-1 Fuse colour code and their current ratings

Color Ratings for STANDARD and MINI Fuses	
Fuse Amp Rating	Identification Color
3	Violet
5	Tan
7.5	Brown
10	Red
15	Blue
20	Yellow
25	Colorless
30	Green

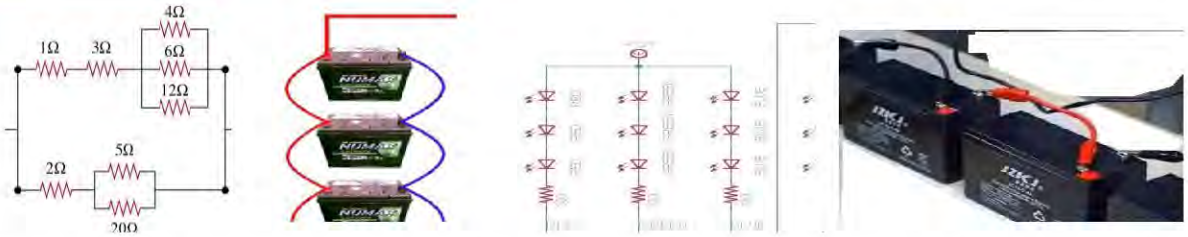
6.3 SAFETY HANDLING TIPS

1. Do not attempt repairs on line-powered circuits with the power on. Always remove the main power first.
2. Wear eye protection: large plastic-lens eyeglasses or safety goggles.
3. Don't wear any jewelry or other articles that could accidentally contact circuitry and conduct current.
4. When building power supplies and other instruments, make sure that all wires and components are enclosed in a metal box or insulated plastic enclosure.
5. Make sure all components that are connected to ac power lines meet required power ratings.
6. Use only shielded (insulated) lead probes when testing circuits. Never allow your fingers to slip down to the metal probe tip when testing a "hot" circuit. Also, make sure to remove power from a circuit when making a connection with wires and cables.
7. Perform as many tests as possible with the power off and the equipment unplugged.
8. Switch off electrical appliances which do not need to be left on when equipment is not in use.
9. Keep work area clean and tidy during and after use and unplug/ switch off equipment after use.
10. When working on ac-line circuits, wearing rubber-bottomed shoes or sneakers, or standing on a sheet of rubber or wood, can reduce possible shocks.
11. **Soldering:**
    a. Wear safety glasses and avoid inhaling the fumes produced
    b. Always place soldering iron in holder
    c. Always solder over a workbench
    d. Always treat iron as hot
    e. Unplug with 5 to 10 minutes left in class
12. **Never** plug in an electronics project without first asking the instructor
13. **Never** work on electronics equipment with wet hands/ in wet areas
14. **Never** work on energized electronics equipment with both hands
15. If you were not trained how/ asked to use it in this class, don't touch it.
16. Open flames should not be left unattended and no open flames should be used near flammable solvents.
17. Keep fire escape routes clear at all times.
18. Before starting work, all staff and students are to become familiar with the fire procedures and location and use of fire-fighting equipment within the laboratory.

ELECTRONICS: GOING FURTHER

PART 2

CHAPTER 7 SERIES AND PARALLEL ARRANGEMENTS

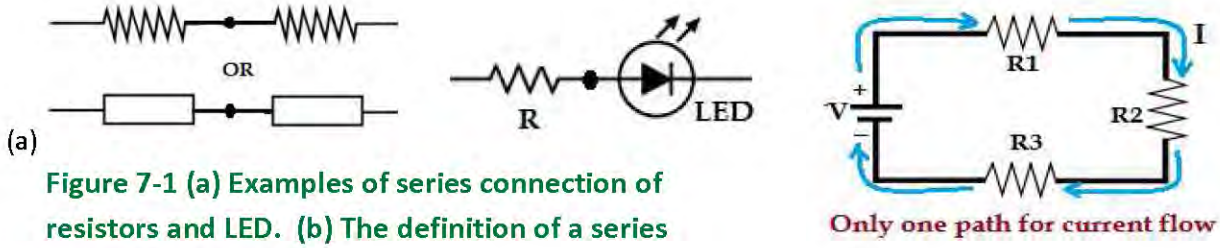


We are going to take this lesson further as we learn about different circuit arrangement. A simple circuit is easy to setup and understand, that is, having a power supply and a load connected together by wires. In reality, we could have more than one sources connected to a networks of components which forms a load in a circuit.

There are two major ways of combining sources and components to form a complex circuit namely; **series** and **parallel** arrangements.

7.1 SERIES ARRANGEMENT

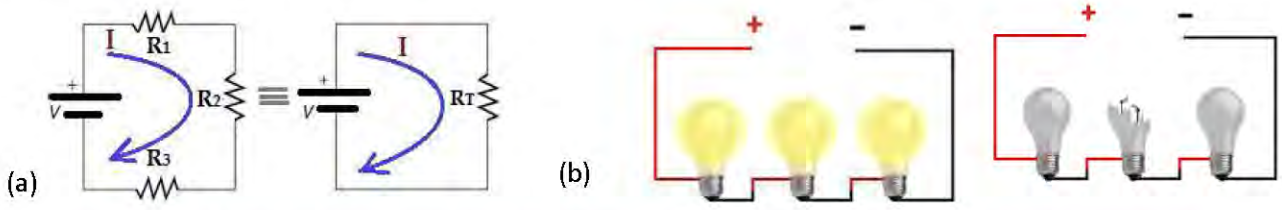
In a series arrangement, the current flows through only a **single path** which starts from the positive terminal of the power supply through the load and then back to the negative terminal of the same source.



(a) (b)

Figure 7-1 (a) Examples of series connection of resistors and LED. (b) The definition of a series connection circuit.

The series arrangement forms an end-to-end connection of the circuit and for this reason, the **same amount of current** flows through all the components in the series network. If any of the components along a series connection is removed or gets damaged so that it has an infinitely high resistance (or an open circuit), it will prevent the flow of current in the circuit and the circuit will not function.



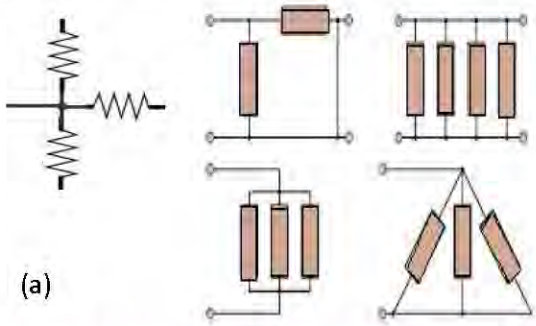
(a) (b)

Figure 7-2 (a) Three resistors connected in series are added to give one equivalent resistor (b) A faulty bulb in series prevent the whole circuit from functioning

The same current flows through all the components in a series arrangement but the voltage across each component may not be the same but divided in a given proportion as determined by their resistances. When the voltage across all the components in the series arrangement is added up, it will be equal to the voltage from the power source.

7.2 PARALLEL ARRANGENT

In a parallel arrangement, the components are connected in such a way that the voltage across each of them is the same. In that case, the components are independent of each other because the current flows through each component separately. Each of the components in parallel forms a **branch** of network for current. The total current flowing from the positive terminal of the power source gets divided along each branch of the network in a given proportion determined by their resistances. The current then flows out of each component branch to get combined and then flows back into the negative terminal of the power supply.



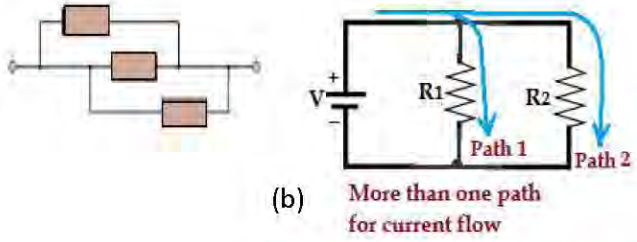


Figure 7-3 (a) Examples of parallel connection of resistors

(b) The definition of a parallel connection circuit.

Unlike the series arrangement, when any of the components in the branch of the parallel arrangement is removed or get damaged so that it leads to an open circuit, the circuit should still function. But if the damage or open circuit is along the main path from which each branch is tapped, then the rest of the network after that open circuit will not function. Also, sum of the currents through all the branches in a parallel arrangement will usually equal to the total amount of current supplied by the power supply.

Table -7-1 Series Vs Parallel

Points for comparison	Arrangements of bulbs in:	
	Series	Parallel
Number of paths for the electric current	Only one path: current passes through components one after the other	2or more paths: current splits up and passes through each branch at the same time: paths are independent of each other
Brightness of bulbs	Dimmer	Brighter
If one bulb is removed or damaged	Electric current cannot flow through the circuit, the remaining bulb will not light up	Electric current can still flow through the other path and the other bulb still light up.
Application	Used for the placement of switches and fuses in circuits	Used in all possible connection of circuits in houses and other related installation works

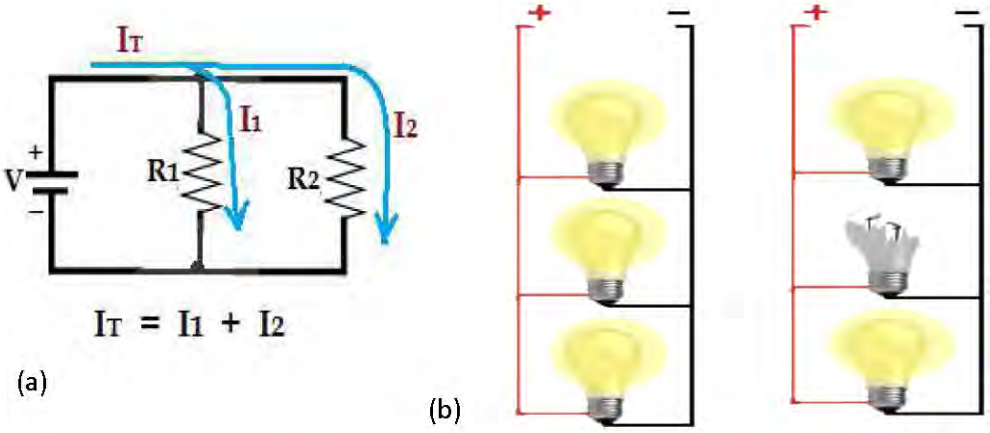


Figure 7-4 (a) Current relationship in a parallel circuit (b) A faulty bulb in parallel does not affect the rest of the circuit from functioning.

7.3 CALCULATING TOTAL RESISTANCE IN SERIES ARRANGEMENT

When resistors are connected in series, the total resistance can be determined by adding the voltage drops across each of the resistors.

$$V_{TOTAL} = V_1 + V_2 + V_3 + V_4 \ldots \qquad (1)$$

The dots means the resistors can be as many as possible. The equation (1) above is also known as the **Kirchhoff's Voltage Law (KVL).** The same current flows through series circuit so that we can re-write the equation (1) as;

$V = I\,R$ - from Ohm's law

$$IR_{TOTAL} = IR_1 + IR_2 + IR_3 + IR_4 \ldots \qquad (2)$$

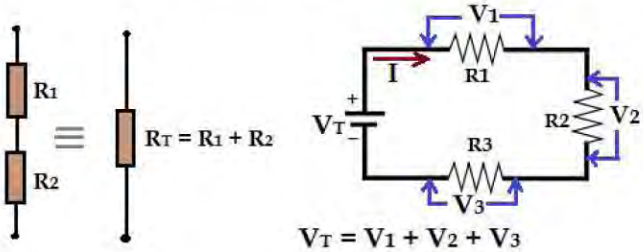
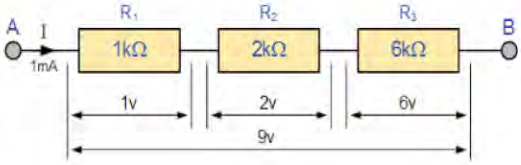


Figure 7-5 (a) Equivalent resistance for two resistances in series. (b) The voltage relationship for resistances in series. The sum of their voltage drop will equal to the voltage of the power supply.



(c) Example 1

Solution; $R_1 = 1k\Omega, R_2 = 2k\Omega, R_3 = 6k\Omega$

$V_{PS} = 9V$

$R_{TOTAL} = R_1 + R_2 + R_3 = 1k\Omega + 2k\Omega + 6k\Omega$

$$R_{TOTAL} = 9k\Omega$$

From Ohms law, $I = {}^{V_{PS}}/_{R_{TOTAL}}$

$I = {}^{9V}/_{9k\Omega} = 1mA$

If we factorize the current (I) on both sides if the equation, we get

$$IR_{TOTAL} = I(R_1 + R_2 + R_3 + R_4) \ldots \quad (3)$$

Eliminating the I on both sides gives

$$R_{TOTAL} = R_1 + R_2 + R_3 + R_4 \ldots \quad \text{EQUAVALENT RESISTANCE IN SERIES}$$

When resistors are connected in series, the result is a amounts to a higher resistance value than the resistor with the highest resistance.

7.4 CALCULATING TOTAL RESISTANCE IN PARALLEL ARRANGEMENT

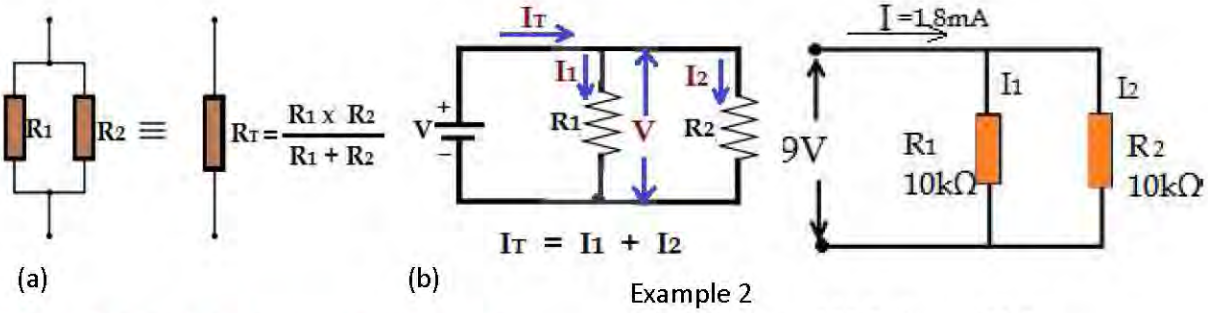
When we connect resistors in parallel, the total resistance of such arrangement can be calculated by summing the current flowing through each of the branches and then applying the Ohm's law to the current equation as follows;

$$I_{TOTAL} = I_1 + I_2 + I_3 + I_4 \ldots \quad (1)$$

The above equation (1) is known as the **Kirchhoff's Current Law (KCL).** Using the Ohm's law, we can replace the current as follows;

$$I = \left(\frac{V}{R}\right) \quad \text{from Ohm's law}$$

So that, $$\frac{V}{R_{TOTAL}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} + \frac{V}{R_4} \ldots$$



(a) (b)

Figure 7-6 (a) Equivalent resistance for two resistances in parallel. (b) Two resistances in parallel and their current relationship. The sum of the current for each of the branches will equal the total current.

Example 2

Solution; $R_1 = 10k\Omega, R_2 = 10k\Omega$

$$R_{TOTAL} = \frac{R_1 \times R_2}{R_1 + R_2} = \frac{10k\Omega \times 10k\Omega}{10k\Omega + 10k\Omega} = 5k\Omega$$

From Ohms law, $I = {}^{V_{PS}}/_{R_{TOTAL}}$

$$I_{TOTAL} = {}^{9V}/_{5k\Omega} = 1.8mA$$

$$Check \quad I_1 = I_2 = {}^{9V}/_{10k\Omega} = 9mA$$

We can then factorize the voltage (V) from both side of the equation and eliminate it.

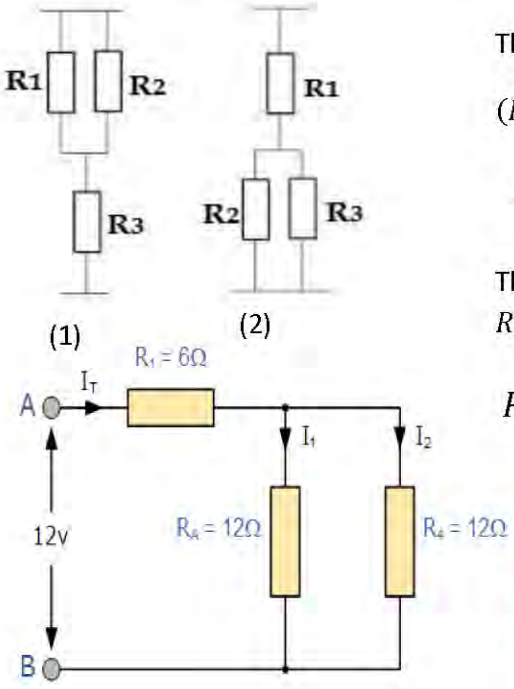
$$\frac{V}{R_{TOTAL}} = V(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4})$$

$$\frac{1}{R_{TOTAL}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \ldots \text{EQUVALENT RESISTANCE IN PARALLEL}$$

The parallel arrangement of resistance produces an equivalent resistance of lower value than the lower resistance in the arrangement.

7.5 COMBINING SERIES AND PARALLEL CONNECTIONS

It is possible to make a combination of both series and parallel connection. When such an arrangement is made, it will possess the characteristics of both the series and parallel arrangements.



The first arrangement (1) can be calculated as:

$(R_1\ parallel\ R_2)series\ R_3\ or\ (R_1\ //\ R_2) + R_3$

$$R_{TOTAL} = \left(\frac{R_1 \times R_2}{R_1 + R_2}\right) + R_3$$

The second arrangement (2) can be calculated in similar way:

$R_1\ series(R_2\ parallel\ R_3)\ or\ R_1 + (R_2\ //R_3)$

$$R_{TOTAL} = R_1 + \left(\frac{R_2 \times R_3}{R_2 + R_3}\right)$$

Figure 7-7 A series-parallel arrangement of resistances can be calculated by applying the same principle of series and parallel arrangement

7.6 CELLS IN SERIES AND PARALLEL ARRANGEMENT

Cells can also be added in series, parallel or a combination of series-parallel arrangement. When cells are added in series the result will give a setup with an overall larger voltage which is the sum of all the voltage of the individual cells. For a parallel arrangement of cells, this will give a setup with an overall high current output capacity.

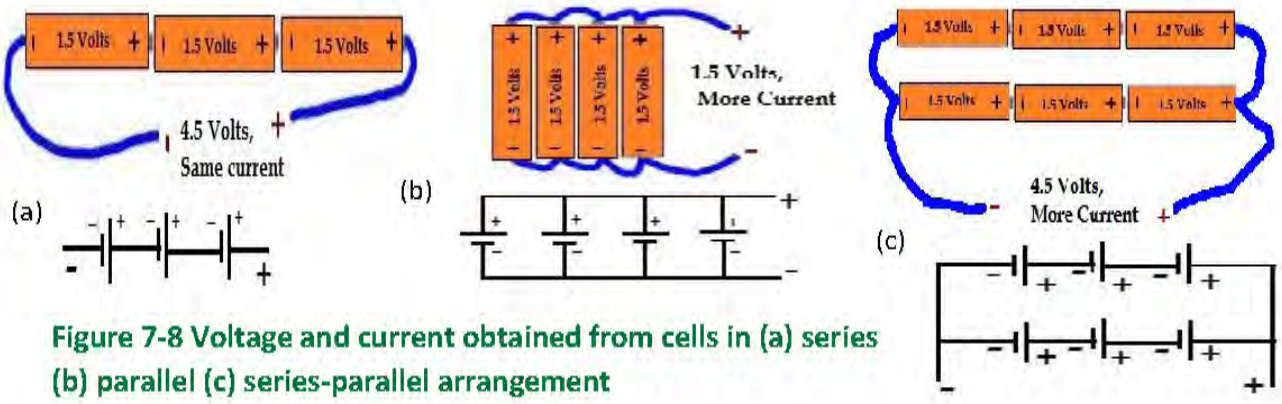


Figure 7-8 Voltage and current obtained from cells in (a) series (b) parallel (c) series-parallel arrangement

Cells are not 100% efficient due to an internally existing resistance inside them which tends to limit the current flow and is responsible for heating up the cells when in use, according the power ohmic law. This inherent resistance in cells is called the **internal resistance, R_{in}.** The internal resistance also develops a voltage drop which lowers the nominal voltage of the cell when a load is connected to it.

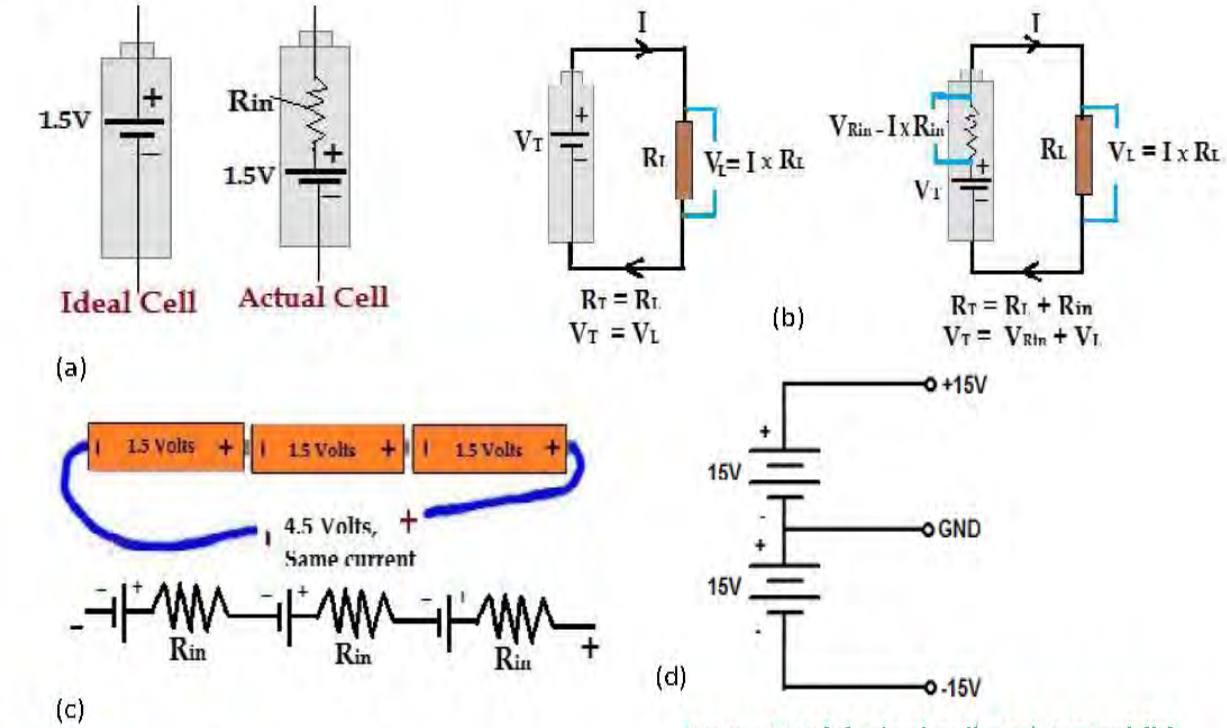
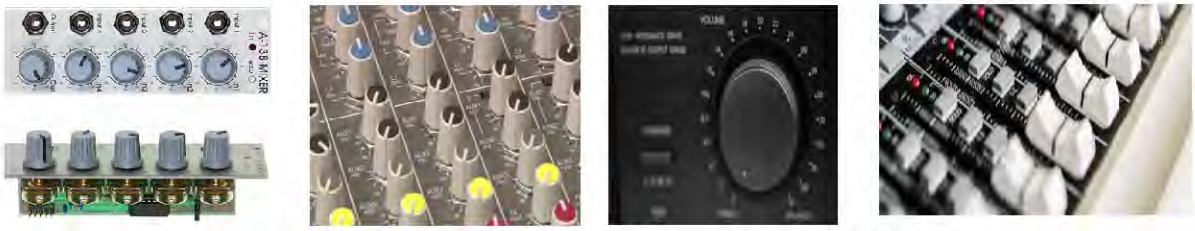


Figure 7-9 (a) Ideal cell and typical (b) Cell voltage drop resulting from internal resistance of a cell when connected (c) Cells in series and parallel with internal resistance (d) Series cell create dual polarity supply.

CHAPTER 8 VARIABLE RESISTORS AND VOLTAGE DIVIDER



Variable resistors and voltage divider circuit are very useful for varying the current and voltage from a power supply. If the voltage from the power supply available is higher than the voltage required powering a circuit, with the aid of a variable resistor or a voltage divider circuit, the power supply voltage can be reduced to the needed voltage. Variable resistors have been known to be used as manual volume controls in electronic devices.

8.1 VARAIBLE RESISTORS

A variable resistor is a resistor which has the feature that allows for adjusting the resistance of the resistor. The change in resistance could be from a very low resistance to a very high resistance value. A variable resistor which is made to vary the current flow in a circuit is called a **rheostat** while a variable resistor which is designed to divide voltage is called a **potentiometer** (commonly called **pot**). A **trimmer** is a type of potentiometer which is design to be adjusted occasionally within a circuit.

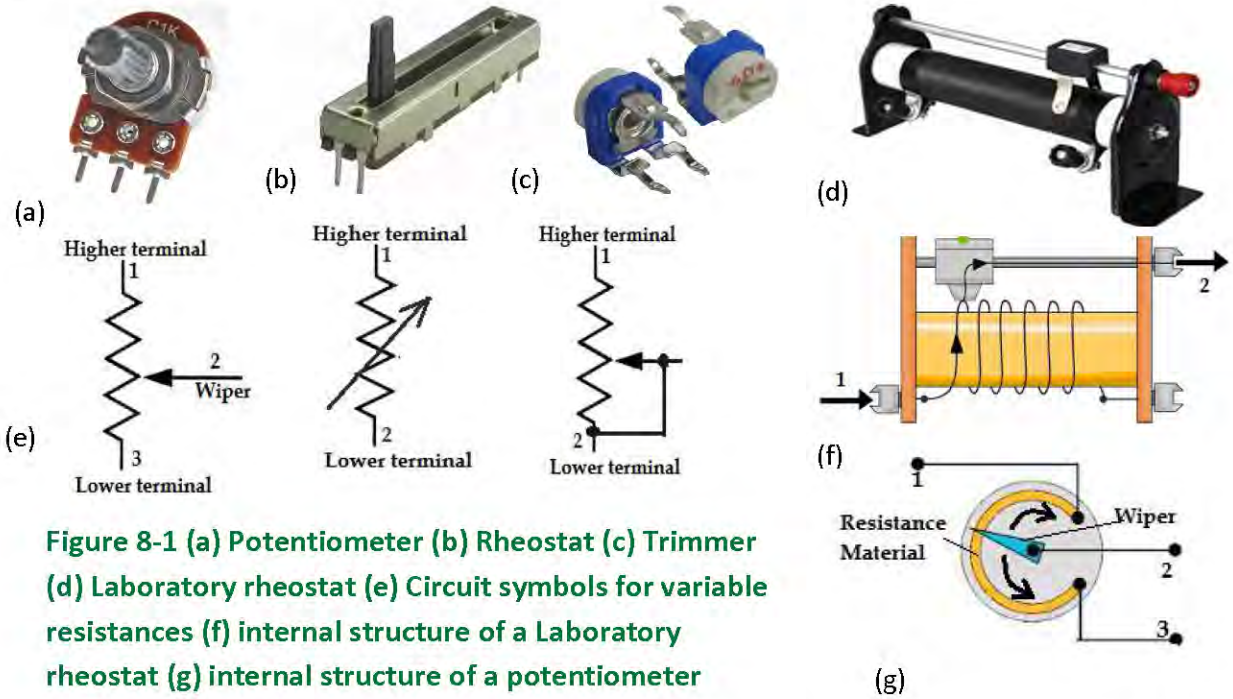


Figure 8-1 (a) Potentiometer (b) Rheostat (c) Trimmer (d) Laboratory rheostat (e) Circuit symbols for variable resistances (f) internal structure of a Laboratory rheostat (g) internal structure of a potentiometer

The values of variable resistors are usually marked as follows; 100k, 10k, 20k e.t.c These values indicate the maximum obtainable resistance from the variable resistor.

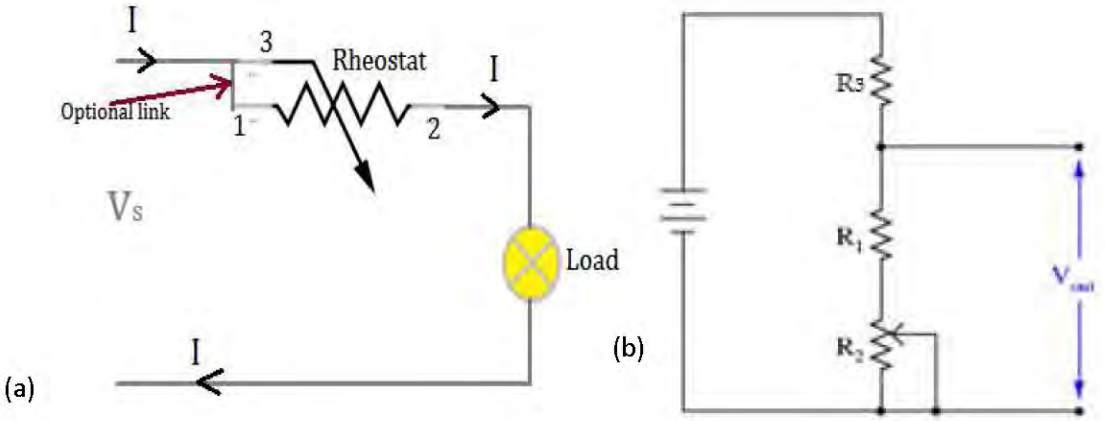
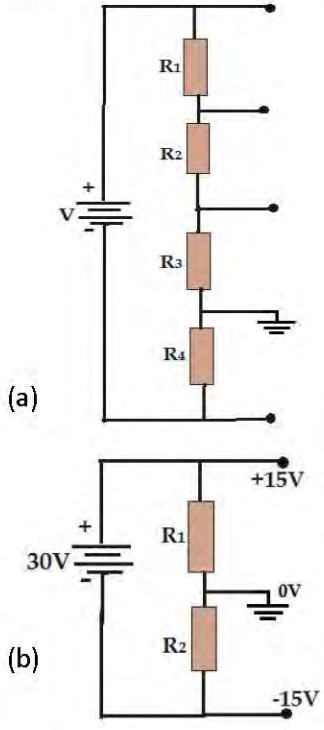


Figure 8-2 (a) A potentiometer converted to a rheostat is used for varying current through the load in the circuit. (b) A potentiometer (R_2) used for achieving variable voltage output from a power supply.

8.2 VOLTAGE DIVIDER

As the name goes, it is a circuit that can be used to divide up a voltage to obtain several fractions voltages from just one voltage source with respect to a reference point. It can also be used to get a dual polarity output voltage from a power supply. It can be constructed from resistors arranged in a series connection between the terminals of the source voltage. The joints of the resistors will form the outputs for the voltage divider.



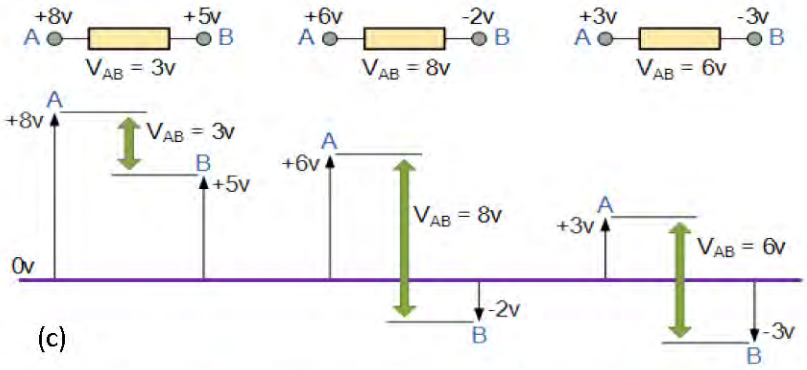


Figure 8-3(a) Voltage divider constructed from fixed resistors (b) a single battery has been used to create dual polarity supply using a voltage divider of two resistors, with the reference at the middle of the resistors. (c) V_{AB} means the voltage of A starting from B. If +1V equal a step on the stairs, then we take three (3) steps upward to move from +5V to +8V. A downward step means negative voltage change -1V.

8.3 VOLTAGE DIVIDER EQUATION

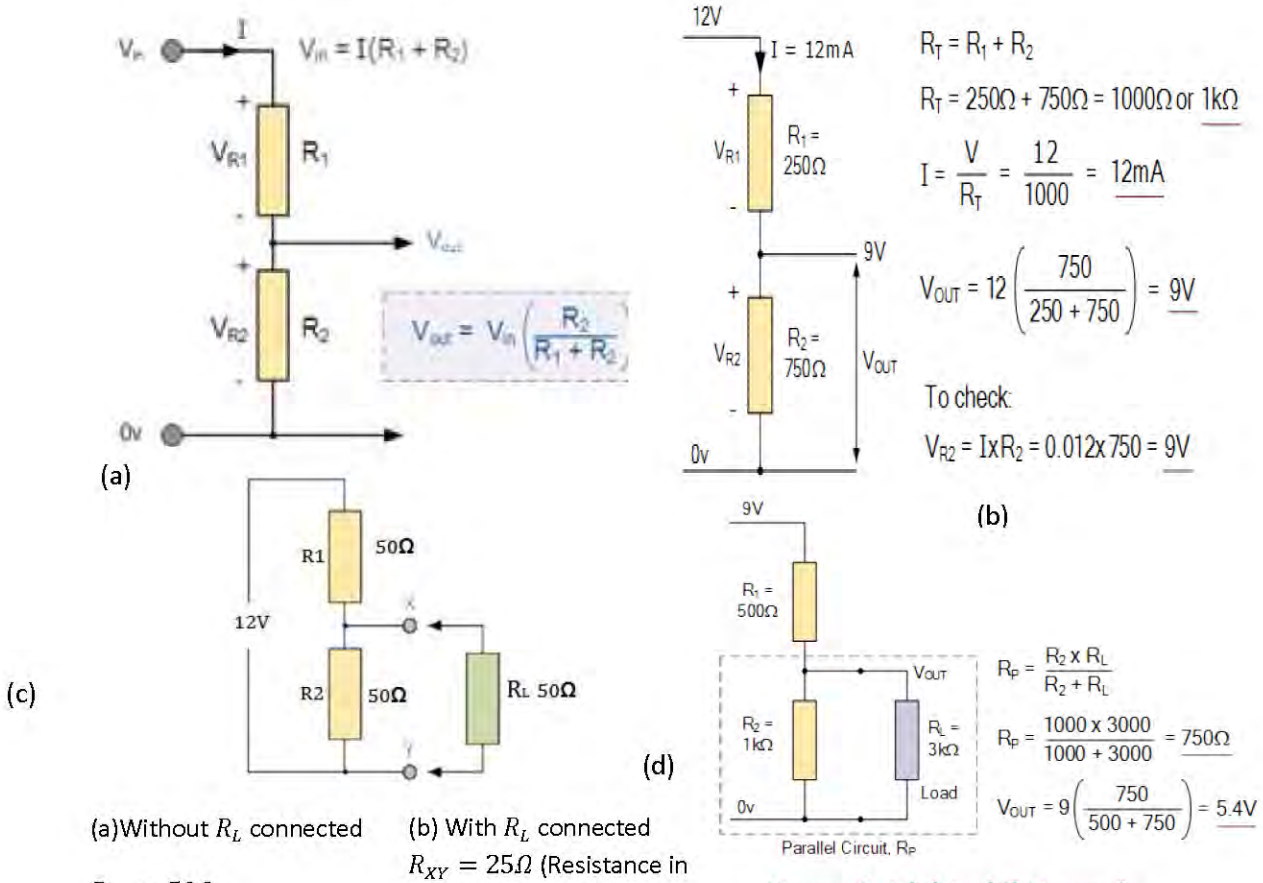
Recall that the voltage across resistors in series adds up to give the source voltage. For any number of resistor in series in a voltage divider, the general equation for the voltage across any resistor is given as;

$$V_x = V_{SOURCE}\left(\frac{R_x}{R_{TOTAL}}\right)$$

where $R_{TOTAL} = R_1 + R_2 + R_3 + R_4 \ldots$

For a two-resistor, the equation can be written as:

$$V_1 = V_{SOURCE}\left(\frac{R_1}{R_{TOTAL}}\right) \text{ and } V_2 = V_{SOURCE}\left(\frac{R_2}{R_{TOTAL}}\right)$$



(a)Without R_L connected

$R_{XY} = 50\Omega$

$V_{out} = V_{in} \times \left(\frac{R_2}{R_1 + R_2}\right)$

$V_{out} = 12V \times \left(\frac{50}{50+50}\right)$

$= 6.0V$

(b) With R_L connected

$R_{XY} = 25\Omega$ (Resistance in Parallel)

$V_{out} = V_{in} \times \left(\frac{R_{XY}}{R_1 + R_{XY}}\right)$

$V_{out} = 12V \times \left(\frac{25}{50+25}\right)$

$= 4.0V$

Figure 8-4 (a) to (d) Example calculation of voltage divider and decrease in voltage when a load is connected.

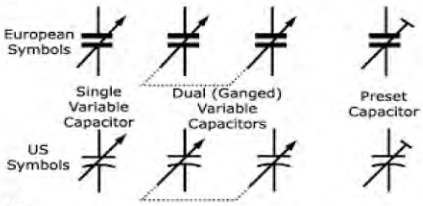
CHAPTER 9 CAPACITORS

The capacitor is another component you will usually find in a typical electric circuit. The capacitor is also a passive component just like the resistor which we have discussed. A capacitor can perform different functions in a circuit, one of which is the ability to **store charges** which can be release back into the circuit to perform useful work. A capacitor can be charged and discharged as many times as possible in just on second. Unlike a battery, a capacitor can withstand a short circuit without damaging it. A capacitor is therefore suitable for applications that require quick high current flow in a circuit. It is also very useful for separating a mixture of DC and AC signal (electrical voltages or current carrying useful information) in a circuit.

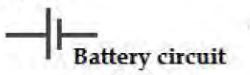
(a)

Battery short circuit

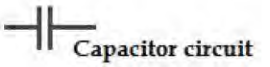
(c)



(b)



Battery circuit symbol; two parallel lines, one line shorter than the other



Capacitor circuit symbol; two parallel lines with equal length

(d)

Table 9-1 Comparison of capacitor and battery

Batteries	
Pros	**Cons**
Power density	Limited cycle life
Storage capacity	Voltage and current limitations
Better leakage current than capacitors	Long charging times
Constant voltage that can be turned off and on	More temperature sensitive than capacitors
Capacitors	
Pros	**Cons**
Long cycle life	Low specific energy
High load currents	Linear discharge voltage
Short charging times	High cell discharge
Excellent temperature	High cost per watt

Figure 9-1 (a) Different capacitor types (b) Capacitor circuit symbols and different standards (c) Short circuit a battery leading to damages (d) Difference between the battery and capacitor circuit symbols

9.1 UNIT OF A CAPACITOR

The unit used to express the amount of charges that a capacitor can store is called the **capacitance**. The capacitance can be obtained as the ratio of the charges on a capacitor plate to the voltage applied across the leads of the capacitor. Capacitance can is measured in **farad, F.**

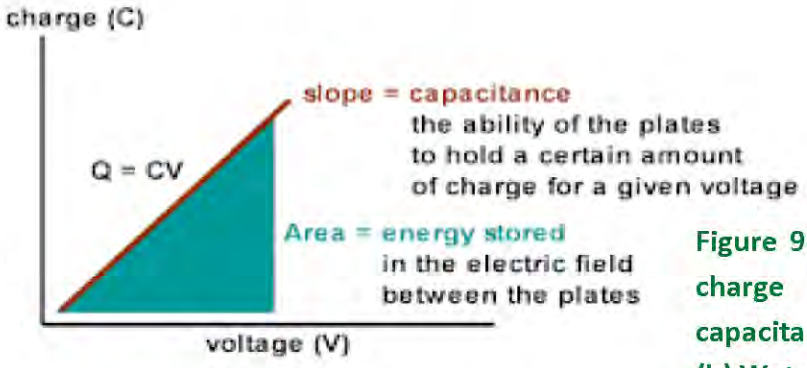
$$C = \frac{Q}{V}$$

Where C- capacitance in farad (F)

Q - charges on capacitor plate in coulomb (C)

V – applied voltage in volt (V)

(a)



(b)

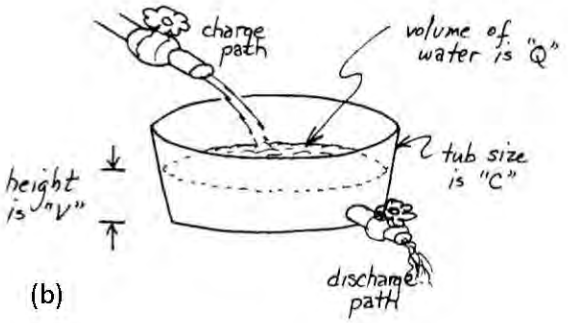


Figure 9-2 (a) Straight line graph of charge against voltage. The capacitance is the slope of the graph. (b) Water analogy of a capacitor. The capacitor is like a container that stores water (charges; current flow for a specify time). The height of the water stored is the capacitor voltage The pipe with a tap (resistance) determines how fast the container will be filled up.

9.2 MAKING A CAPACITOR

A simple capacitor can be constructed by placing two parallel metals plates close each other, so that they are separated from each other by an electrical insulator (referred to as **dielectric**) placed between them. When one metal plate of the capacitor store positive charges on it, the other will store negative charges during the same time. The dielectric has the ability to support the flow of electric field (i.e. be **polarized**) but does not conduct electricity. The different materials that can be used for the metal plates include; aluminium, tantalum and silver e.t.c. The materials used as dielectric in the capacitor include; air, paper, glass, rubber, ceramic, plastics e.t.c.

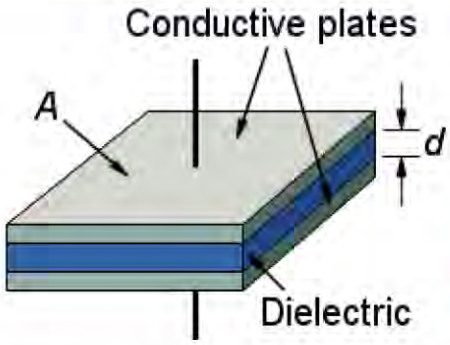


Figure 9-3 Parallel plate capacitor showing the internal structure.

9.3 FACTORS AFFECTING THE CAPACITANCE OF A CAPACITOR

The capacitance of a capacitor depends on some factors which include the area of the metal plates (A), the distance between the plates (d) and the material used for the dielectric of the capacitor. For a parallel plate capacitor, the capacitance can be written in terms above mentioned factors as;

$$C = \varepsilon \frac{A}{d}$$

Where C- capacitance in farad (F)

A- Area of metal plate in meter-squared (m^2)

d- distance between plates in meter (m)

ε- permittivity of the dielectric

In vacuum or free space, the permittivity is given as

$$\varepsilon_0 = 8.85 \times 10^{-12}\ C^2/N.m^2$$

The relationship between the dielectric permittivity and the permittivity of free space is given as the relative permittivity, ε_r:

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

So that we can write,

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d}$$

For multiple-plate capacitors, the capacitance is given as;

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d}(n-1)$$

Where n – the number of plates.

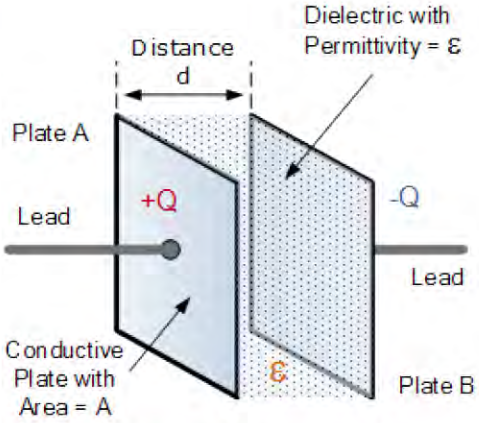


Figure 9-4 Parallel plate capacitor with charges on its plates and dielectric permittivity.

Table 9-2 Dielectric constant and breakdown strength for different materials

Material	Dielectric Constant ϵ_r (Dimensionless)	Dielectric Strength E(V/m)
Barium titanate	1200	7.5×10^6
Water (sea)	80	
Water (distilled)	81	
Nylon	8	
Paper	7	12×10^6
Glass	5–10	35×10^6
Mica	6	70×10^6
Porcelain	6	
Bakelite	5	20×10^6
Quartz (fused)	5	30×10^6
Rubber (hard)	3.1	25×10^6
Wood	2.5–8.0	
Polystyrene	2.55	
Polypropylene	2.25	
Paraffin	2.2	30×10^6
Petroleum oil	2.1	12×10^6
Air (1 atm.)	1	3×10^6

On limitation of storing as many charges as we would have like to is the factor referred to as the **dielectric strength**. The dielectric material has a maximum amount of charges per voltage build up that they can handle. For example, for a paper dielectric, if the voltage on the mil is about $600V$,

NOTE: A mil is the thousandth of an inch, $1\ mil = \frac{1\ inch}{1000}$; 1 inch = 2.5 cm

the paper starts to conduct because the opposite charges on the metal plates begin to jump across the paper to recombine. This leads to static current flow through the capacitor. This will not be a delight to have happen in a typical capacitor.

(a)

(b)

Figure 9-5 (a) Dielectric breakdown leading to a spark jumping from one conductor to another conductor nearby through air. The air becomes a conductor during the process. (b) Dielectric breakdown in a capacitor.

9.4 INTERNAL WORKING OF A CAPACITOR

When a voltage is applied across the leads of a capacitor, it causes charges to build up on the plates of the capacitor. On one of the plate is the positive charges while on the other plate will be stored negative charges. These charges also cause the atoms within the dielectric material to get polarized (having a little separation within the atom).

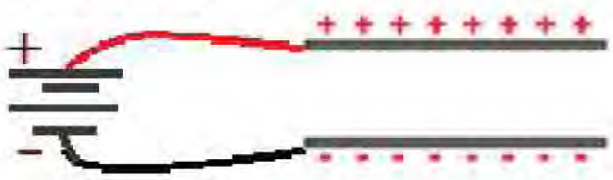


Figure 9-6 Charges (positive and negative) building up on a capacitor plates when connected to power supply.

Before a dielectric is introduced into the capacitor, the opposite charges build up on the plates of the capacitor sets up an attraction to each other leading to the creation of an electric field. The electric field therefore sets up a corresponding electric field potential and a voltage. The voltage existing as a result of this field acts in opposition to the applied voltage on to the capacitor. The process of building up charges on the capacitor plates from the applied voltage is called **charging.** When the opposing voltage on the capacitor plates is equal to the applied voltage, the capacitor is said to be **fully charged.**

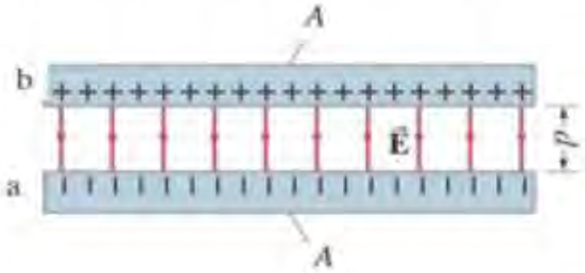


Figure 9-7 Electric field between the positively charged plate and the negatively charged plate as charges build up on the plates.

When we c y ns in an insulator are free to move, it will not allow the aid electricity but then in the presence of an electric field, it forces a little separation between the rest of the atom and the electron within the atom. The separation within the atom is referred to **polarization** and the atom is said to be **polarized**.

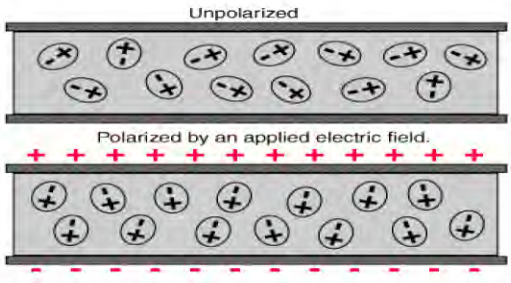


Figure 9-8 A dielectric becomes polarized by the presents of an electric field inside the capacitor. The polarization leads to lower electric field strength.

Wh s polarized by the electric field between the metal plates. The opposite charges of the metal plate and the dielectric then get attracted to each other within the capacitor. This recombination causes the electric field strength to become lowered and consequently, the opposing voltage of the capacitor. Since there is a difference between the applied voltage and the opposing voltage, the capacitor begins to charge once more leading to more charges being stored on the capacitor plate.

The overall effect of the dielectric is the ability to store more charges. The higher the dielectric relative permittivityε_r, the higher will be the capacitance for the same metal plate area and the same separation.

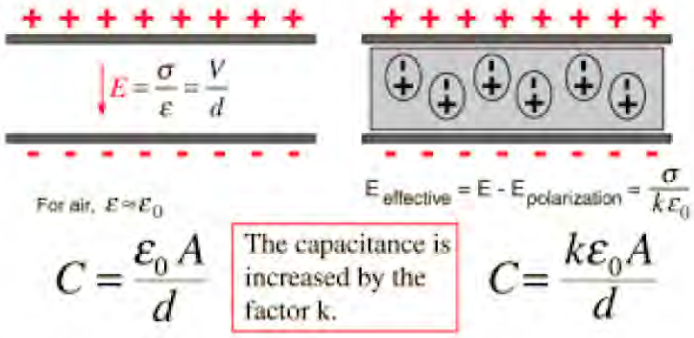


Figure 9-9 The dielectric polarization give the capacitor to store more charges and the capacitance is increased by a factor k, which is the dielectric constant.

Once the charges on the capacitor plates sets up another opposing voltage which equal the applied voltage, the charges stop flowing to the plates and the capacitor becomes fully charged again.

9.5 CHARGING AND DISCHARGING OF A CAPACITOR

The process of charging a capacitor means charges are flowing to the metal plates in the capacitor. If by any mean, the charges on the metal plates of the capacitor are made to leave, then the capacitor is said to **discharging.** When it is discharging, the charges flowing out of it can be put to do useful work. In practice, a resistor is usually placed in series with the capacitor in order to regulate the charging and discharging, this means it will take some time to charge and discharge the capacitor. In the absence of the resistor, the charging and discharging will be instantaneous (very rapidly).

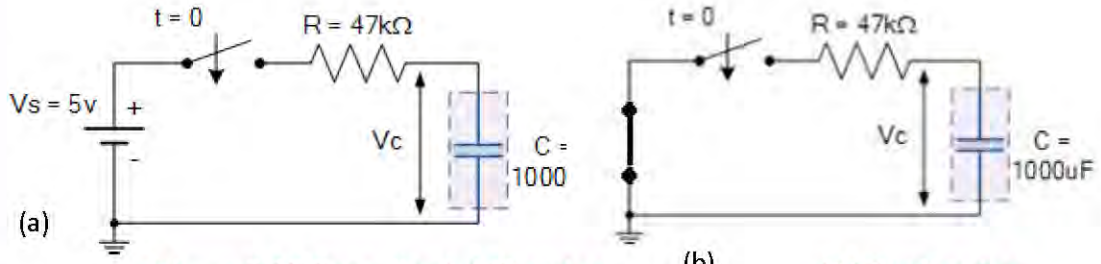


Figure 9-10 Capacitor (a) Charging (b) Discharging

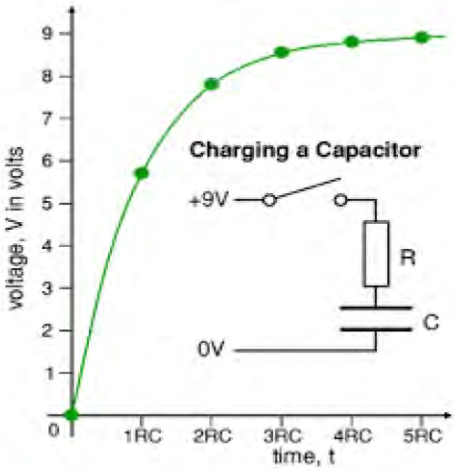
In product ne **constant, τ** (pronounced, Tau). A practical capacitor actually **never** gets charged to the applied voltage but is approximated to be fully charged at **5 times** the value of its time constant (τ). The unit of time constant (τ) is second, s. The capacitor voltage will always acquire 63.2 percent of the difference between the applied voltage and the stored opposing voltage, for each time constant (τ).

For each τ, $\tau = R \times C$ unit in second (s)

$Voltage\ stored = 63.2\% \times (\text{Applied Voltage} - \text{Voltage On Capacitor})$

After, $5RC,\ V_c \cong V_{applied}$ Capacitor Approximated Fully Charged

and $5RC,\ V_c \cong 0$ Capacitor Approximated Fully Discharged



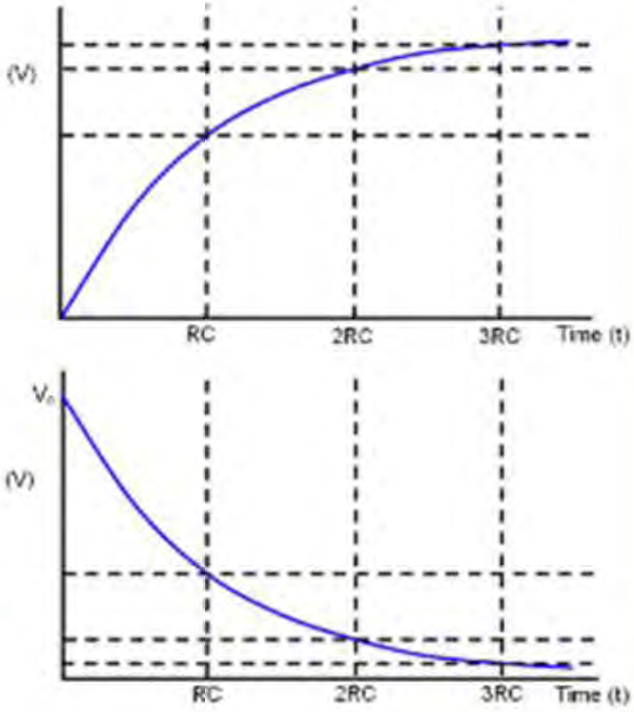


Figure 9-11 (a) Charging a capacitor through a series resistor. Charges up in about 5RC. (b) Charging curve (top) and discharging curve (bottom).

9.6 ENERGY STORED IN A CAPACITOR

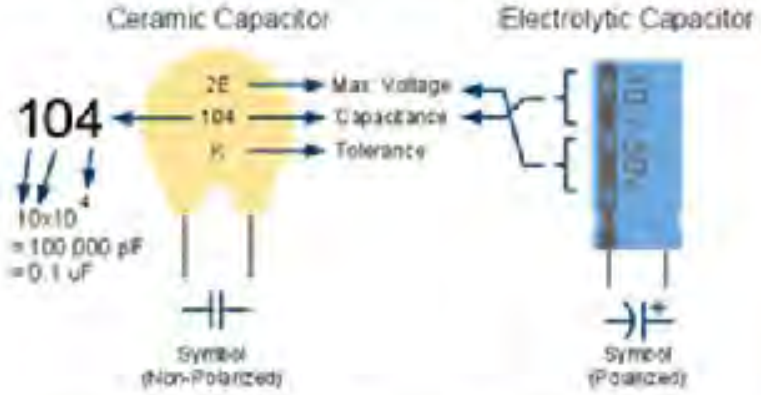
The energy stored in the capacitor is given as;

$$E_{CAP} = \frac{1}{2} QV$$

Since, $C = \frac{Q}{V}$, we can also write

$$\text{or } E_{CAP} = \frac{1}{2} CV^2 \quad \text{or} \quad E_{CAP} = \frac{1}{2} Q^2/C$$

9.7 CAPACITOR VALUE CALCULATOR



Max Operation Voltage

Code	Max Voltage
1H	50V
2A	100V
2T	150V
2D	200V
2E	250V

Capacitance Conversion Values

Microfarads (μF)	Nanofarads (nF)	Picofarads (pF)
0.000001 μF	0.001 nF	1 pF
0.00001 μF	0.01 nF	10 pF
0.0001 μF	0.1 nF	100 pF
0.001 μF	1 nF	1000 pF
0.01 μF	10 nF	10,000 pF
0.1 μF	100 nF	100,000 pF
1 μF	1000 nF	1,000,000 pF
10 μF	10,000 nF	10,000,000 pF
100 μF	100,000 nF	100,000,000 pF

Tolerance

Code	Percentage
B	±0.1pF
C	±0.25pF
D	±0.5pF
F	±1%
G	±2%
H	±3%
J	±5%
K	±10%
M	±20%
Z	+80%, −20%

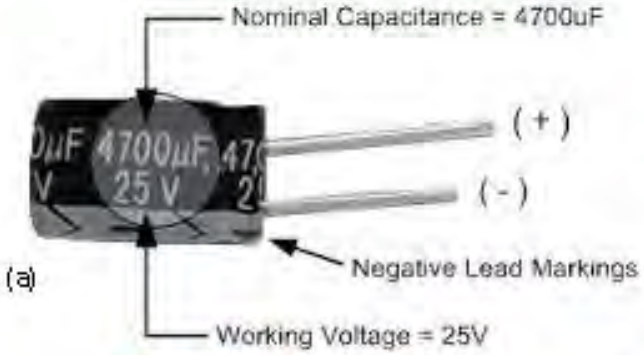


Figure 9-12 Chart of capacitor value calculator showing the metric conversion, maximum voltage and tolerance (top). (a) An electrolytic capacitor showing the capacitance information, breakdown voltage and lead markings.

(b) Capacitor becomes bloated by making wrong polarity connection or connecting a voltage higher than its DC working voltage.

9.8 CAPACITOR SPECIFICATIONS

Below are some of the basic factors to be considered when choosing a capacitor:

- **DC Working Voltage (DCWV)**: This is the maximum DC voltage that can be applied on a capacitor. If a higher value of voltage is applied to the capacitor, it will lead to a dielectric breakdown and damage the capacitor.
- **Capacitor Polarity**: some capacitors have polarity markings on them to indicate how to be connected in a circuit. Care must be taken in making sure the given polarity is follow so as not to damage the capacitor. An example is the electrolytic capacitor.
- **Temperature Coefficient**: this is the change in the capacitance resulting from changes in the temperature of the capacitor. It usually reduces the efficiency of the capacitor.
- **Tolerance**: this is the range in which the capacitor value can vary. Apart from the nominal capacitance stated on it body, the tolerance will also be indicated.

9.9 TYPES OF CAPACITORS

Capacitors are usually named after the kind of material used as their dielectric. Below is a summary of capacitors and their properties.

Figure 9-13 Types of capacitor

Table 9-3 Capacitor types and their characteristics

Type	Capacitance range	Maximum voltage	Accuracy	Temperature stability	Leakage	Comments
Mica	1pF–0.01μF	100–600	Good		Good	Excellent; good at RF
Tubular ceramic	0.5pF–100pF	100–600		Selectable		Several tempcos (including zero)
Ceramic	10pF–1μF	50–30,000	Poor	Poor	Moderate	Small, inexpensive, very popular
Polyester (Mylar)	0.001μF–50μF	50–600	Good	Poor	Good	Inexpensive, good, popular
Polystyrene	10pF–2.7μF	100–600	Excellent	Good	Excellent	High quality, large; signal filters
Polycarbonate	100pF–30μF	50–800	Excellent	Excellent	Good	High quality, small
Polypropylene	100pF–50μF	100–800	Excellent	Good	Excellent	High quality, low dielectric absorption
Teflon	1000pF–2μF	50–200	Excellent	Best	Best	High quality, lowest dielectric absorption
Glass	10pF–1000pF	100–600	Good		Excellent	Long-term stability
Porcelain	100pF–0.1μF	50–400	Good	Good	Good	Good long-term stability
Tantalum	0.1μF–500μF	6–100	Poor	Poor		High capacitance; polarized, small; low inductance
Electrolytic	0.1μF–1.6F	3–600	Terrible	Ghastly	Awful	Power-supply filters; polarized; short life
Double layer	0.1F–10F	1.5–6	Poor	Poor	Good	Memory backup; high series resistance
Oil	0.1μF–20μF	200–10,000			Good	High-voltage filters; large, long life
Vacuum	1pF–5000pF	2000–38,000			Excellent	Transmitters

9.10 CAPACITORS IN SERIES AND PARALLEL ARRANGEMENT

Capacitors can likewise be arranged in both series and parallel arrangement as discussed earlier.

9.10.1 Capacitor in Parallel:

When capacitors are connected in parallel, the total capacitance will be the sum of the individual capacitance of the capacitors. This is similar to the result obtained for resistors in series. The total capacitance in parallel will produce a higher capacitance value.

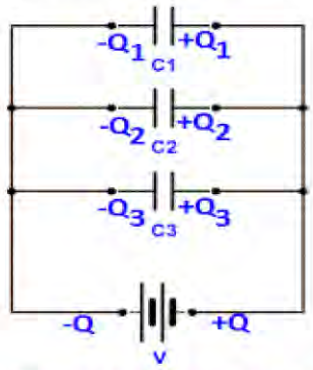


Figure 9-14 Capacitors in parallel

Total capacitance in parallel is given as:

$$C_{TOTAL} = C_1 + C_2 + C_3 + C_4 \ldots$$

The maximum voltage that must be applied to the parallel arrange of capacitor must be less than the value of the capacitor with the least DC working voltage.

9.10.2 Capacitors In Series

When capacitors are connected in series, the total capacitance can be calculated as;

$$\frac{1}{C_{TOTAL}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}$$

The total capacitance in series will result to a lower value of total capacitance.

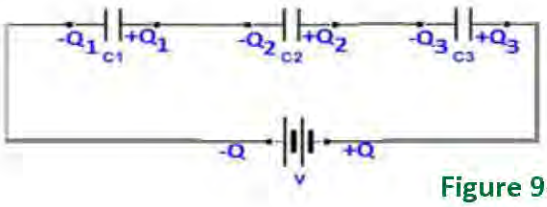


Figure 9-15 Capacitors in series

The advantage of having the capacitance in series is that it can be used to obtain a capacitor that can withstand a higher voltage. The trade off is the lower capacitance.

9.11 BASIC FUNCTION OF CAPACITORS IN A CIRCUIT

1. **AC coupling and DC Blocking**: a capacitor can be used to allow only AC signals to pass from one part of a circuit to another while blocking off any DC signal. This is also called a **high pass filter**. As a high pass filer, it allows high frequency signal while blocking low frequency signals.

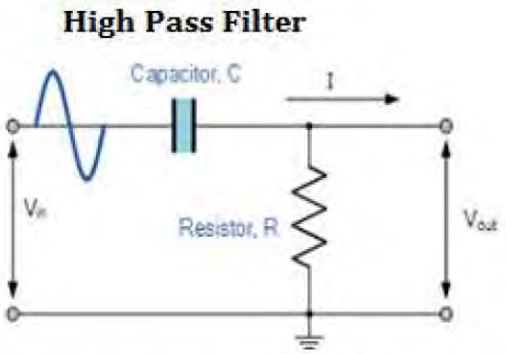


Figure 9-16 DC blocking or High pass filter circuit

2. **Capacitor Bypass**: this is when the capacitor is connected in a way to remove AC or high frequency signals while allowing on DC signals to pass through it. It is also called a **low pass filter.** This capacitor application is used in the rectification of AC signals to DC signals.

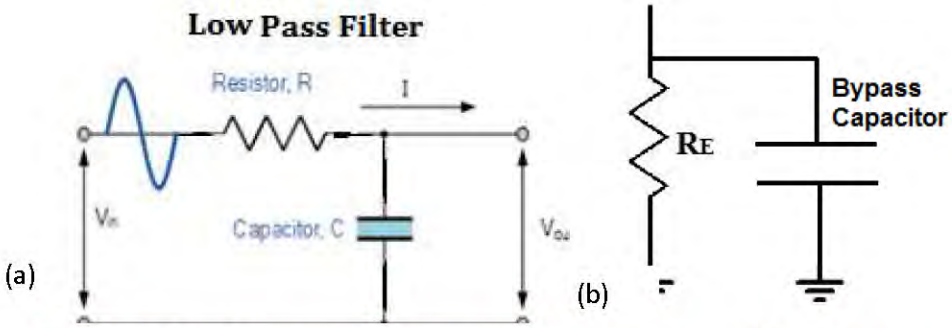


Figure 9-17 (a) Low pass filter circuit (b) Capacitor used for bypass

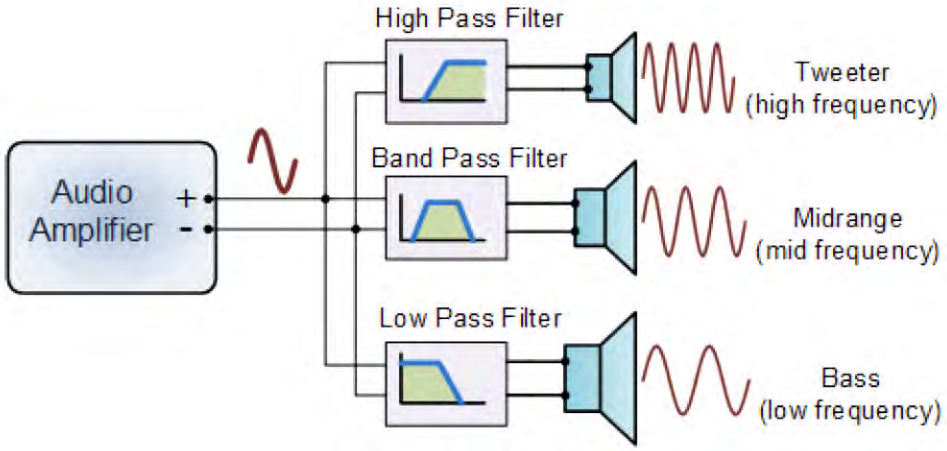


Figure 9-18 Application of filter circuits for frequency separation

9.12 CIRCUIT TROUBLESHOOTING GUIDE

STARTING POINT

Does the circuit appear to be receiving power?

No →

- Check power (batteries, ac outlet).
- Check fuses.
- Test various dials and switch setting to make sure the circuit isn't just in a weird mode.
- Check switches to see if they're malfunctioning.

Yes ↓

Does the circuit initially work, but fails sometime later?

No →

- Check to see if there are any lose connections.
- Consult the schematic to see if you've left out any components, or if you've made any bad connections.
- Check to see that electrolytic capacitors, transistors, diodes, and IC pins are in their correct orientations.
- When working with digital circuits, problems may result from improperly terminating unused digital IC leads. See if this is the case.
- Check to see that you've made power supply wires to digital ICs and op amps as short and direct as possible. Long wires often result in poor risetimes, and noise pickup. A possible solution to these problems is to use shorter wires, or to place a 0.1 µF capacitor across the power supply pins of each chip. Placing a 1 to 10 µF capacitor across power supply leads that enter the board may also help eliminate unwanted transients that can lead to erratic circuit performance.
- Consider the possibility that your schematic is incorrect. Often published schematics contain errors too.

Yes ↓

Check to see if any components are becoming excessively hot to the touch. Do you smell anything burning? If so, the problem may be that you're overheating a component. In such a case, simply replacing the component with another that has a higher power rating may be the answer. Or perhaps, a heat-sink is all that's needed.

If all else fails . . . →

Attempt to isolate the area of the circuit where you think the problem lays. Perhaps, simply replacing a suspect part may be the answer. If you're still in doubt, consult literature that talks about circuits similar to yours. These sources often mention possible sources of error, and then give you a solution.

ELECTRONICS: STEPPING UP

PART 3

CHAPTER 10 SWITCHES

A switch is a component designed for the purpose of opening or closing a circuit path. It could also be used to control the flow of current from one part of a circuit to another. In this topic, our focus will be on mechanical switches.

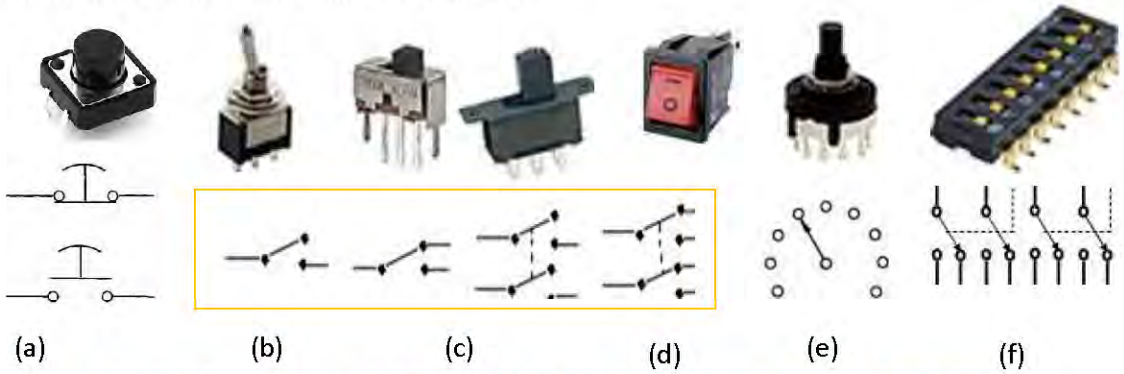


Figure 10-1 (a) Pushbutton (b) Toggle (c) Slide (d) Rocker (e) Rotary (f) DIP

10.1 HOW DOES A SWITCH WORKS

A simple switch usually will have two terminals for external connections and a movable part which does the work of connecting and disconnecting the terminals. The movable part which does the work of bridging the two terminals usually employs a push, slide contacts or other physical forces e.g. magnetic effect and heat effect. When the switch is closed, it should have zero resistance (resistance = 0) while an opened switch should have infinite resistance.

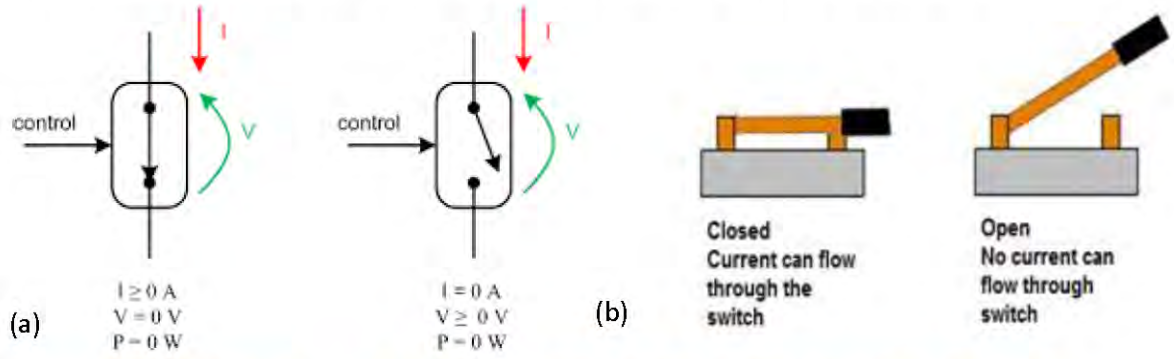


Figure 10-2 (a) Switch action (b) Simple Switch closing and opening circuit path.

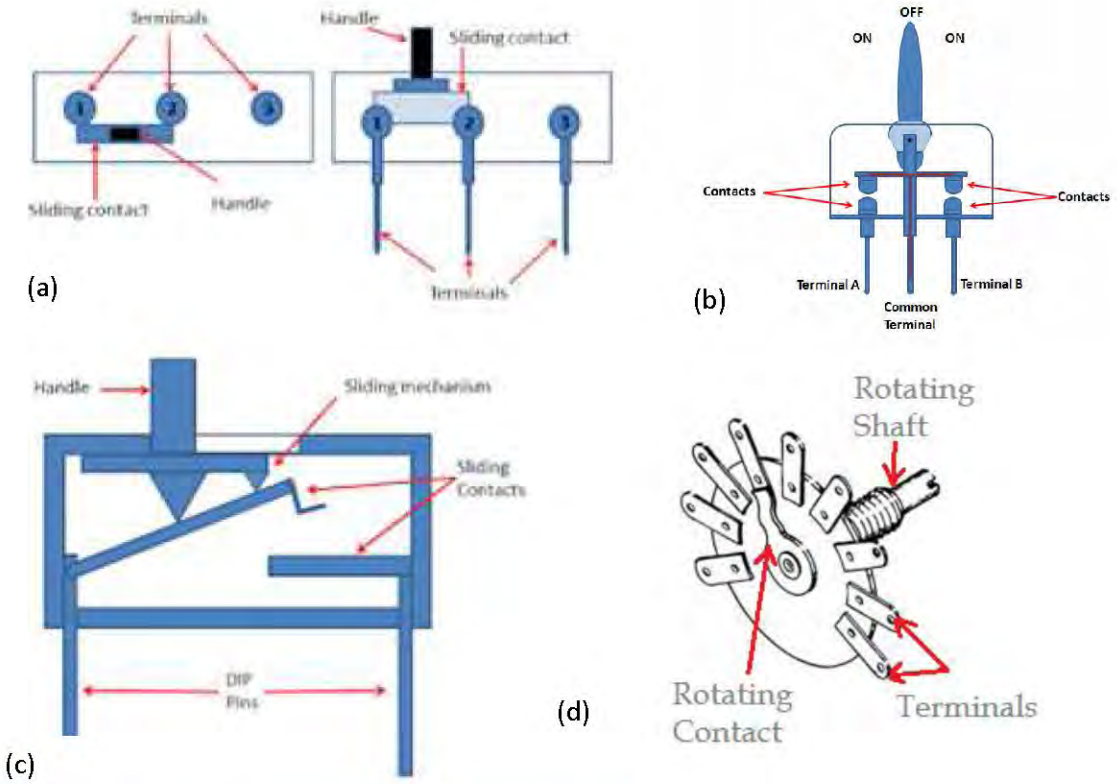


Figure 10-3 Internal working of some switches

The action of opening or closing a circuit path depends on how the switch is connected and not necessarily on the physical mechanism of the switch. The contacts of a switch are required to be very firm so as to prevent sparks across the contacts and this will also prevent unwanted resistance within the switch.

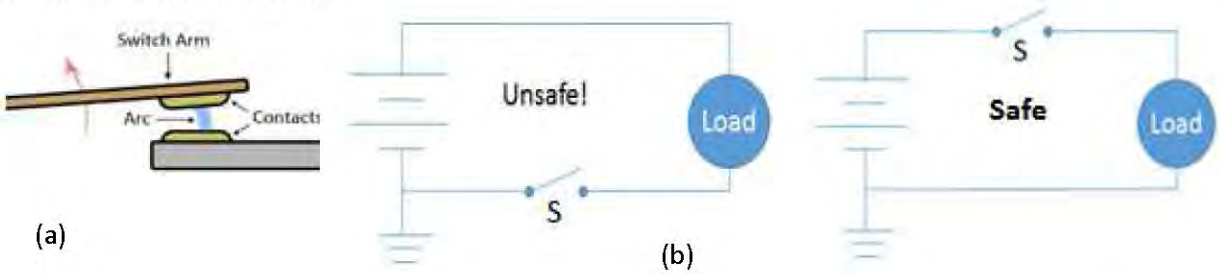


Figure 10-4 (a) Partial contact in a switch (b) Placement of switch in a circuit

10.2 SWITCH CHARACTERISTICS AND DESCRIPTION

- **Maintained and Momentary**: a ***maintained switch*** can be operated so that when it is opened or closed, it stays in that position until it is operated to change it position.

An example of the maintained switch is the wall switches at homes. Another type of switch is called the ***momentary switch.*** The momentary switch is a type of switch that will only maintain its opened or closed position as long as there is a force on it to keep it opened or closed. An example of the momentary switch is the keys on a computer keyboard.

(a) (b)

Figure 10-5 Examples of (a) Maintained switch (b) Momentary switch

- **Poles and Throws**: the pole of a switch represents the number of independent pairs of contacts a switch can control. It is usually represented by the letter "**P**" in switch description. The throw indicates the number of separate contacts that can be controlled by a single moveable bridging parts. It is usually represented by the letter "**T**" in switch description. For one pole or throw, it is usually represented by the letter "**S**" in switch description. When the two features are combined, we have, single pole single throw

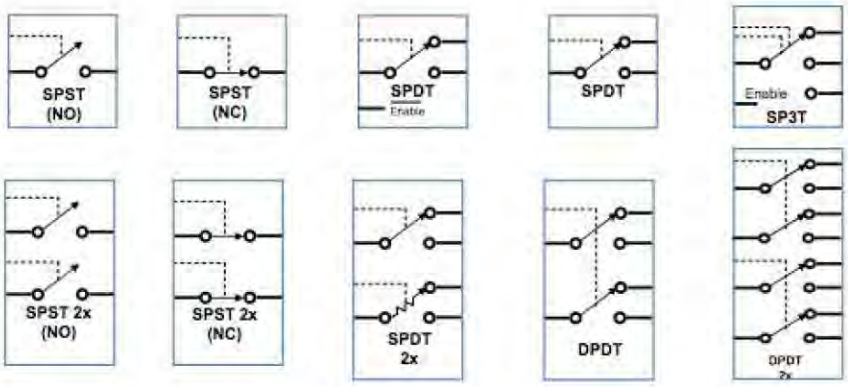


Figure 10-6 Examples of switch symbols with the Poles and Thrown label.

- **NORMALLY OPEN AND NORMALLY CLOSED:** these terms is only used when describing the momentary switch. A normally closed (NC) switch has its contacts already closed so that any press on it will only open the switch contacts. A normally open (NO) switch has it contacts unconnected from the poles so that any force on the switch will only close the switch contacts.

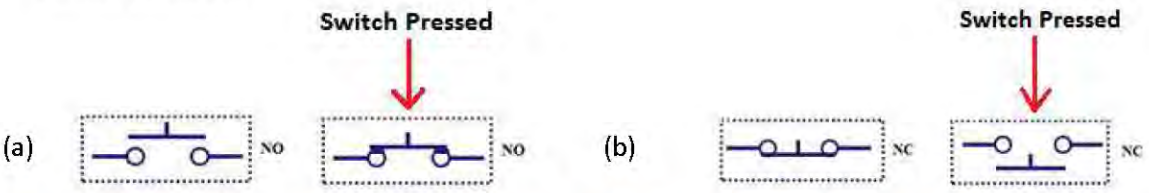


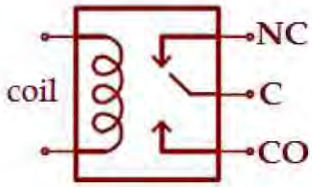
Figure 10-7 (a) Normally open push button (b) Normally closed push button

CHAPTER 11 RELAYS

Relays are electrically controlled switches. A relay has the capacity of switching ON/OFF a large amount of current at o ne part of a circuit using a small control voltage at another part of a circuit. This makes it possible for the control circuit of the relay to be in a separate location from the relay itself. There are two major types of relays which are the electromechanical relays and the solid-state relay.

(a)

(b)



(c)

Figure 11-1 (a) Solid-State Relay (b) Electromechanical Relay c) Relay symbol

An electromechanical relay has some moving parts that assist in making contacts when powered while the solid state relay is entirely electronically controlled and has no moving part to make contact. The advantages of a solid state relays over the electromechanical relay include the efficiency, very fast switching and small control power. The scope of the book will be limited to the electromechanical relays.

(a)

(b)

Figure 11-2 (a) Inside a solid-state relay showing printed circuit board and no moving parts (b) Inside an electromagnetic relay showing the coils and contacts and the

11.1 HC

An electromechanical relay uses a magnetic coil which generates a magnetic field in achieving the switching from one contact to another. When the relay is powered, current flows through the circuit part connected to the **coil** leading to the generation of a strong magnetic field. The magnetic field is designed to attract an **Armature** which holds the **Common Contact** used for making contacts. The conductive plate is usually connected to a common lead at one side while the other side is used for switching between contacts. Inside the relay, there is a **spring** connected to the magnetic rod which helps to pull the contacts of the conductive plate back to the former position before the relay was powered. The voltage for

controlling the relay can either be an AC or DC. If a relay with a DC coil is powered by AC, the conductive plate flips back and forth within the relay.

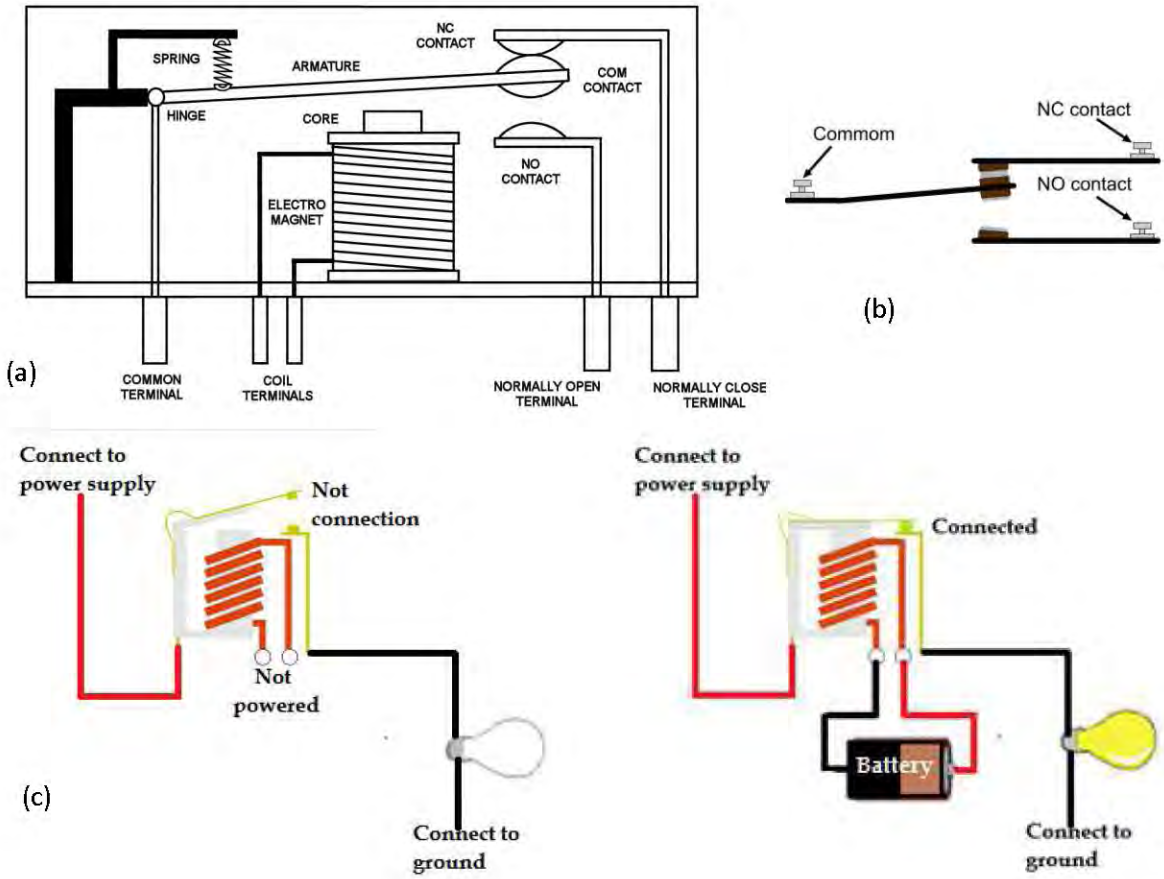


Figure 11-3 (a) Diagram of an electromagnetic relay showing the parts of the relay. (b) Common contact and the normally closed (NC) and normally open (NO) contacts. (c) Unpowered relay with common contact connected to the normally closed (NC) contact (Left) Relay coil is energized so that it develops a magnetic field for attracting the armature through which current can flow through the common contact to the connected load (right).

11.2 DESCRIBING A RELAY

Like a switch, the electromechanical relay can also be described by their poles (P) and throws (T) and also as either normally opened (NO) or normally closed (NC).

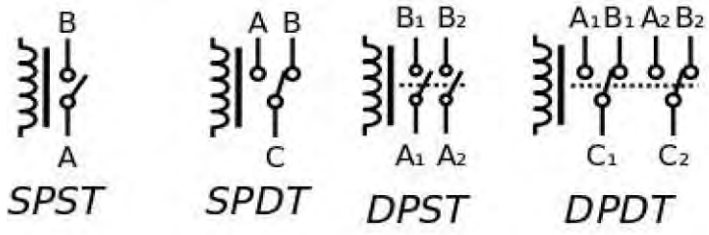


Figure 11-4 Poles and Throws identification for some relay units

11.3 TYPES OF ELECTROMECHANICAL REALY PACKAGES

Relays come in various sizes, packages and capacities as shown below;

11.4 USING RELAYS IN CIRCUITS

When a relay is connected in a transistor circuit as shown below, it is usually required that a diode, called **Flywheel Diode**, is connected in the reverse bias across the coil of the relay. This is help in eliminating voltage spikes arising from within the relay because of the changing voltages when operating the relay.

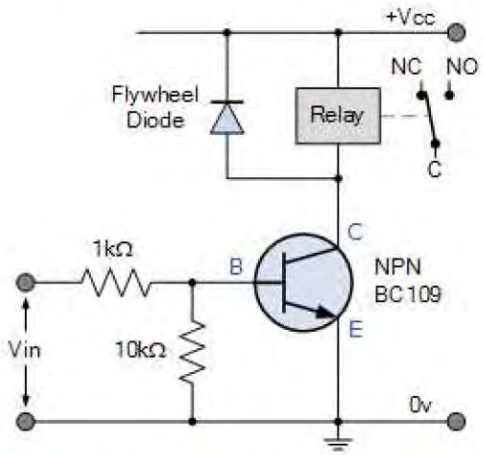


Figure 11-5 Flywheel diode connected across relay

11.5 INTRODUCTION TO ELECTROMAGNETISM

The earth moves round the Sun under the influence of the Sun's gravitational pull, so also does electric and magnetic fields affects the motion of any charged particle around such fields. The atoms of matter have electron moving around the nucleus in an orbit and when a moving electron passes through a magnetic field, it can cause a change in the motion of such electron. Charged particles possess not only electric properties but also magnetic property which interacts with external electric and magnetic field around them. A magnetic field can be found around a **magnet** which has two poles namely; North and South poles. The **like poles** of a magnet repel each other while the **unlike poles** attract each other. Magnet was naturally discovered in nature and was observed to have the ability to attract other ferromagnetic materials such as iron. Magnets can also be made artificially for various purposes. Apart from a magnet, it was also discovered that a current carrying conductor has the ability to produce magnetic fields around it. This magnetic field can also interact with other ferromagnetic materials. This discovery shows the relationship between electricity and magnetism.

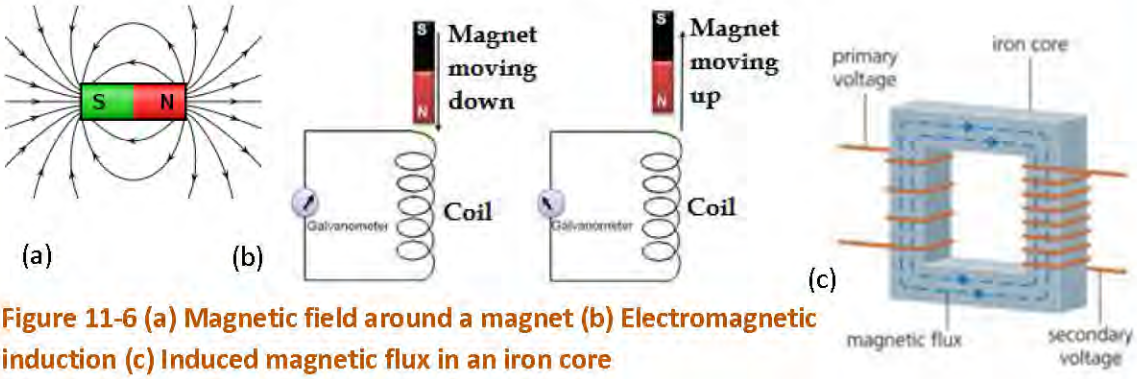
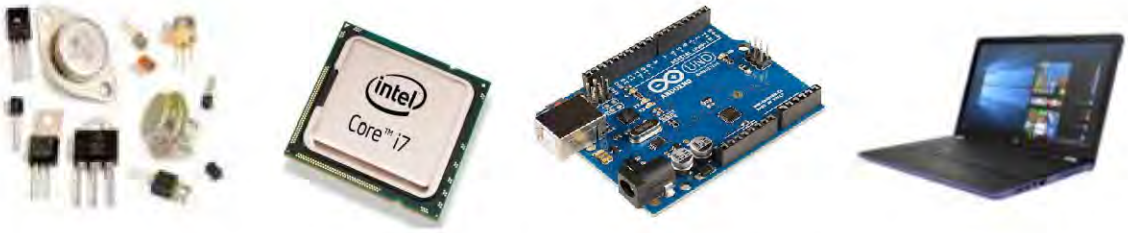


Figure 11-6 (a) Magnetic field around a magnet (b) Electromagnetic induction (c) Induced magnetic flux in an iron core

It was observed experimentally that when a magnet is moved towards/away from a coil or when a coil is moved towards/away from a magnet, an electric current is induced in the coil. The amount of current and the directions of current can be determined by various factors which can be determined using the Lenz and Faraday's Laws. The electromagnetic principle has found applications in speaker, antenna, motors, radio communication, inductors and transformer.

Figure 11-7 Examples of applications of electromagnetism

CHAPTER 12 DIODE AND TRANSISTOR



A diode and a transistor are examples of the semiconductor devices made from semiconductor materials that lead to a revolution in the world of electronics. The semiconductor devices are the heart of modern electronic gadgets, such as a digital wristwatch, a computer and a satellite. So, what is a semiconductor? A semiconductor, as the name implies is a material that is part - conductor and part-insulator. It behaviour is in between that of a conductor and insulator, and

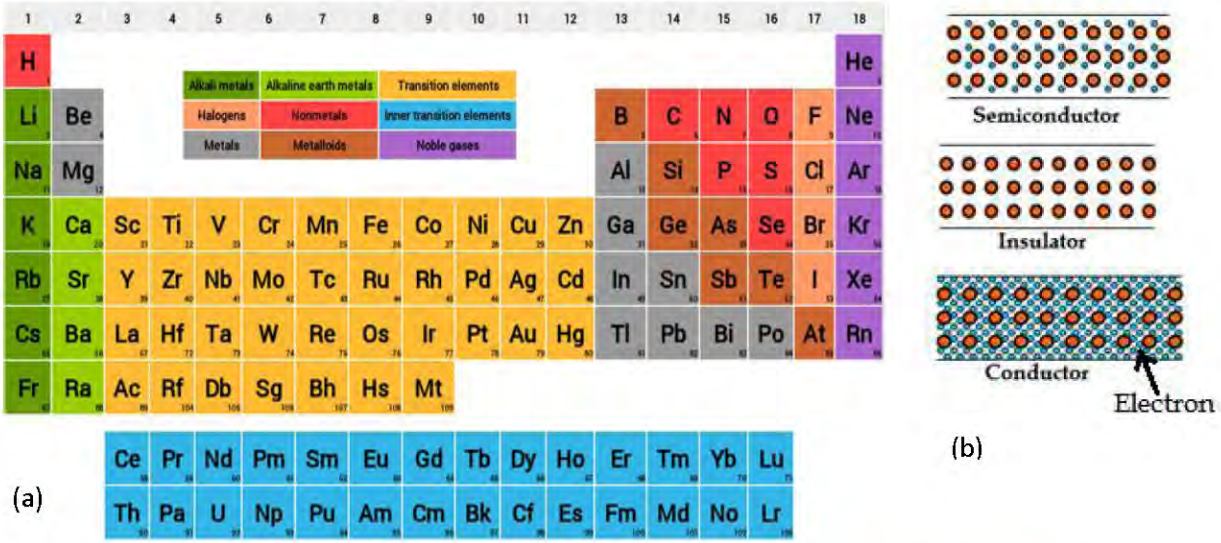


Figure 12-1 (a) Periodic table of elements (b) Electron distribution in different materials

Scientist have been able to enhance the ability of pure semiconductors to behave more like a conductor by the addition of impurities through a process known as **doping.** The result of doping gave two major types of semiconductor materials which are the **n-type semiconductor** and the **p-type semiconductor** materials. The n-type semiconductors have more negative charges carriers (called **electrons**) and achieve the conduction of electricity through it by the movement of electrons. The p-type semiconductors have more positive charge carriers (called **holes**) and achieve conduction of electricity through it by the movement of holes. The various semiconductor devices available are constructed majorly from the different combinations of n-type and p-type semiconductor materials.

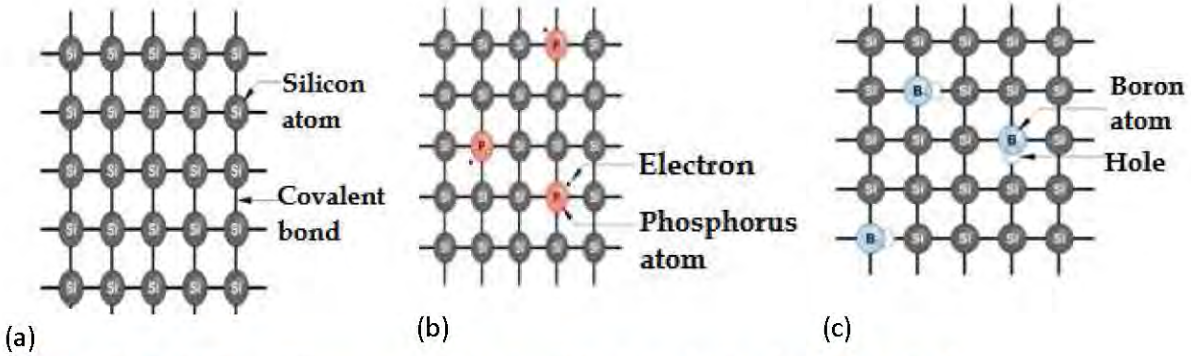


Figure 12-2 (a) Pure Silicon semiconductor (b) n-type doping (p-type doping)

12.1 DIODES

A diode is a semiconductor device which acts as a one-way switch to electric current flow. This means that current can pass through the diode in only one direction. When the current is made to flow in the reverse direction, the diode will not allow it and circuit will disconnected at that point.

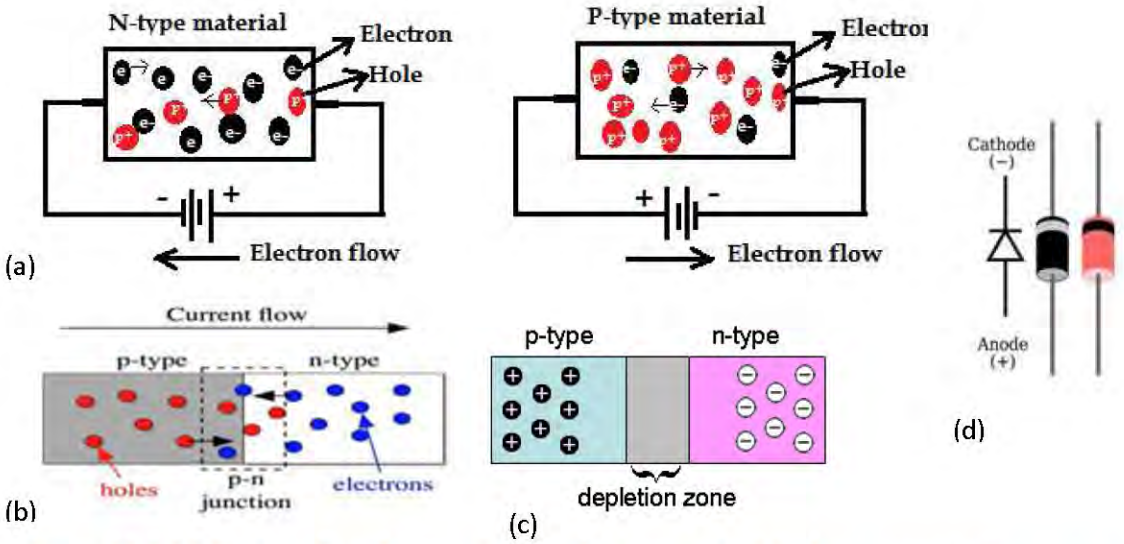
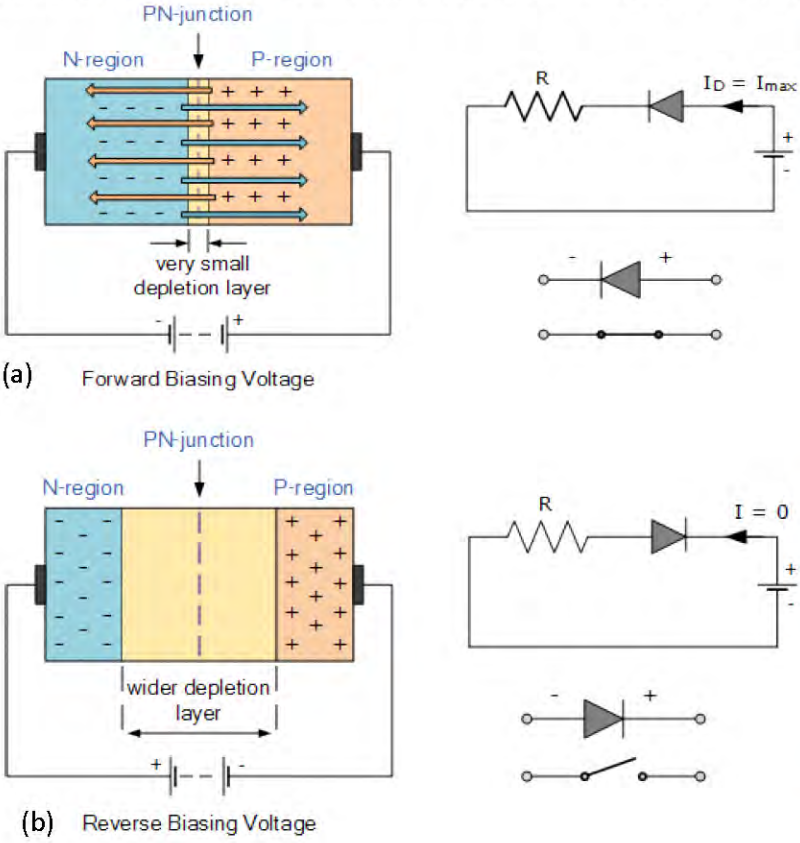


Figure 12-3 (a) Electron flow for an n-type and p-type material when connected to power supply (b) N-type and P-type joined together (c) P-N junction develops depletion layer where no charge exist after recombination (d) P-N junction diode symbol

12.1.1 HOW TO USE A DIODE

The diode has two terminals for connections in a circuit, one side is positive called the **anode** while the other side is negative called the **cathode**. An ideal diode can allow current to flow only from the anode to cathode but will prevent current from flowing from cathode to anode. The physical diode has a mark on it which indicates the cathode and also corresponds to straight line drawn on the triangle of the circuit symbol of the diode.

When the diode is connected to a power supply so that the anode is made more positive than the cathode, it behaves as a closed switch and will allow current to flow through it, then the diode is said to be **forward biased**. When the cathode is made more positive than the anode, then no current flows through it and the diode is said to be **reversed biased**.



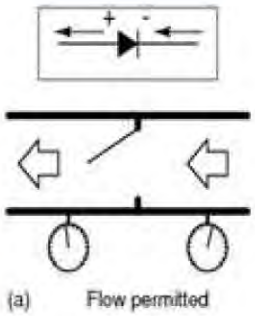
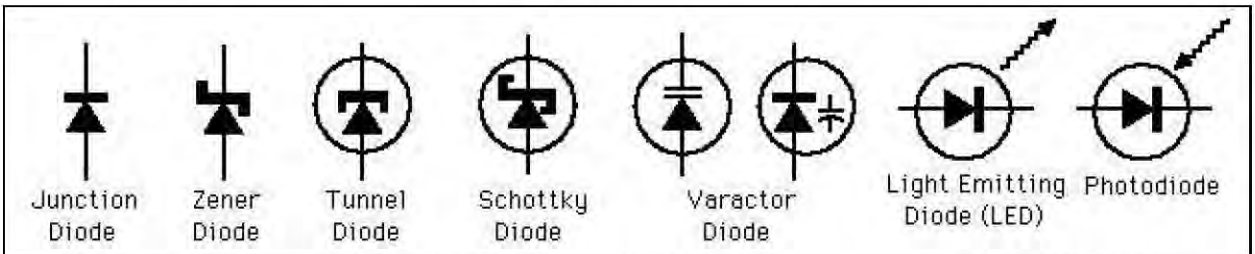


Figure 12-4 (d) Water analogy of a diode showing the forward and reverse flow. Water can only flow in one direction through the pipe as show

Figure 12-4 (a) Forward bias showing depletion layer becomes narrow (b) Reverse bias showing depletion layer widen (c) I-V characteristics of an ideal diode (Left) and a practical diode (Right)

12.1.2 DIODE SPECIFICATIONS

A practical diode will usually require a minimum voltage to make it start working when forward biased. This voltage is about 0.6V for diodes made from Silicon semiconductor material and about 0.2V for diode made from Germanium semiconductor materials. This minimum voltage to forward bias the diode is a called **diode forward voltage (V_F).** A practical diode also does not totally cut off the current when reversed biased but allow a very small amount of current to flow. Also, there is a maximum allowable current that can flow through the diode which will not cause it to get damaged. This maximum current the diode can allow is called the **maximum forward current** (I_F). The **breakdown voltage** (V_{BR}) is the maximum voltage that can be placed on diode in the reverse bias without damaging it. All these information are usually provided by the manufacturer in a book known as the **datasheet**.



Diode Type	Application	Diode Type	Application
LED	Emits visible light when forward biased.	Zener	Used as a constant voltage source. Operates in the reverse bias.
Junction Diode	Mostly used as rectifier, for converting AC to DC.	Laser Diode	Used for producing Laser radiations and circuits.
Varactor Diode	Acts as a variable capacitor when reverse bias.	Schottky	High current diode used for high current applications.
Photo Diode	Produces reverse current when light falls on it.	Tunnel	Used in oscillators circuit and microwave applications.

Figure 12-5 Diode symbols, types and application

Table 12-1 Diode Datasheet

FAIRCHILD
SEMICONDUCTOR®

1N4001 - 1N4007

Features

- Low forward voltage drop.
- High surge current capability.

DO-41
COLOR BAND DENOTES CATHODE

General Purpose Rectifiers (Glass Passivated)

Absolute Maximum Ratings*

T_A = 25°C unless otherwise noted

Symbol	Parameter	Value							Units
		4001	4002	4003	4004	4005	4006	4007	
V_{RRM}	Peak Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
$I_{F(AV)}$	Average Rectified Forward Current, .375 " lead length @ T_A = 75°C	1.0							A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	30							A
T_{stg}	Storage Temperature Range	-55 to +175							°C
T_J	Operating Junction Temperature	-55 to +175							°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	3.0	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	50	°C/W

Electrical Characteristics

T_A = 25°C unless otherwise noted

Symbol	Parameter	Device							Units
		4001	4002	4003	4004	4005	4006	4007	
V_F	Forward Voltage @ 1.0 A	1.1							V
I_R	Maximum Full Load Reverse Current, Full Cycle T_A = 75°C	30							µA
I_R	Reverse Current @ rated V_R T_A = 25°C T_A = 100°C	5.0 500							µA µA
C_T	Total Capacitance V_R = 4.0 V, f = 1.0 MHz	15							pF

©2001 Fairchild Semiconductor Corporation

12.1.3 DIODE APPLICATIONS

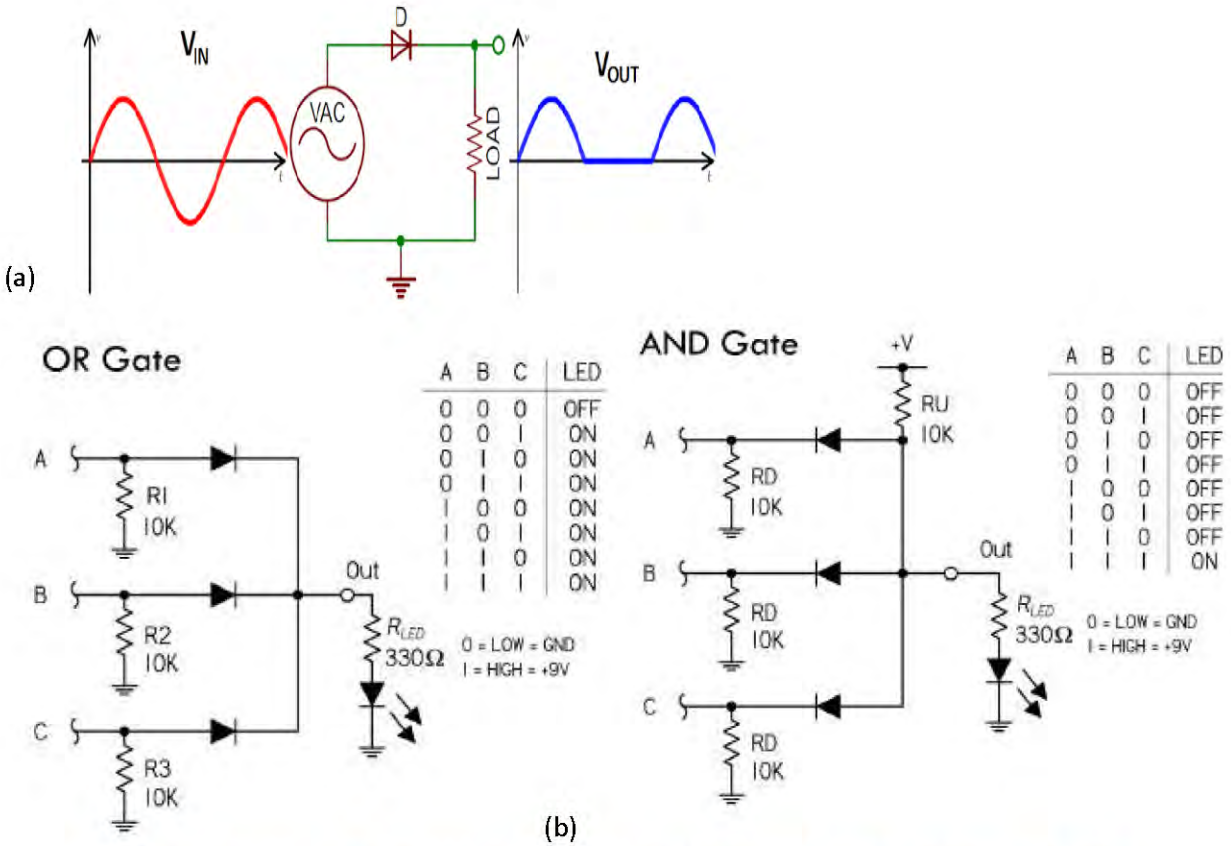
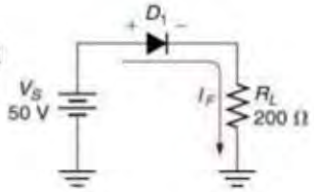


Figure 12-6 (a) Single diode used for rectification of AC signal to produce a positive half wave output (b) Application of diodes in making logical OR and AND gates.

Example 1:
Determine the minimum average forward current rating that would be required for the diode shown.



Solution

$I_F = (V_S - 0.7) / R_L$
$= (50 - 0.7) / 200 = 246.5\text{mA}$

Therefore, D_1 must have an $I_O > 246.5\text{mA}$.

$I_O = 1.2\ I_F = (1.2)\ (246.5) = 295.8\text{mA}$ (minimum)

Note: when dealing with ac circuits, you will need to determine the *average* (*dc equivalent*) current for the circuit.

12.2 TRANSISTORS

Transistors are the core functional devices that make it possible to develop various electronic systems. A transistor is a three- terminal devices and uses and can control both voltage and current flow in a circuit. It is an example of an active element (active elements can control the flow of electric energy).

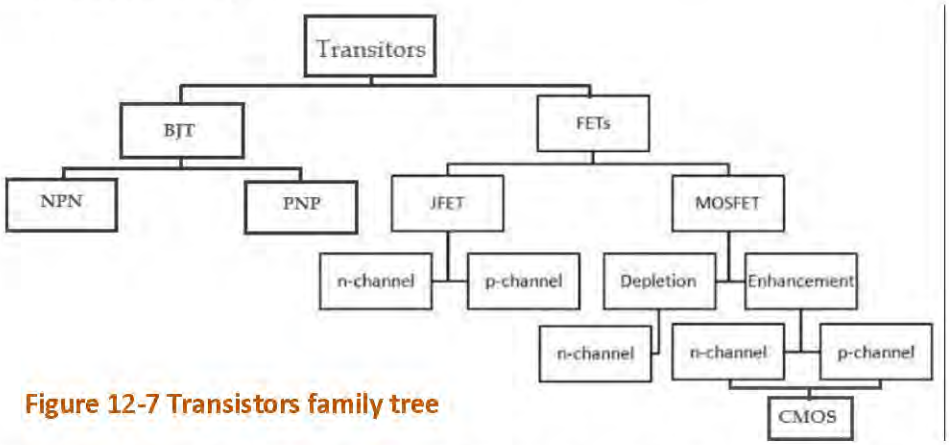


Figure 12-7 Transistors family tree

A transistor operates in a way that it uses small voltage or current applied to one of its leads to control a large current or voltage change in the other leads of the transistor. The transistor can be used majorly as an **electronic switch** and an **amplifier**. There are two major classes of transistors, namely, the **bipolar junction transistors** (BJT) and the **field-effect transistors (FET).** This lesson will be focused on only the bipolar transistors (BJT).

12.2.1 BIPOLAR JUNCTION TRANSISTORS (BJT)

There are also two types of **bipolar transistors** (**BJT**) which are the **PNP** and the **NPN**. PNP is an acronym for layers P-type: N-type : P-type while NPN stands for layers N-type: P-type : N-type. The two bipolar junction transistors (BJT) variant can be used to accomplish the same results and they also complement each other in various applications.

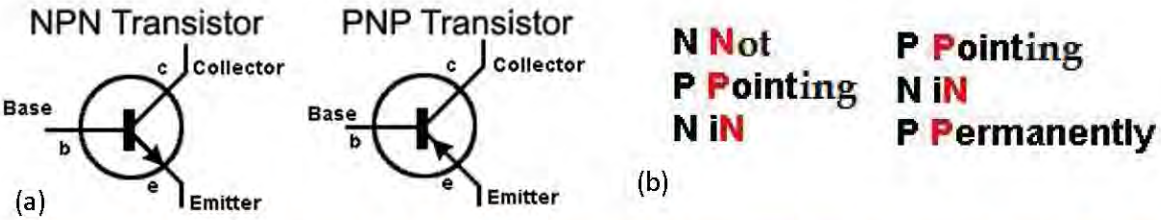


Figure 12-8 (a) BJT schematic symbol (b) mnemonics for recalling the transistor arrow direction.

12.2.2 BIPOLAR JUNCTION TRANSISTORS (BJT) CONSTRUCTION AND PINS

Transistor internal structure can be represented by using a p-n diode approximation. When we compare the diode approximation model and the transistor symbol, we observe that the arrow on the diode and that of the transistor circuit symbols are pointing outward in the same direction.

In the PNP, the arrow is seen pointing inward. The three leads of a transistor are **base (B), collector (C) and emitter (E).** The direction of the diode in the base to emitter shows the direction in which the current should flow in the transistor.

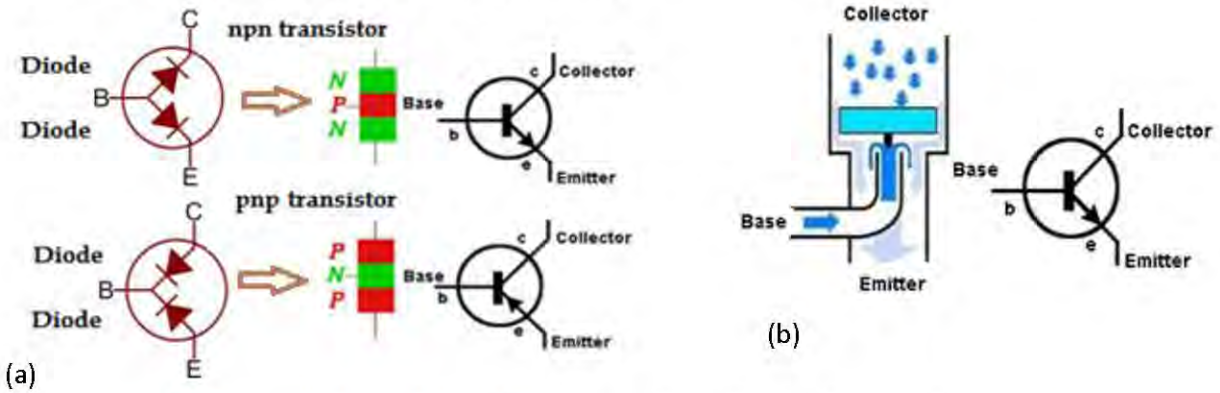


Figure 12-9 (a) BJT two-diode model (b) BJT water analogy showing base as the control lead.

An actual transistor has three layers made from the combination of n-type and p-type semiconductor material given as layers P-type: N-type : P-type (PNP) and layers N-type: P-type : N-type (NPN).

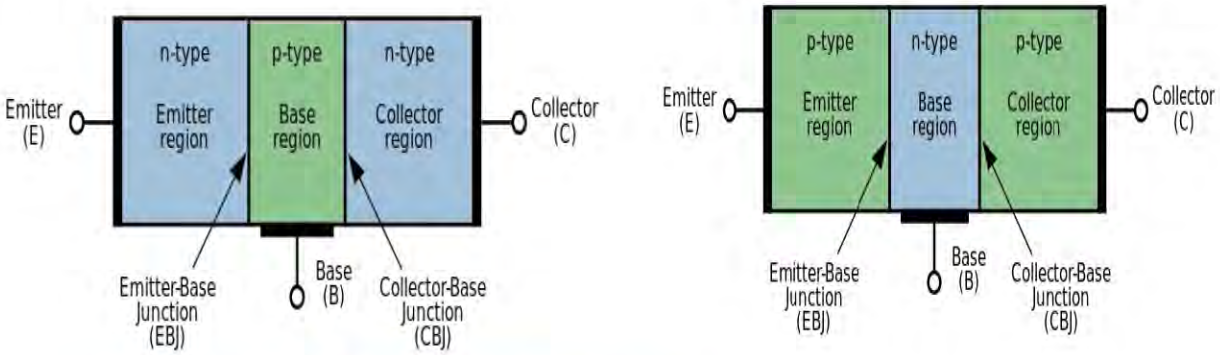
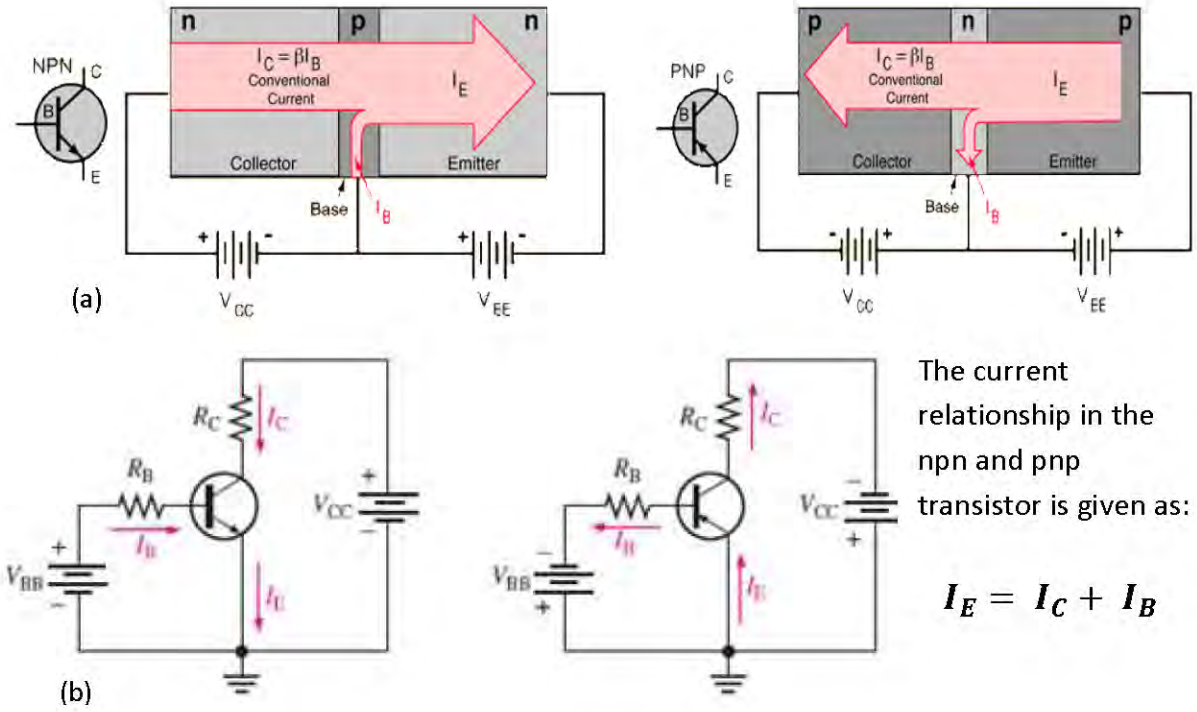


Figure 12-10 layers of and NPN and PNP Transistors

12.2.3 TRANSISTOR OPERATION

For explanation purposes, we will focus more on the operation of the NPN transistor. From the knowledge of a p-n junction diode operation, we know that the forward bias occur when electrons flow from the n-type material to the p-type material. In an actual transistor, electrons can flow from the p-type region to the n-type region when the n-p diode in the base-emitter region is forward biased. As the name goes, the emitter region is where the electrons are "generated" while the electrons are "collected" in the collector region and a small part of the electrons will flow through the base region. In terms of the conventional current flow, the small base current flowing into the emitter acts as a control to make a large current flow in the emitter-collector region.



The current relationship in the npn and pnp transistor is given as:

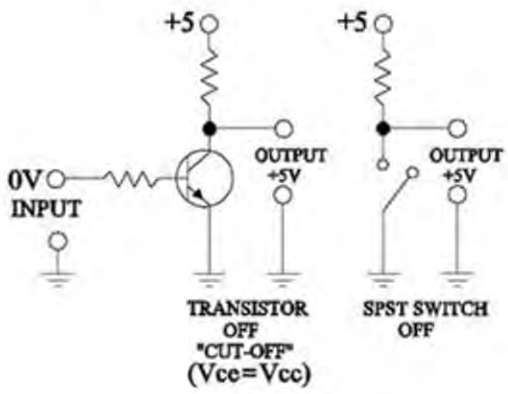
$$I_E = I_C + I_B$$

Figure 12-11 (a) Biasing the transistor showing layer structure (b) transistor biasing

12.2.4 DIFFERENT OPERATION MODES OF A TRANSISTOR

The name transistor is derived from the compound word, **transfer of resistor**. This means the transistor operation can be considered as a non-linear (i.e. does not obey Ohm's law) resistor with the ability to control the current flowing from the collector to the emitter. The three main operation modes describing how much current is flowing from the collector to the emitter of a transistor are the **cut-off**, **active** and **saturation** modes.

- **Cut-off mode**: when the transistor is in the cut-off mode, it acts like an **open circuit**. This means no current flows from the collector to the emitter and no current is flowing into the base of the transistor.

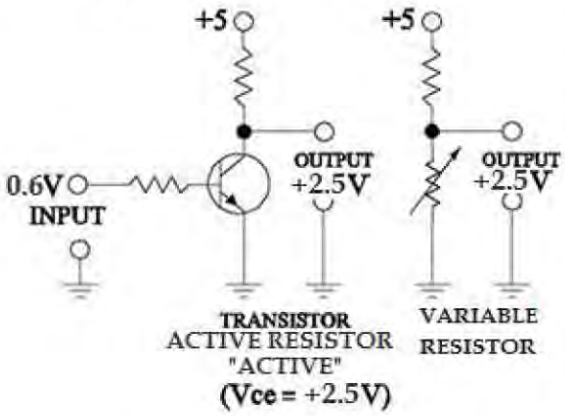


In the cut-off region, the voltage relationship between the collector, emitter and base is given as:

$$V_E > V_B \quad \text{and} \quad V_C > V_B$$

Figure 12-12 Transistor in cut-off region

- **Active mode**: in the active mode, the transistor acts like a resistor and has a **linear** characteristics. The change in the base current is **directly proportional** to the change in current flowing from the collector to emitter of the transistor. This mode is used for amplification design.

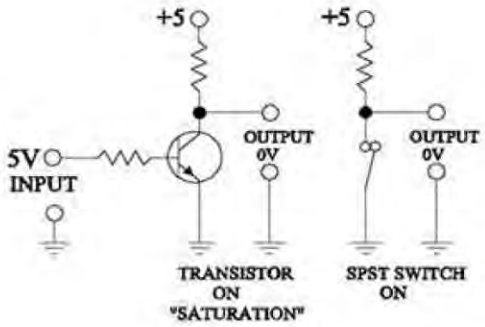


In the active region, the voltage relationship between the collector, emitter and base is given as:

$$V_C > V_B > V_E$$

Figure 12-13 Transistor in active region

- **Saturation mode**: when the transistor is in saturation, it acts like a **short circuit**. The base current is so high and the maximum current flows from the collector to the emitter. Change in base current is **not proportional** to changes in collector to emitter current.



In the saturation region, the voltage relationship between the collector, emitter and base is given as:

$$V_E < V_B \quad \text{and} \quad V_C < V_B$$

Figure 12-14 Transistor in saturation region

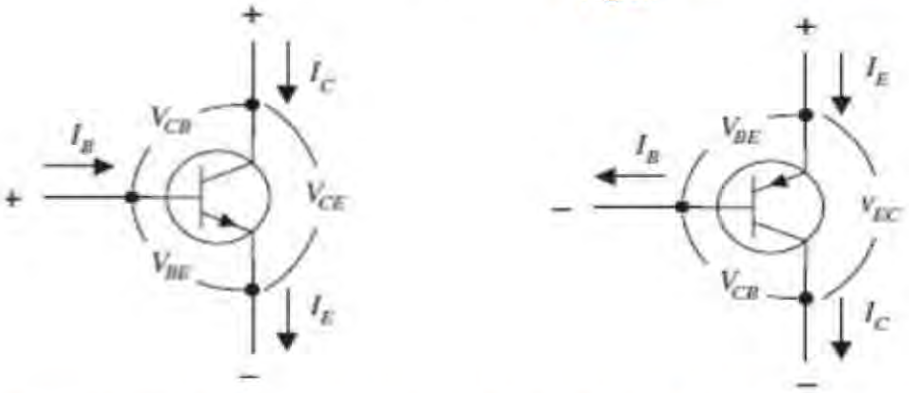


Figure 12-15 Voltage, current and polarity distribution for operating the BJT

Table 12-2 Summary of voltage relationship for all three regions

Applied Voltage	B-E junction bias (NPN)	B-C junction bias (NPN)	Mode (NPN)
E < B < C	Forward	Reverse	Forward -active
E < B > C	Forward	Forward	Saturation
E > B < C	Reverse	Reverse	Cut-off
Applied Voltage	B-E junction bias (PNP)	B-C junction bias (PNP)	Mode (PNP)
E < B < C	Reverse	Forward	Reverse -active
E < B > C	Reverse	Reverse	Cut-off
E > B < C	Forward	Forward	Saturation

12.3 TRANSISTOR PACKAGING TYPES

Below is a collection of various transistor packages you may come across;

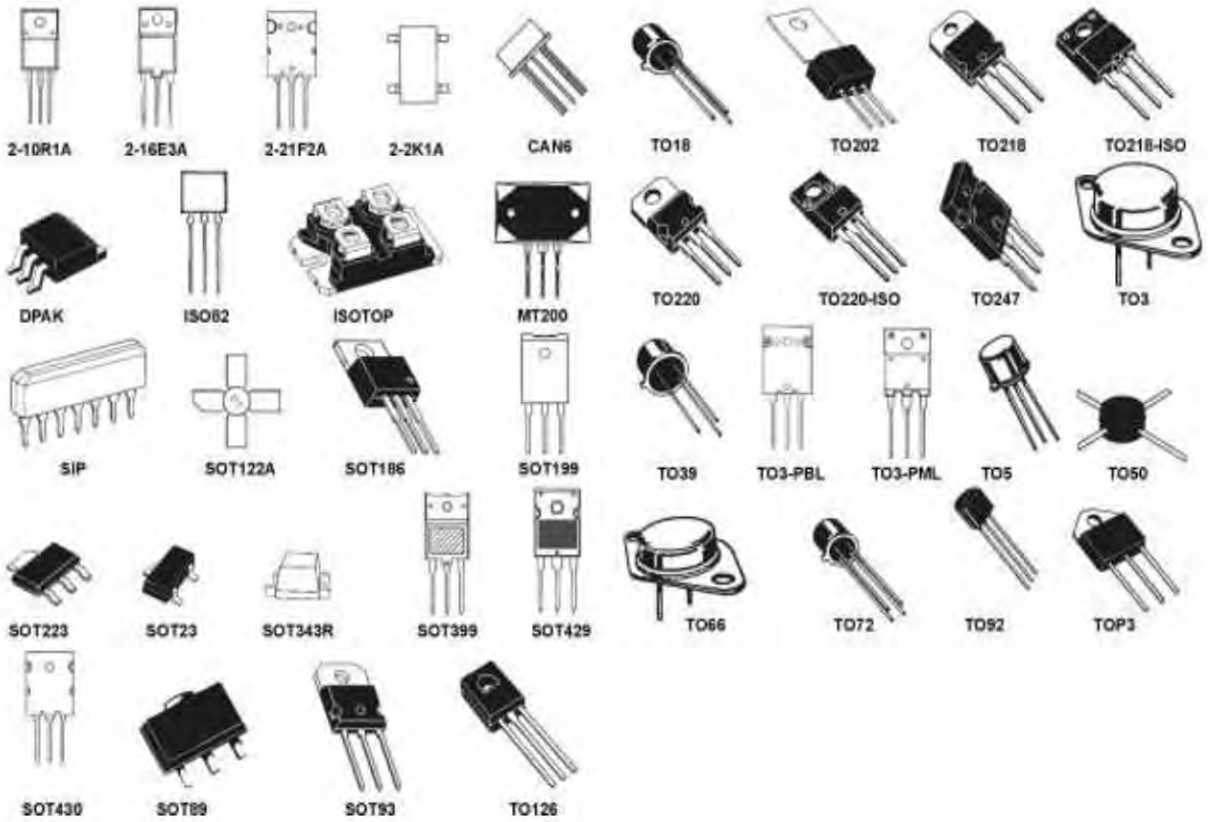


Table 12-3 Transistor datasheets

FAIRCHILD
SEMICONDUCTOR®

BC546/547/548/549/550

Switching and Applications

- High Voltage: BC546, V_{CEO}=65V
- Low Noise: BC549, BC550
- Complement to BC556 ... BC560

1

TO-92

1. Collector 2. Base 3. Emitter

NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings T_a=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage : BC546	80	V
	: BC547/550	50	V
	: BC548/549	30	V
V_{CEO}	Collector-Emitter Voltage : BC546	65	V
	: BC547/550	45	V
	: BC548/549	30	V
V_{EBO}	Emitter-Base Voltage : BC546/547	6	V
	: BC548/549/550	5	V
I_C	Collector Current (DC)	100	mA
P_C	Collector Power Dissipation	500	mW
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	-65 ~ 150	°C

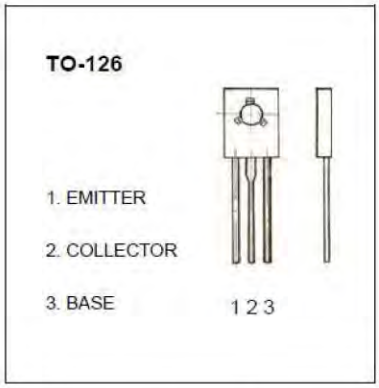
Electrical Characteristics T_a=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Units
I_{CBO}	Collector Cut-off Current	V_{CB}=30V, I_E=0			15	nA
h_{FE}	DC Current Gain	V_{CE}=5V, I_C=2mA	110		800	
V_{CE} (sat)	Collector-Emitter Saturation Voltage	I_C=10mA, I_B=0.5mA		90	250	mV
		I_C=100mA, I_B=5mA		200	600	mV
V_{BE} (sat)	Base-Emitter Saturation Voltage	I_C=10mA, I_B=0.5mA		700		mV
		I_C=100mA, I_B=5mA		900		mV
V_{BE} (on)	Base-Emitter On Voltage	V_{CE}=5V, I_C=2mA	580	660	700	mV
		V_{CE}=5V, I_C=10mA			720	mV
f_T	Current Gain Bandwidth Product	V_{CE}=5V, I_C=10mA, f=100MHz		300		MHz
C_{ob}	Output Capacitance	V_{CB}=10V, I_E=0, f=1MHz		3.5	6	pF
C_{ib}	Input Capacitance	V_{EB}=0.5V, I_C=0, f=1MHz		9		pF
NF	Noise Figure : BC546/547/548	V_{CE}=5V, I_C=200μA		2	10	dB
	: BC549/550	f=1KHz, R_G=2KΩ		1.2	4	dB
	: BC549	V_{CE}=5V, I_C=200μA		1.4	4	dB
	: BC550	R_G=2KΩ, f=30~15000MHz		1.4	3	dB

h_{FE} Classification

Classification	A	B	C
h_{FE}	110 ~ 220	200 ~ 450	420 ~ 800

D882 TRANSISTOR (NPN)



MAXIMUM RATINGS* T_A=25℃ unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage	40	V
V_{CEO}	Collector-Emitter Voltage	30	V
V_{EBO}	Emitter-Base Voltage	6	V
I_C	Collector Current -Continuous	3	A
P_D	Total Device Dissipation	1.25	W
T_J	Junction Temperature	150	℃
T_{stg}	Junction and Storage Temperature	-55-150	℃

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

ELECTRICAL CHARACTERISTICS(Tamb=25℃ unless otherwise specified)

Parameter	Symbol	Test conditions	MIN	TYP	MAX	UNIT
Collector-base breakdown voltage	$V(BR)_{CBO}$	I_C=100uA ,I_E=0	40			V
Collector-emitter breakdown voltage	$V(BR)_{CEO}$	I_C= 10 mA , I_B=0	30			V
Emitter-base breakdown voltage	$V(BR)_{EBO}$	I_E= 100 mA ,I_C=0	6			V
Collector cut-off current	I_{CBO}	V_{CB}=40 V , I_E=0			1	uA
Collector cut-off current	I_{CEO}	V_{CE}=30 V , I_B=0			10	uA
Emitter cut-off current	I_{EBO}	V_{EB}=6V , I_C=0			1	uA
DC current gain	$h_{FE(1)}$	V_{CE}= 2V, I_C= 1A	60		400	
	$h_{FE(2)}$	V_{CE}=2V, I_C= 100mA	32			
Collector-emitter saturation voltage	V_{CE}(sat)	I_C=2A, I_B= 0.2A			0.5	V
Base-emitter saturation voltage	V_{BE}(sat)	I_C=2A, I_B= 0.2A			1.5	V
Transition frequency	f_T	V_{CE}=5 V, I_C=0.1mA f = 10MHz	50			MHz

CLASSIFICATION OF hFE(1)

Rank	R	O	Y	GR
Range	60-120	100-200	160-320	200-400

NEC

PNP SILICON POWER TRANSISTOR
2SB772

PNP SILICON POWER TRANSISTOR

DESCRIPTION

The 2SB772 is PNP silicon transistor suited for the output stage of 3 W audio amplifier, voltage regulator, DC-DC converter and relay driver.

FEATURES

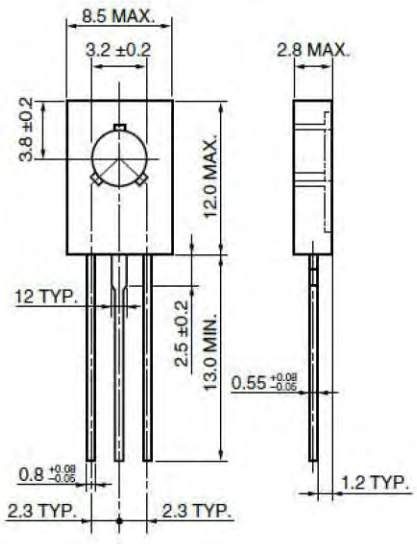
- Low saturation voltage
  $V_{CE(sat)} \leq -0.5$ V ($I_C = -2$ A, $I_B = -0.2$ A)
- Excellent h_{FE} linearity and high h_{FE}
  $h_{FE} = 60$ to 400 ($V_{CE} = -2$ V, $I_C = -1$ A)
- Less cramping space required due to small and thin package and reducing the trouble for attachment to a radiator.
  No insulator bushing required.

ABSOLUTE MAXIMUM RATINGS

Maximum Temperature		
Storage Temperature		−55 to +150°C
Junction Temperature		150°C Maximum
Maximum Power Dissipation		
Total Power Dissipation (T_A = 25°C)		1.0 W
Total Power Dissipation (T_C = 25°C)		10 W
Maximum Voltages and Currents (T_A = 25°C)		
V_{CBO}	Collector to Base Voltage	−40 V
V_{CEO}	Collector to Emitter Voltage	−30 V
V_{EBO}	Emitter to Base Voltage	−5.0 V
$I_{C(DC)}$	Collector Current (DC)	−3.0 A
$I_{C(pulse)}$ Note	Collector Current (pulse)	−7.0 A

Note Pulse Test PW ≤ 350 μs, Duty Cycle ≤ 2%

★ PACKAGE DRAWING (Unit: mm)



1: Emitter
2: Collector: connected to mounting plane
3: Base

ELECTRICAL CHARACTERISTICS (T_A = 25°C)

CHARACTERISTIC	SYMBOL	TEST CONDITIONS	MIN.	TYP.	MAX.	UNIT
DC Current Gain	h_{FE1}	$V_{CE} = -2.0$ V, $I_C = -20$ mA Note	30	220		
DC Current Gain	h_{FE2}	$V_{CE} = -2.0$ V, $I_C = -1.0$ mA Note	60	160	400	
Gain Bandwidth Product	f_T	$V_{CE} = -5.0$ V, $I_C = -0.1$ A		80		MHz
Output Capacitance	C_{ob}	$V_{CB} = -10$ V, $I_E = 0$, f = 1.0 MHz		55		pF
Collector Cutoff Current	I_{CBO}	$V_{CB} = -30$ V, $I_E = 0$ A			−1.0	μA
Emitter Cutoff Current	I_{EBO}	$V_{EB} = -3.0$ V, $I_C = 0$ A			−1.0	μA
Collector Saturation Voltage	$V_{CE(sat)}$	$I_C = -2.0$ A, $I_B = -0.2$ A Note		−0.3	−0.5	V
Base Saturation Voltage	$V_{BE(sat)}$	$I_C = -2.0$ A, $I_B = -0.2$ A Note		−1.0	−2.0	V

Note Pulse Test: PW ≤ 350 μs, Duty Cycle ≤ 2%

CLASSIFICATION OF h_{FE}

Rank	R	Q	P	E
Range	60 to 120	100 to 200	160 to 320	200 to 400

Remark Test Conditions: $V_{CE} = -2.0$ V, $I_C = 1.0$ A

12.4 SIMPLE TRANSISTOR APPLICATIONS

The transistor can be used for two major ways in various applications namely; switch and amplifier.

12.4.1 Transistor Switch: when a transistor is used as a switch, it will be operated in the cut-off and the saturation mode. The transistor will be changing states between ON and OFF. The transistor switch is entirely electronically controlled without any moving part or mechanism within it. See the table below for the comparison between a transistor switch and a relay. The small DC base current (I_B) is related to the DC large collector current (I_C) by a gain factor represented by (β *or* h_{FE}). It is the ratio of the collector DC current to the base DC current.

$$\beta_{DC} = \frac{I_C}{I_B}$$

For a good switch to be fully turned ON, the transistor minimum base current should be high enough so that it will drive the transistor into saturation when powered. The base voltage should be greater than the emitter voltage (base-emitter voltage, V_{BE}) by about $0.6V$ for the transistor to be turned ON, for an NPN while for the PNP, the base voltage should be less than the emitter voltage by $0.6V$. The transistor switch can be used for the following applications; digital logic circuit, H-bridge or DC motor control circuit, pulse oscillator and multivibrators.

Example 2:

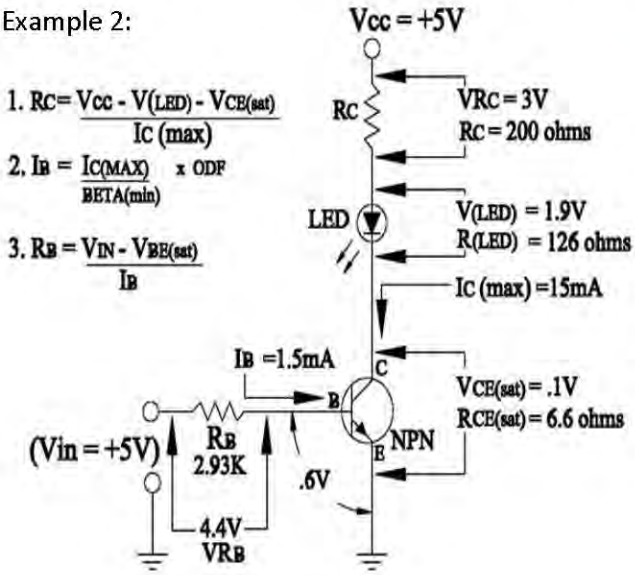


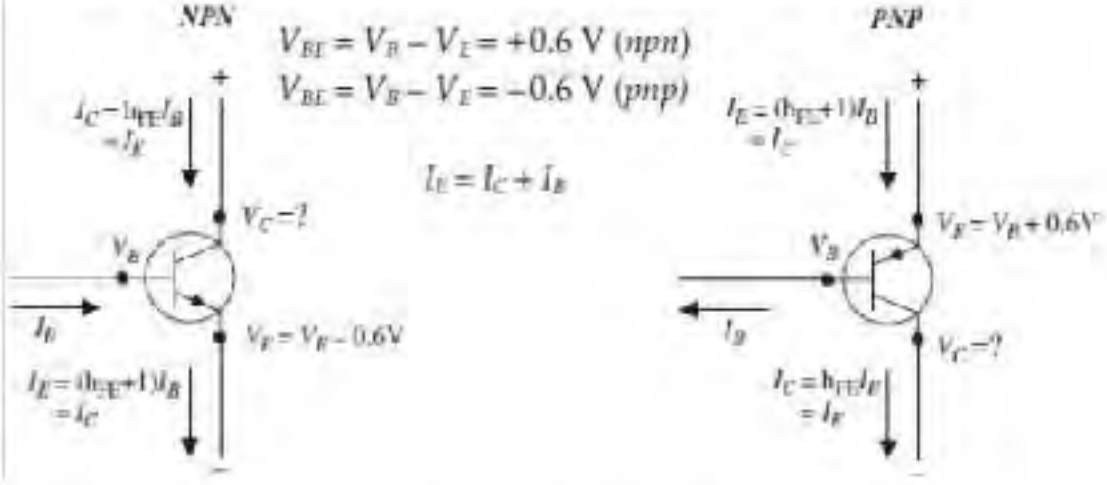
Table 12-4 Transistor and relay switch comparison

	Transistor	Relay
Long-term reliability	Excellent	Limited
Can switch in DP or DT mode	No	Yes
Can switch large currents	Limited	Yes
Can switch alternating current	Usually not	Yes
Trigger able by alternating current	Usually not	Optional
Suitable for Miniaturization	Excellent	Very limited
Able to switch at very high speed	Yes	No
Price advantage for high voltage/current	No	Yes
Price advantage for high voltage/current	Yes	No
Current leakage when nonconducting	Yes	No

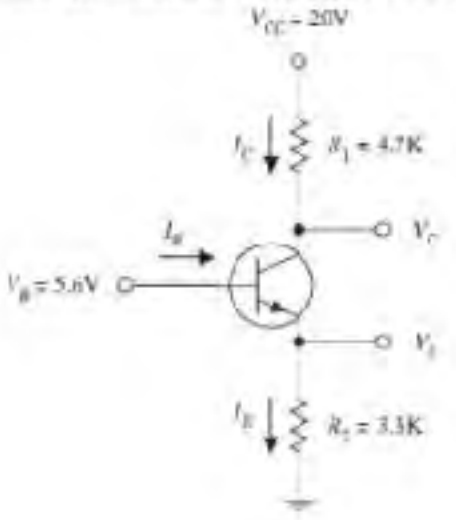
SOME IMPORTANT RULES

Rule 1 For an *npn* transistor, the voltage at the collector V_C must be greater than the voltage at the emitter V_E by at least a few tenths of a volt; otherwise, current will not flow through the collector-emitter junction, no matter what the applied voltage is at the base. For *pnp* transistors, the emitter voltage must be greater than the collector voltage by a similar amount.

Rule 2 For an *npn* transistor, there is a voltage drop from the base to the emitter of 0.6 V. For a *pnp* transistor, there is a 0.6-V rise from base to emitter. In terms of operation, this means that the base voltage V_B of an *npn* transistor must be at least 0.6 V greater than the emitter voltage V_E; otherwise, the transistor will not pass an collector-to-emitter current. For a *pnp* transistor, V_B must be at least 0.6 V less than V_E; otherwise, it will not pass a collector-to-emitter current.



Example 3: Given $V_{CC} = +20$ V, $V_B = 5.6$ V, $R_1 = 4.7$ kΩ, $R_2 = 3.3$ kΩ, and $h_{FE} = 100$, find V_E, I_E, I_B, I_C, and V_C.



$V_E = V_B - 0.6$ V

$V_E = 5.6$ V $- 0.6$ V $= 5.0$ V

$I_2 = \dfrac{V_E - 0\text{ V}}{R_2} = \dfrac{5.0\text{ V}}{3300\ \Omega} = 1.5$ mA

$I_B = \dfrac{I_E}{(1 + h_{FE})} = \dfrac{1.5\text{ mA}}{(1 + 100)} = 0.015$ mA

$I_C = I_E - I_B = I_E = 1.5$ mA

$V_C = V_{CC} - I_C R_1$

$V_C = 20$ V $-$ (1.5 mA)(4700 Ω)

$V_C = 13$ V

12.4.2 Transistor as an Amplifier:

Transistor amplifier can be used to change the level or amplitude of a very small signal at it input, for example 0.0001V to a voltage of about 100V at its output. When a transistor is used as an amplifier, it is usually operated in the active region of the load line. The load line is a straight line drawn on the I-V characteristics curve of a transistor, from the vertical axis (A) when collector current is maximum and collector-emitter voltage is zero ($I_{C(max)}$ or $V_{CE} = 0$) to a point (B) where the collector current is zero while the collector-emitter voltage is equal to the supply

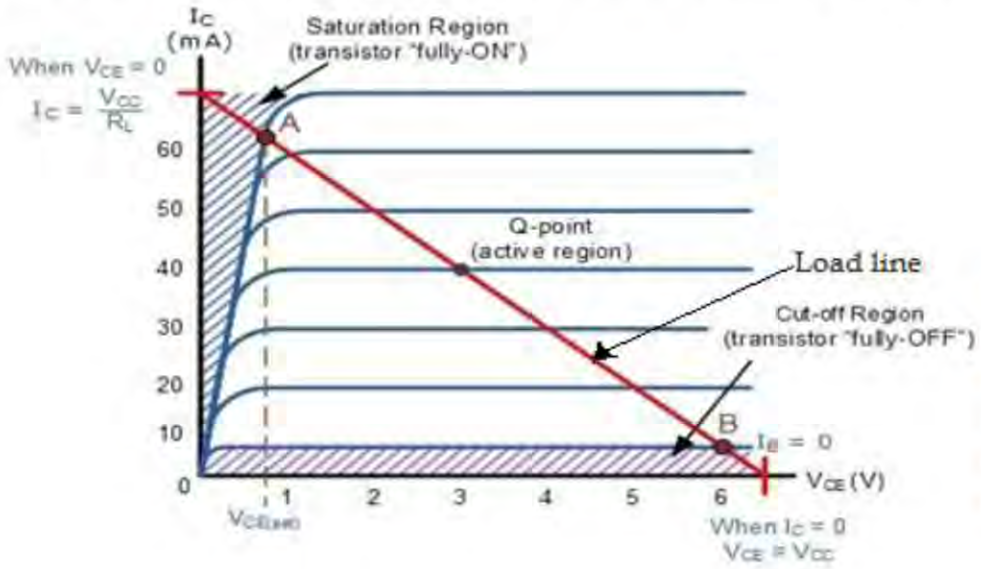


Figure 12-16 Transistor characteristic curves showing all three regions and the load line.

The transistor would have to be biased to a point (Q-point) on the load line where the collector emitter voltage is about half the supply voltage connected to the collector. At the Q-point, when a signal is sent into the transistor for amplification, it will have equal of $\frac{1}{2}V_{CC}$ swing for both positive and negative waveforms.

$$V_{CE} = \frac{1}{2}V_{CC} \quad \text{..... Q-point}$$

Amplifiers categorized into different class depending on the amount of an input signal that each transistor can successfully amplify. The classes include Class A, Class B, Class AB, Class D e.t.c. Amplifiers have found application in audio frequency, radio frequency, video amplification e.t.c.

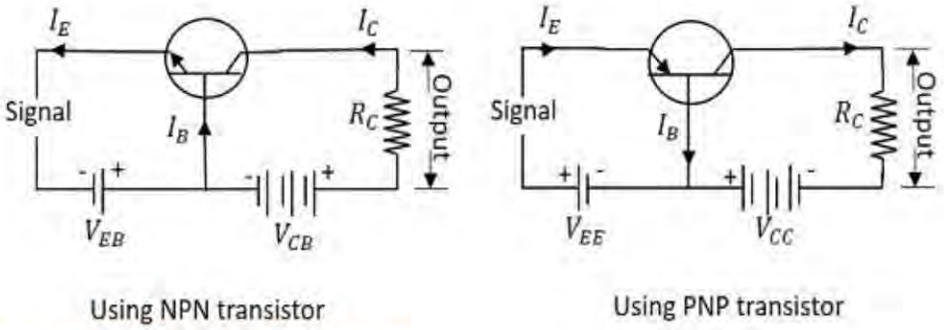
12.4.3 Transistor Configurations

The transistor as we already know has three leads which can be arranged also in three different ways when used as an amplifier. The three arrangements are called the configurations. For any of the configurations chosen, one lead will serve as the common while the other two leads will

be connected such that, the input is connected to one lead and the common and the output is taken from the other lead and the common. The three configuration modes are:

- **Common Base (CB):** when connected in the common base mode, the input signal is supplied across the emitter and the base leads while the output is taken across the collector and the base leads. The common base amplifier has voltage gain but no current gain. The current amplification factor for the common base configuration is given as:

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad \text{.... Common Base current gain}$$

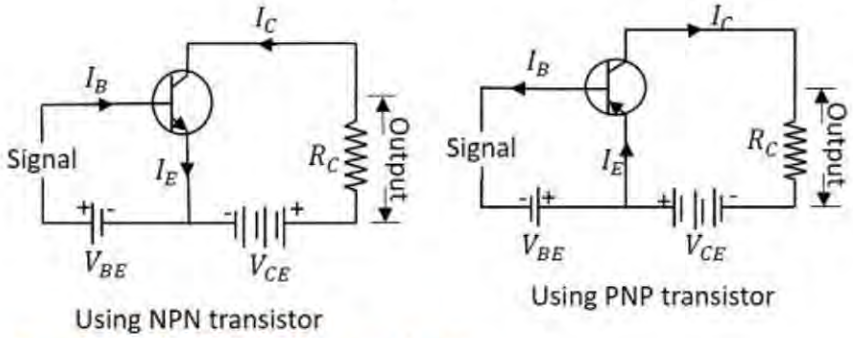


Using NPN transistor Using PNP transistor

Figure 12-17 Common Base circuit

- **Common Emitter (CE):** in the common emitter mode, the input signal is feed across the base and the emitter leads while the output signal is taken across the collector and the emitter leads. This kind of amplifier exhibits both voltage and current gain. The output signal is always inverted, that is 180^0 out of phase with the input signal.

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad \text{.... Common Emitter current gain}$$



Using NPN transistor Using PNP transistor

Figure 12-18 Common Emitter circuit

- **Common Collector (CC):** in the common collector mode, as called **emitter follower**, the input signal is supplied across the base and the collector leads while the output is usually take across the emitter and the collector leads. The emitter follower has current gain but no voltage gain.

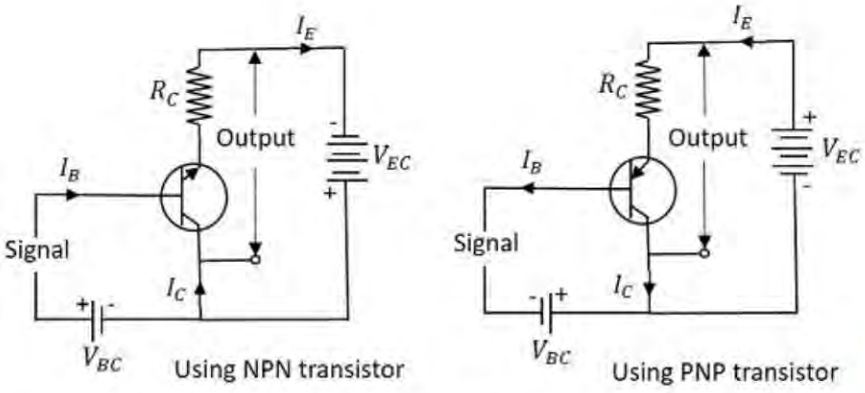


Figure 12-19 Common Collector circuit

Each of the three modes has their unique properties which include their input and output impedances (Resistance when working with AC signals). A good amplifier would be desired to have very high input impedance and very low output impedance. See the table below for the impedance properties of the three configuration modes.

Table 12-5 Summary of transistor configuration properties

Transistor Configuration	Common Base	Common Collector (Emitter Follower)	Common Emitter
Voltage Gain	High	Low	Medium
Current Gain	Low	High	Medium
Power Gain	Low	Medium	High
Input/Output Phase Relationship	0^0	0^0	180^0
Input Resistance	Low	High	Medium
Output Resistance	High	Low	Medium

A simple single stage common emitter amplifier is shown below;

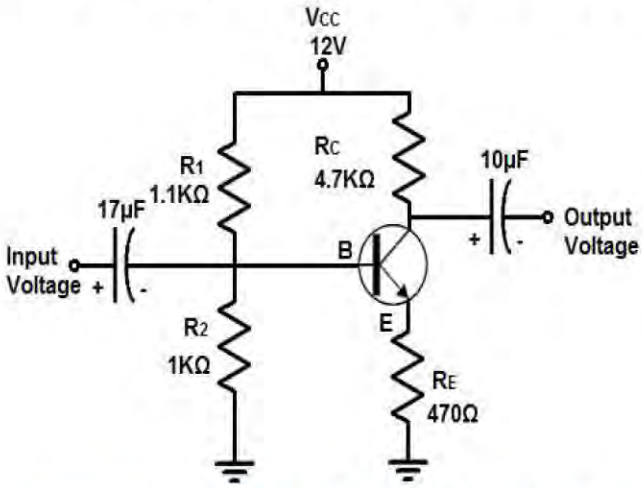


Figure 12-20 Single stage transistor amplifiers with voltage gain

The following information holds for the voltage gain (A_V) of the single stage common emitter (CE) transistor amplifier;

$$A_V = \frac{R_C}{r_e + R_E}$$

Where $r_e = \frac{26mA}{I_E}$

12.5 OTHER USEFUL TRANSISTOR CIRCUITS

- **Current Source:** a current source is a circuit for providing a constant current to a connected load such that when the supply voltage or the load resistance change with a specified ranges the amount of current flowing remains constant through the load.

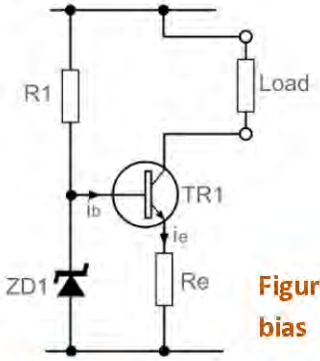


Figure 12-21 Transistor current source with Zener diode base bias

- **Current Mirror:** the current mirror is a very useful circuit for providing a programmable current through one transistor which could then be replicated in any set of transistor circuit connected in parallel with it.

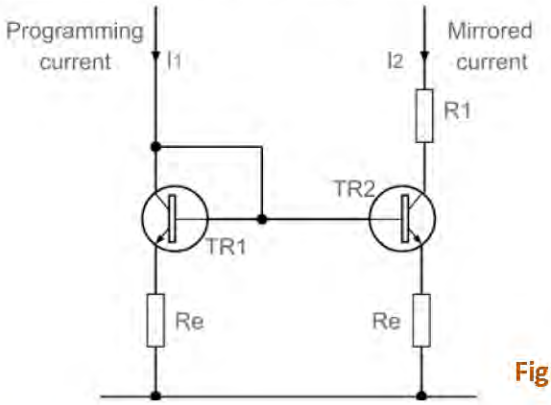


Figure 12-22 Transistor current mirror

- **Darlington Pair:** this is an arrangement of two transistors where the emitter of one is connected to the base of the other while their collectors joined together. It is usually used to achieve high current gain. The resultant current gain from a Darlington pair is the product of the current gain for both transistors.

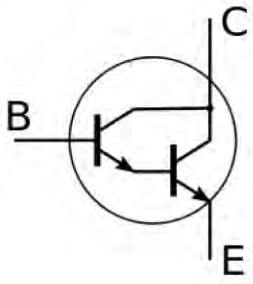


Figure 12-23 Darlington pair

- **Class B Push Pull:** the push pull is a series arrangement of an NPN and a PNP transistor such that their emitters are joined together. The two transistors are used as emitter follower and usually used to achieve high power gain at the output stage of amplifiers. The input signal is feed through the base of each transistor which is then split into two; the positive half of the waveform is amplified by the NPN transistor while the negative half of the waveform will be amplified by the PNP transistor. It is an example of a Class B amplifier.

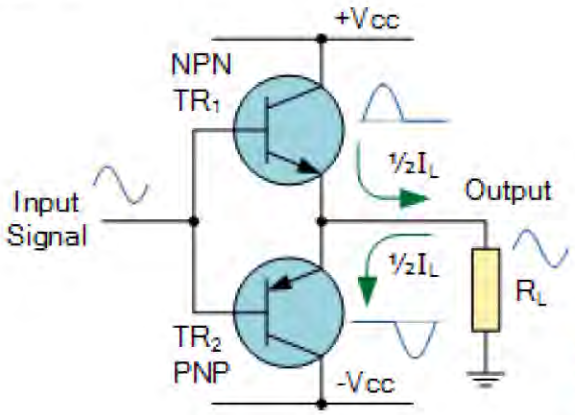


Figure 12-24 Push Pull amplifier output stage

- **Differential Amplifier:** this kind of amplifier is a useful arrange of two transistors connected in parallel with their collectors and emitters joined together. It is used for amplifying difference in input signals sent to the base of each of the transistor. The output from a differential amplifier can be taken from the collector of either of the transistors or across the collector of both transistors. It is very useful for noise cancellation application and inputs of amplifiers for high impedance.

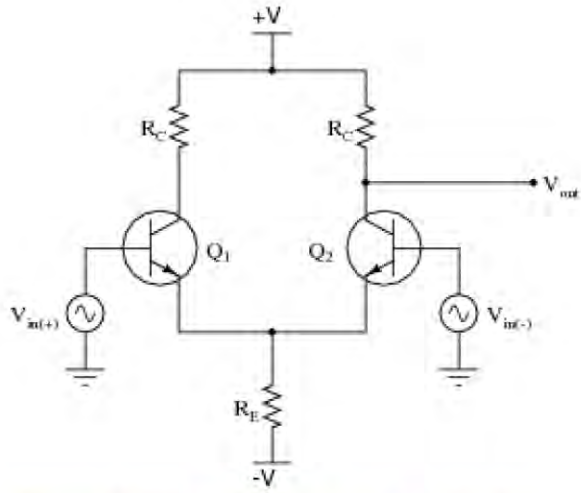
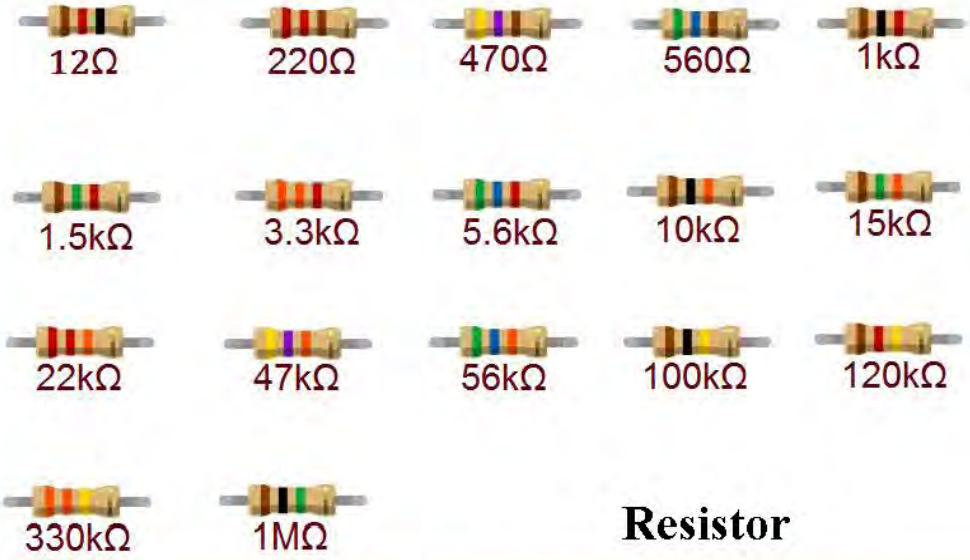


Figure 12-25 Differential amplifier circuit

SECTION TWO

EXPERIMENTS

COMPONENTS PART LIST



Resistor

Jumper

Light Emitting Diode

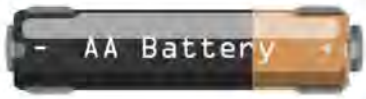
Capacitor

Potentiometer

9V Battery

Battery Connector

Fuse

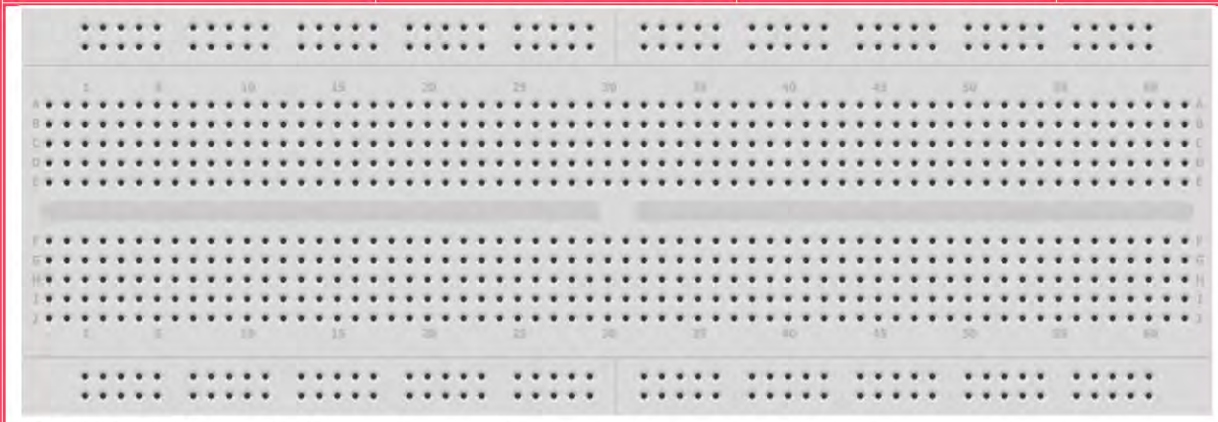
1.5 V Cell 	Press button Switch	Rocker Switch	
Toggle Switch	12 V Relay (SPDT)	PN Junction Diode	Zener Diode
Light Dependent Resistor	Bipolar Junction Transistor		
Buzzer	Infrared LED	Thermistor	Photo diode

DC Motor

Loud Speaker

Audio Jack Plug

Audio Jack Socket



Prototype Board (Breadboard)

Digital Multimeter

Alligator Clips

LIST OF EXPERIMENTS

Page

1. How To Use The Breadboard.....99
2. Setting Up A Multimeter.....104
3. Measuring Voltage With A Multimeter.....108
4. Measuring Resistance With A Multimeter.....113
5. Measuring Continuity With A Multimeter.....115
6. Measuring Current With A Multimeter.....117
7. Lighting Up An Led.....121
8. Resistors In Series.....125
9. Resistors In Parallel.....130
10. Working With The Potentiometers.....140
11. Potential Divider.....143
12. LEDs In Series.....149
13. LEDs In Parallel.....154
14. Cells/Batteries In Series And Parallel.....158
15. Working With Switches.....162
16. Working With Capacitors.....172
17. Working With Relays.....179
18. Working With Diodes.....185
19. Working With Transistors.....194
20. Transistor Logic Gates.....199
21. Transistor Switch With Relay.....206
22. Transistor Voltage Regulator.....211
23. Light Dimmer And Dc Motor Speed Control.....216
24. Transistor Touch Switch.....221
25. Light Controlled Switch.....225
26. Temperature Controlled Switch.....230
27. Transistor Motion Detector.....238
28. Light Flasher.....246
29. Simple Audio Amplifier.....250
30. Transistor H-Bridge.....256

EXPERIMENT 1: HOW TO USE THE BREADBOARD

AIM: To become familiar with the use of a breadboard and understand the breadboard connection table used in this book.

MATERIALS:

- Breadboard (1)
- Jumper wires
- Battery connector (1)
- Alligator clips (2)

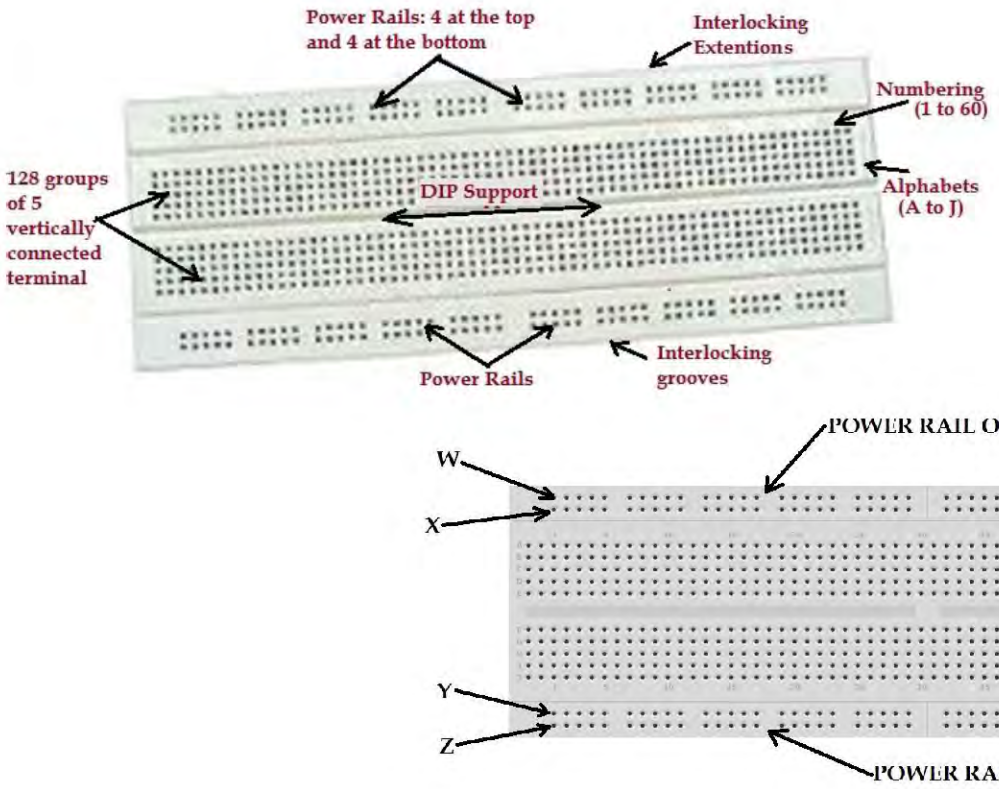
BACKGROUND:

Setting up a circuit on a breadboard could be done in variety of ways and things may get really confusing at the beginning. We will identify the parts of the breadboard and some standard conventional connection used in this book. The breadboard connection table will guide the user on how and where to make connections on the breadboard using the alphabet, A to J and number 1 to 60 label on the breadboard. The power rails are represented with the alphabets W, X, Y and Z starting from the top to the bottom. The legs of components will be label as A, B, C e.t.c depending on the number of legs it has. The position of legs on the breadboard will be indicated by an alpha-numeric set, the alphabet is for the horizontal trace and the number is for the vertical trace e.g. A17, D20, H45 e.t.c. The legs will be placed where the traces meet on the breadboard.

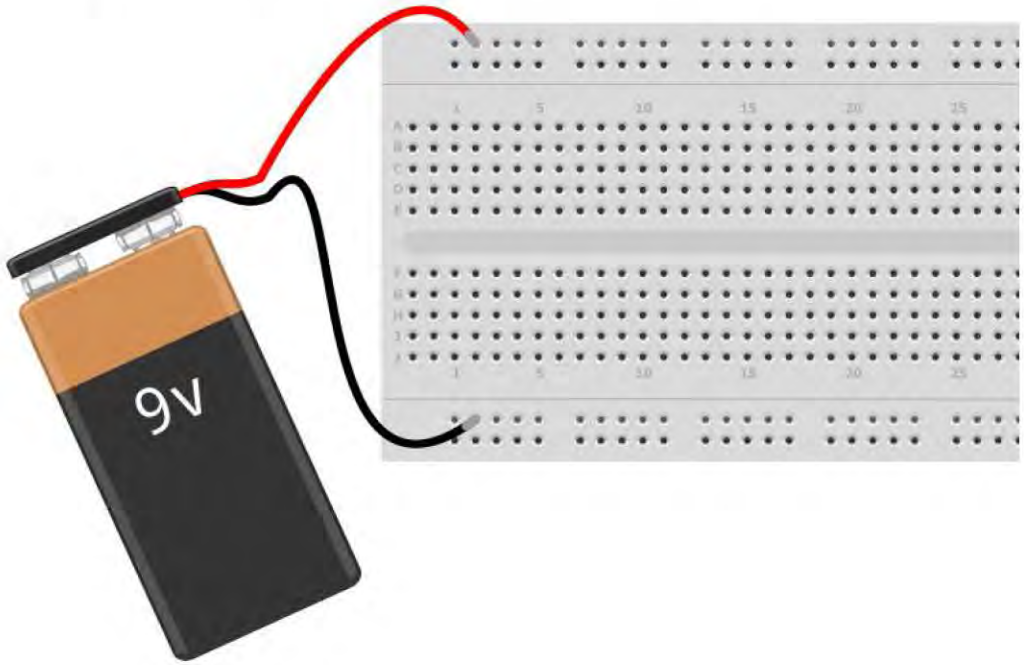
PROCEDURE:

(A) Breadboard Familiarization

1. Identify the various parts as shown in the diagram below;
    - 8 horizontally connected terminals for power rails at top and bottom
    - 128 groups of 5 vertically connected terminals for components
    - The middle Dual-In-Line (DIP) support for Integrated Circuit (IC) and other DIP devices.
    - The alphabet and number labels on the left, right, top and bottom of the vertically connected terminal
    - The interlocking grooves and extensions on the sides of the breadboard.
    - Horizontally and vertically connected areas and where connections are broken.



2. Take a battery connector and connect the red wire to W2 and the black wire to the Y2 of the breadboard as shown bellow. The different possible connection modes can be learnt at a later time as you become familiar with the use of a breadboard.

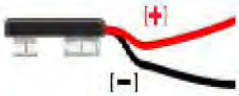


(B) Making a

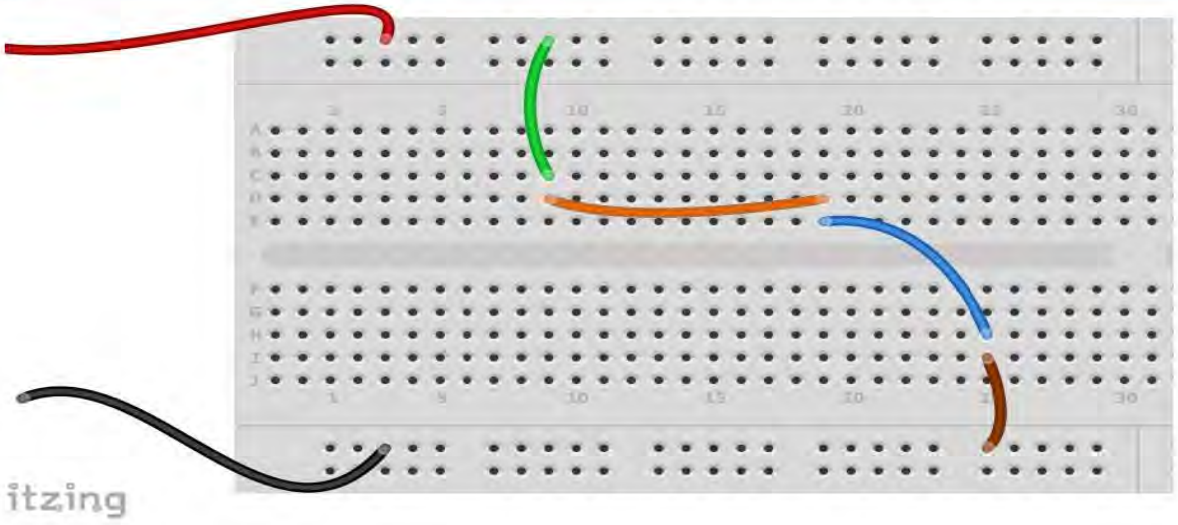
1. You will need a solid core wire that can fit easily into the breadboard slot as the once provided in your kit.
2. Using a cutter cut the wire to your desired length and consider adding an extra length which will be stripped at both ends.
3. Now, gently hold the wire in place with a plier and then softly use the cutter to strip off the insulation on the conductor at both ends. A length of between 5mm to 7mm will be ideal for your breadboard use. OR
4. If you have a wire stripper, then insert the wire into the right groove on the stripper and gently remove wire insulation of the appropriate length at both ends

(C) Understanding the Breadboard Connection Table

1. Make a connection of the four jumper wires using the connection table and observe the position as shown in the breadboard diagram below;
   - **Component name and value**: contains the information of the component description
   - **Component image and label**: gives the pictorial identification of component
   - **Connection Description**: summary of what the connection will achieve when correctly done
   - **Breadboard connection:** gives the information of the exact location of each component's leg on the breadboard using the alpha-numeric traces.
   - **Notes**: contains extra information and note for making connection

Component name and value	Component image and label	Connection Description	Breadboard connection	Notes
Battery connector (9V Clip)		Simple connection of jumper wires and the and the battery connector on the breadboard.	Red(+)=> W3 Black(-)=> Y3	1. Power Rail are represented by alphabets W, X, Y and Z starting from the top power rail to the bottom. 2. Ensure that the breadboard is positioned so that the numbers and the alphabets are not upside down.
Jumper wire 1			J1(A) =>W8 J1(B) =>C9	
Jumper wire 2			J2(A) =>D9 J2(B) =>D19	
Jumper wire 3			J3(A) =>E19 J3(B) =>H25	
Jumper wire 4			J4(A) => I 25 J4(B) =>Y21	

NOTE1: The different jumper colours used in the connection table and breadboard setup were chosen to allow for easy recognition of jumper. For your setup on the breadboard, any of the jumper wire colour could be used; it does not affect the performance of the circuit.
NOTE2: The wire colours RED and BLACK are usually reserved for the power connection only.



FUTHER ACTIVITIES:

1. If you have access to another breadboard around you, then, extend the area of the breadboard by joining them together using the interlocking groove and extension provided.
2. Read more about the different methods of making power connection of the breadboard.

EXPERIMENT 2: SETING UP A MULTIMETER

AIM:

To become familiar with the use of a digital multimeter and how to replace multimeter battery and fuse.

MATERIALS:

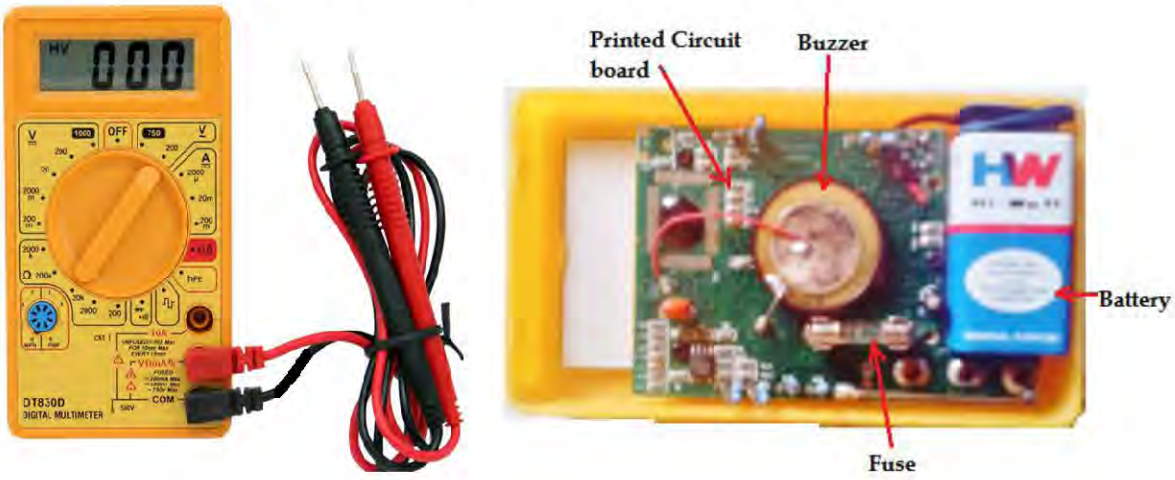
- Digital Multimeter (1)
- Multimeter leads (2)
- 9V Battery pack (1)
- Cartridge Fuse (1)
- Alligator clips pair (2)

BACKGROUND:

The multimeter is a very useful tool for testing components and making measurements of voltage, current, resistance, continuity e.t.c. it is also very useful for troubleshooting electric circuits. For this experiment, we will be using a three-port multimeter namely; COM, VΩmA and 10ADC. The COM is always fixed while the other two are used depending on the amount of current to be measured. Proper selection of port is important when using a multimeter. When the battery inside the multimeter is low, a battery symbol (symbol in here) will be displayed on its screen, indicating a need for battery replacement. Also, when a current higher than 200mA is measured while using the 200mA range, the multimeter fuse may be blown. When the fuse gets blown, it should be replaced with a fuse having the same rating as the blown fuse.

PROCEDURE:

1. Identify the various parts of the multimeter shown in the diagram below.



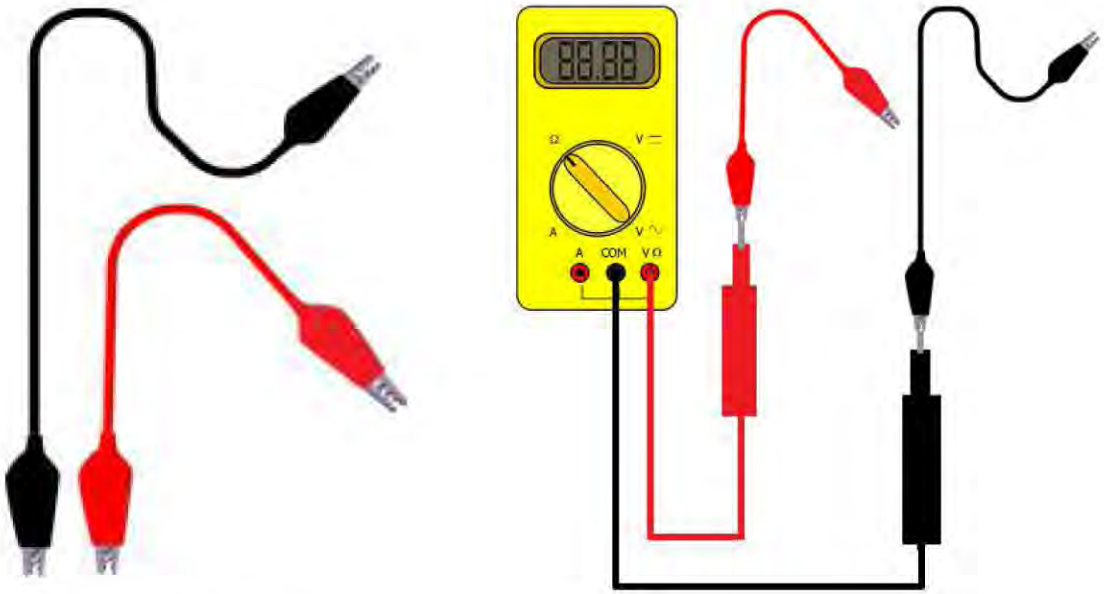
2. Using the table below identify symbols and objects on the multimeter, meanings and their application.

s/n	Symbol	Meaning	Application
1.	DCV or V⎓	DC Voltmeter	For measuring DC voltage
2.	ACV or V~	AC Voltmeter	For measuring AC voltage
3.	DCA or A⎓	DC Ammeter	For measuring DC current
4.	10ADC or 10 A⎓	10A DC Ammeter	For maximum 10 ampere current
5.	h_{FE}	Transistor Tester	For identification transistor pins
6.		Continuity Tester	For testing for continuity
7.		Diode Tester	For testing a diode status and pin
8.	Ω	Ohmmeter	For measuring resistance values
9.	−	Negative Reading	Polarity reversal in measurements
10.	HV	High Voltage	Identification of high voltage measurements and safety in use.
11.	COM	Common Port	Black lead plug-in port
12.	VΩmA	Volt-Ohm-miliampere	Red lead plug-in port for measuring voltage, resistance and maximum current of 0.2A (200mA)
13.	OFF	Power Off	Turning off the multimeter
14.	m	milli (1×10^{-3})	Multiply your multimeter display by the milli (0.001)
15.	k	Kilo (1×10^{3})	Multiply your multimeter display by the kilo (1000)
16.	µ	micro (1×10^{-6})	Multiply your multimeter display by the micro (0.000001)
17.	and	Danger and Caution	Danger of high voltage and caution warnings. Observe safety rules at all times.
18.		Low Battery	Low battery display
19.		Square Wave Injector	Low power signal source/ generator
20.	10A	10 Ampere Port	Port for 10 ampere current
21.	Fuse	Multimeter fuse	Over current protection fuse for the multimeter
22.	Buzzer	Beeper or Tone output	Makes sound when multimeter is used for continuity testing
23	Battery	Multimeter battery	Powers the multimeter
24	Printed Circuit Board	Multimeter circuit connection board	Assembly board for components and circuit to make that make the multimeter

3. Plug the black lead into the COM port and the red lead into the VΩmA port on the multimeter.

Note: The multimeter leads will be expected to be connected as stated using procedure (3) for the rest of this book, unless otherwise stated.

4. Clamp the one alligator clip on the red multimeter probe and another alligator clip on the black multimeter probe. Always use the alligator clips whenever you need to make a measurement while you require holding the probes firmly connected to a component or the measured point.



5. To replace the battery;

(a) Switch OFF the multimeter, unplug the leads from the ports and unscrew the back of the multimeter with a small star screw driver.

(b) Locate the 9V battery and disconnect it from the battery connector.

(c) Replace the battery by connecting a new 9V battery to the battery connector.

(d)Cover the multimeter as you replace the screw and then switch it ON.

6. To replace the fuse

7. (a) Repeat step 5 (a), locate the fuse and gently lift it out of the fuse holder to remove it. (b)Now replace it with the same kind of fuse having the same rating as the blown one (the multimeter fuse is **500mA** rating) and repeat step 5 (d). It's that simple!

NOTE: the multimeter can still be used to measure voltage, resistance and continuity even when the fuse is blow but will not give reading for current measurement.

Do not replace a fuse with another fuse having a different fuse rating.

NOTE: Always remember to switch off you multimeter after using it so that it does not drain the battery when left ON for a long period of time. Once the battery is low you will see the low battery symbol on the screen.

FUTHER ACTIVITIES:

1. Get more information about various other testing equipments used for electronics systems.
2. Learn about the block diagram of a digital multimeter and their functions.

EXPERIMENT 3: MEASURING VOLTAGE WITH A MULTIMETER

AIM:

To measure the voltage of a DC power source and the voltage across two points in a circuit.

MATERIALS:

- Digital multimeter (1)
- 9 V Battery (1)
- 9V Battery connector (1)
- Resistor: 120kΩ (1), 330kΩ (1), 1MΩ (2)
- Breadboard (1)
- Alligator clip pair (2)
- Jumper wires

BACKGROUND

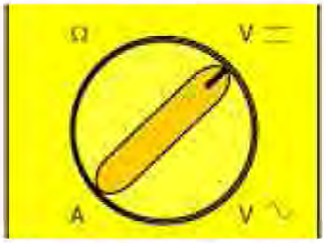
In order to measure the voltage of a DC power supply, we need to place the dial at the DCV section and select the appropriate range for the measurement. The range to be selected will depend on the amount of voltage to be measured, but amount of voltage is not known, it is safe to select the highest range on the multimeter. Voltage is measured by placing the multimeter in parallel across the components or points of interest within a circuit. The measurement displayed on the multimeter screen will inform us if the correct range and polarity was used.

PROCEDURE:

(A) Measuring the Voltage of A 9V Battery

1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port.
2. Rotate the dial to the DCV or V⎓ section and place it on the 20V range. We will only work with DC voltages in this book.

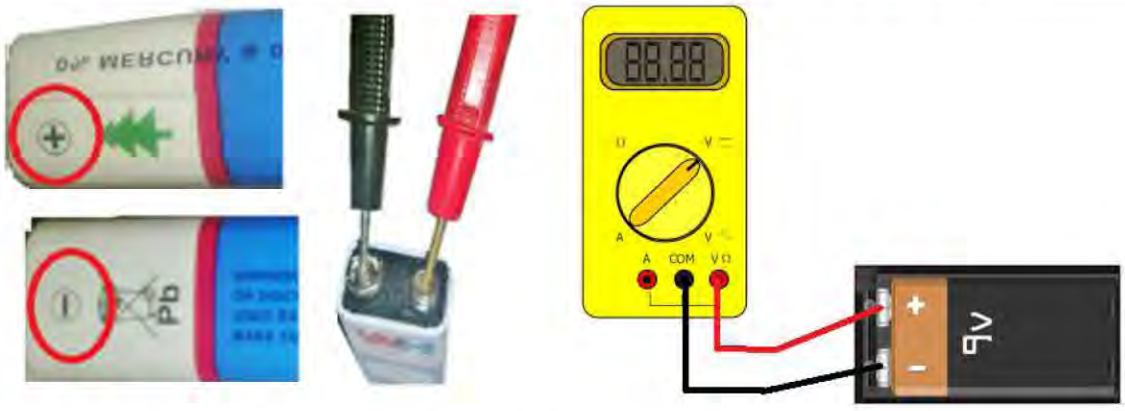
WARNING: Do not measure AC voltage without proper understanding and guidance to avoid the risk of shock, burn or electrocution.



3. Identify the polarity of the battery printed on its sides as; positive (+) and negative (-).

4. Now, place the black probe of the multimeter on the negative (-) terminal of the battery and the red probe on the positive (+) terminal of the battery. The multimeter should now give a reading of the battery voltage on its screen. OR Using an alligator clip, attach one end of the black clip to the black multimeter probe and red clip to red multimeter probe. Now attach the other end to the terminals of the battery; black to negative (-) and red to positive (+).

Make sure the probes of the multimeter are not touching when connected to the battery. If this happen, it could lead to a short circuit of the battery.



5. Negative Reading; interchange the probes of the multimeter such that the red is on the battery negative terminal (-) and the black probe on the positive terminal. This will display a negative reading on the screen.

6. Range too high; set the range to 1000V and observe the reading on the screen. Your reading may not be so accurate and it will have leading zero(s) in front it. It is best to have some decimal points without leading zeros when taking measurement. To have a better reading, then select a lower range, 20V in this case.

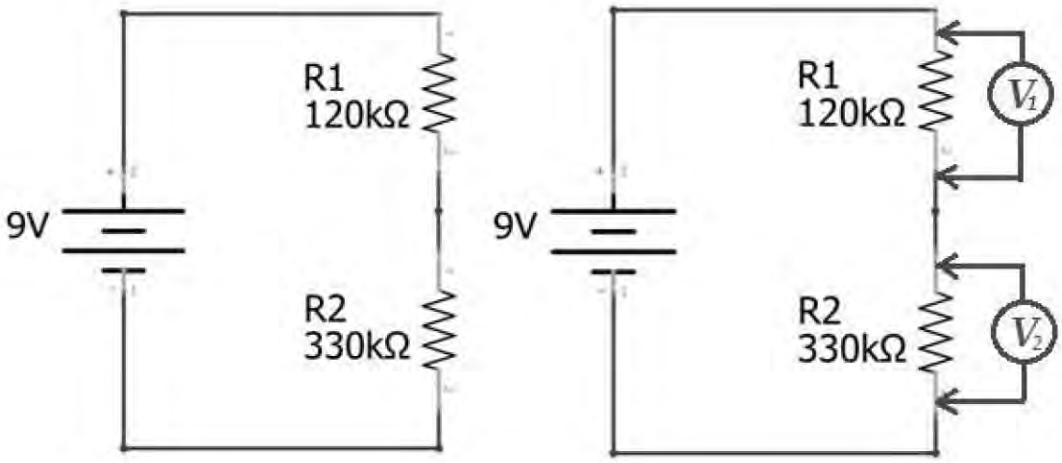
7. Range too low; set the range to 2V and observe the reading on the screen. You should see a 1 (some meters show OL) indicating an overload or out of range reading. For voltage reading, the meter will not be damaged by this. To get a better reading, then select a higher range, 20V in this case.

NOTE: Always ensure to take note of the metric conversion of the selected range when measuring. For a range of 2000m, it means that any reading displayed on the multimeter screen has to be multiplied by the metric "m" which is 10^{-3} or 0.001. Refer to the table in experiment 2 for other metric units on the multimeter.

Voltmeter Range (Volt)	Measurable Values (Volt)
200m	0V to 0.199V
2000m	0V to 1.999V
20	0V to 19.99V
200	0V to 199.9V
1000	0V to 999V

(B) Measuring Voltage in a Circuit

1. Using the connection table below, set up the circuit shown above.

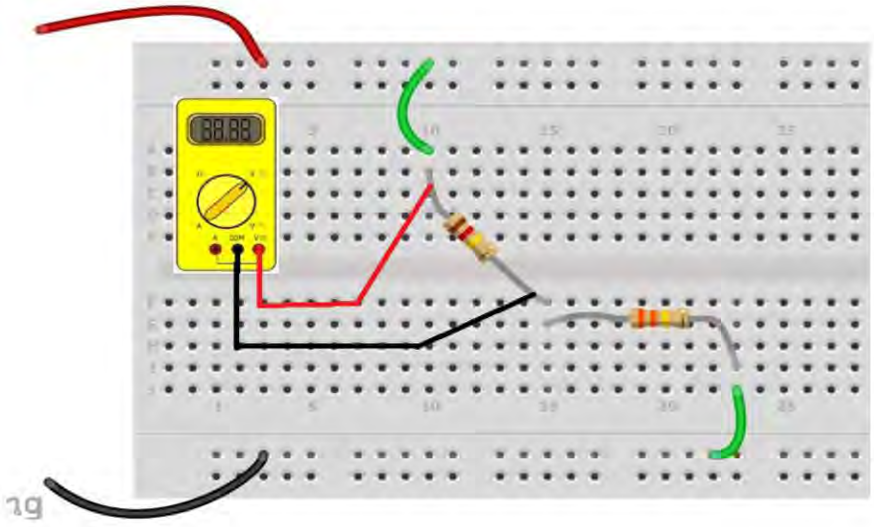


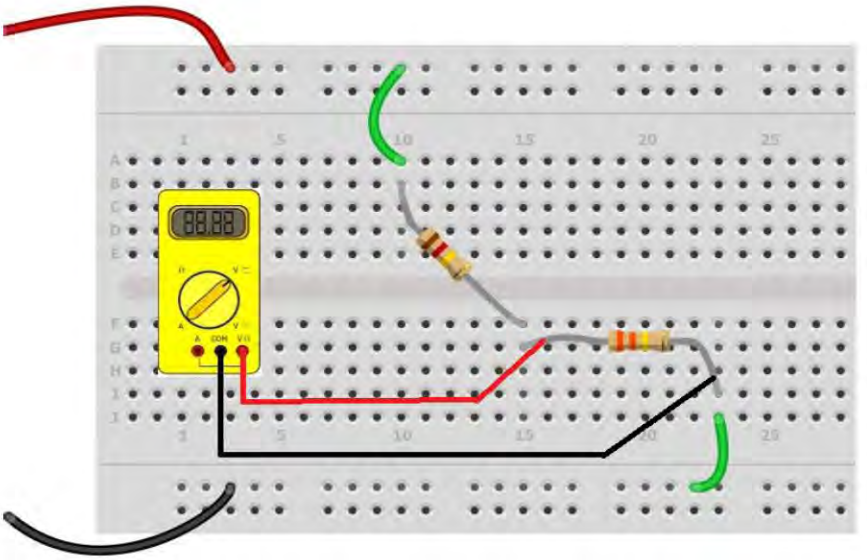
Component Name and Value	Component image and label	Connection Description	Breadboard Connection	Further notes
Jumper wire 1		The multimeter is required to be connected in parallel across the point to be measured when measuring voltage.	J1(A) => W9 J1(B) => A10	Alligator clip could be attached to the probes of the multimeter. Resistors have no polarity, therefore any of the leads can be made A or B.
Resistor1: 120kΩ Brown, Red, Yellow			R1(A) => B10 R1(B) => F15	
Resistor2: 330kΩ Orange, Orange, Yellow			R2(A) => G15 R2(B) => I 23	
Jumper wire 2			J2(A) => J23 J2(B) => Y19	
Battery connector			Red(+) => W3 Black (-)=> Y3	

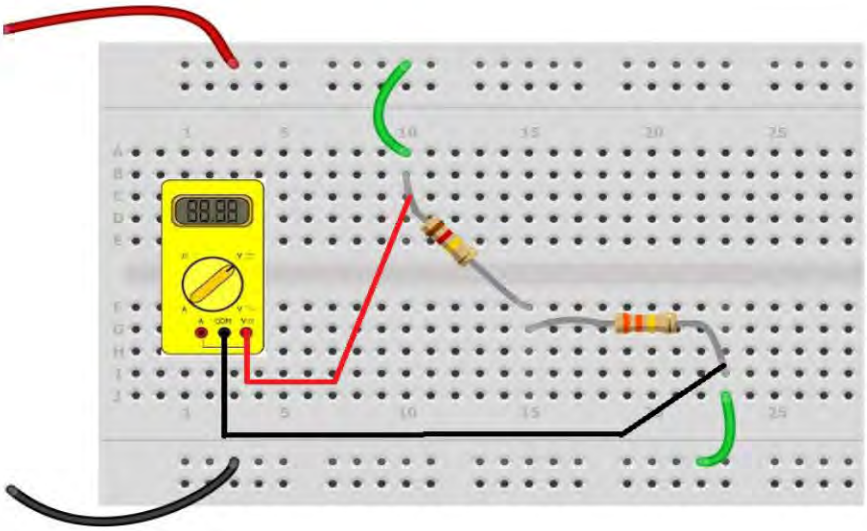
2. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the dial of the selector to the voltage section (DCV or V⎓) and place it on the 20V range.

NOTE: The 9V battery and its connector will be referred to altogether as the 9V battery pack for the rest of the book.

3. Interchange the leads of the multimeter and observe the negative sign of the readings.
4. Change the range of the multimeter to a higher and lower value for each of the done above and observe the reading as explained in procedures A(6) and A(7) of this experiment.







FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Replace the resistors in the circuit; R1 and R2 = 1M (Brown , Black, Green) and measure the voltage across each resistor.

EXPERIMENT 4: MEASURING RESISTANCE WITH A MULTIMETER

AIM:

To understand how to measure the resistance with a multimeter

MATERIALS:

- Digital Multimeter (1)
- Alligator clip pair (2)
- Resistor: 12Ω(1), 220Ω(1), 5.6kΩ, 100kΩ, 1 MΩ

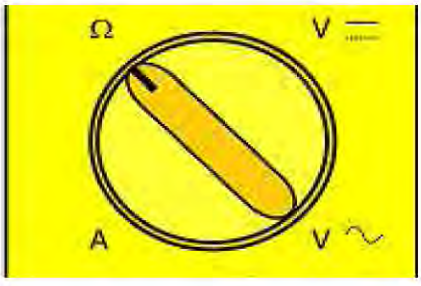
BACKGROUND:

Measuring the resistance of a resistor with a multimeter gives a more accurate value of the resistance because the color codes usually have to tolerance band which tell us the range between which the resistance should be. A resistor with colour code value of 1000Ω and 5% tolerance for example will usually have it resistance value between 950Ω and 1050Ω when measured with a multimeter. It is important to isolate the particular resistor you want to measure unless you want to measure the resistance of the entire circuit. The display on the multimeter will usually indicate if the correct range has been selected or to change to a higher or lower one.

WARNING: Ensure no current is flowing in the circuit or component when you want to measure resistance. Switch off all power supply, remove power plug from the socket and remove any battery connected.

PROCEDURE:

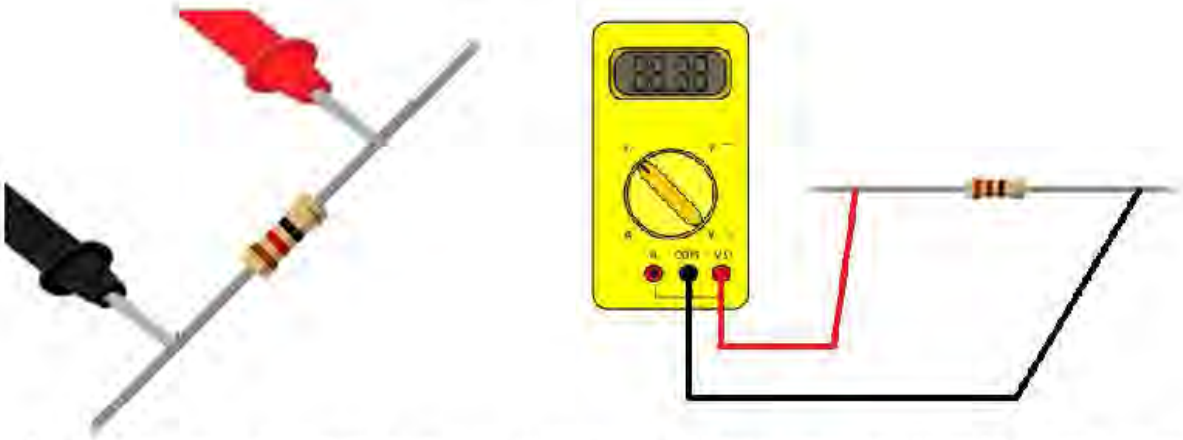
1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port.
2. Set up the multimeter to the resistance (Ω) section and point the selector to the 200Ω range.



Ohmmeter Range (Ohm)	Measurable Values (Ohm)
200	0Ω to 199Ω
2000	0Ω to 1999Ω
20k	0Ω to 19,999 Ω
200k	0Ω to 199,999Ω
2000k	0Ω to 1,999,999 Ω

3. Place your 12Ω resistor on an insulated plane surface and then touch the two ends of the resistor with the multimeter probes OR attach alligator clips to the probes of the multimeter and then attach the other ends to the resistor legs.

NOTE: The resistors have **no polarity** (+ or -) and so, the multimeter probes can be connected in any order to the resistor legs.



4. Now change the range of your multimeter to a higher range and then to a lower range.
    - Range too high: when the selected range for measuring the resistance is too high, you will get a reading of almost zero displaying on the multimeter screen. To get a better reading, turn the selector to a lower range until a value is displayed.
    - Range too low: when the range is too low, the multimeter will display either a **1** or **OL (Over load)** on the screen. The two possibilities for show a 1 or OL are;
        i. When the resistance value is too high for the selected range. At this point, what you need to do is to turn the selector to a higher range to get a better reading.
        ii. When there is an open circuit. Since an open circuit has an infinite resistance, you will always get the reading of 1 or OL for any selected range on your multimeter.

    NOTE: Always ensure to take note of the metric conversion of the selected range when measuring. For a range of 20k, it means that any reading displayed on the multimeter screen has to be multiplied by the metric "k" which is 10^3 or 1000. Refer to procedure 2 of experiment 2 for other metric units.
5. Compare your reading with the colour code values of the resistors (refer to component list at the beginning of section two.
6. Repeat the procedure 3 to 5 for each of the resistors listed in the material section of this experiment.

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.

EXPERIMENT 5: MEASURING CONTINUITY WITH A MULTIMETER

AIM:

To understand how to use the multimeter to test for continuity (Open circuit and Closed circuit)

MATERIALS:

- Digital Multimeter (1)
- Alligator clip pair (2)
- Breadboard (1)
- Jumper wire wires
- Cartridge Fuse (1)

BACKGROUND:

Continuity test is usually carried out to know if two points are electrically connected. It provides for a quick way of checking if a connection has been correctly done and so determine if current will flow or not. It is also very useful for troubleshooting wrong connections in a circuit or network. If there is continuity between two points, the resistance between the points will usually be very low since the resistance measured is that of the conductor connecting. Recall that the resistances of conductors used for wires and cable are made of metals of very low resistances. With the aid of the multimeter, once a continuity exits between two points you should hear a tone or beep. If no tone or beep is heard, then that could mean a very high resistance or an open circuit in the circuit path.

WARNING: Ensure no current is flowing in the circuit or component when you want to test for continuity. Switch off all power supply, remove power plug from the socket and remove any battery connected.

PROCEDURE:

1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port.
2. Turn the selector knob to the continuity tester indicated by the sound wave icon ( ).
3. Now touch the two multimeter probes against each other and you should get a beep if corrected done. Your multimeter will display a zero on its screen meaning no resistance is measured.

4. With the multimeter at the continuity tester, check for continuity for each of the following ;
   i. Jumper wires
   ii. Alligator clip
   iii. Fuse
5. Now check the continuity on you breadboard to know the connected slots. Pick up jumper wires and insert them into the breadboard as follows;
   i. Horizontal slots: insert the jumper wires same rows of the four horizontal slot namely W, X, Y and Z respectively and check for continuity. Also do this for the adjacent horizontal rows.
   ii. Vertical slots: now insert the jumper wires to the vertical slots, some to the same column and other to adjacent column and check for continuity. Do these for the entire board as you get familiar with making connections.

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Check for the continuity of a cable by joining on end and testing the other end.
5. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 6: MEASURING CURRENT WITH A MULTIMETER

AIM:

To understand how to use the multimeter to measure the current flowing in a DC circuit

MATERIALS:

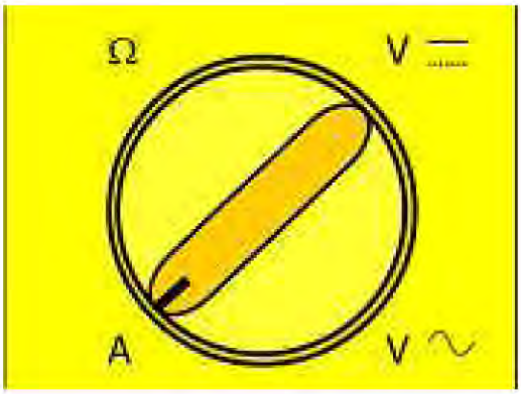
- Digital Multimeter (1)
- Alligator clip pair (2)
- Breadboard (1)
- Jumper wire
- 9V battery pack (1)
- Resistors: 1kΩ (1), 560Ω (1), 1.5kΩ (1), 3.3kΩ (1)

BACKGROUND:

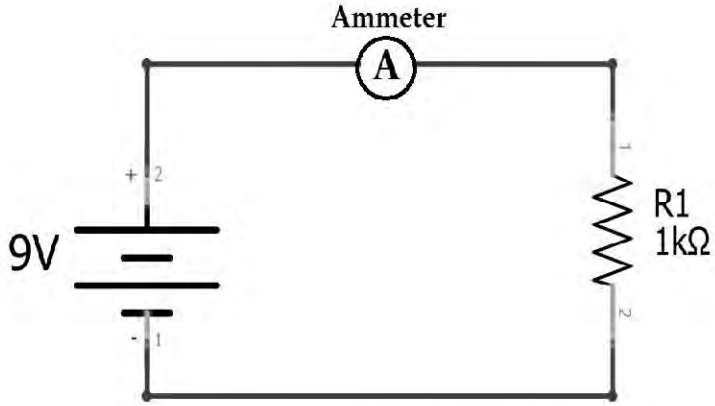
Current measurement requires a little more attention. The proper range must be selected. A wrong range selection could lead to blowing the fuse. Also, a break will have to be made in the circuit path. The multimeter must be connected in series so that current can flow through it when measuring current. It is also very important to know that unlike voltage measurement where the multimeter can be connected directly to the battery without a load (or a resistor), for current measurement on the other hand; there **MUST** be a load connected in series with the multimeter and the battery. A series resistor will help to limit the current flowing through the circuit which also flows through the multimeter. For current values of less that 200mA (or 0.2A) the red multimeter lead should be plugged to the VΩmA port while for a maximum of 10A current it should be plugged to the 10ADC port.

PROCEDURE:

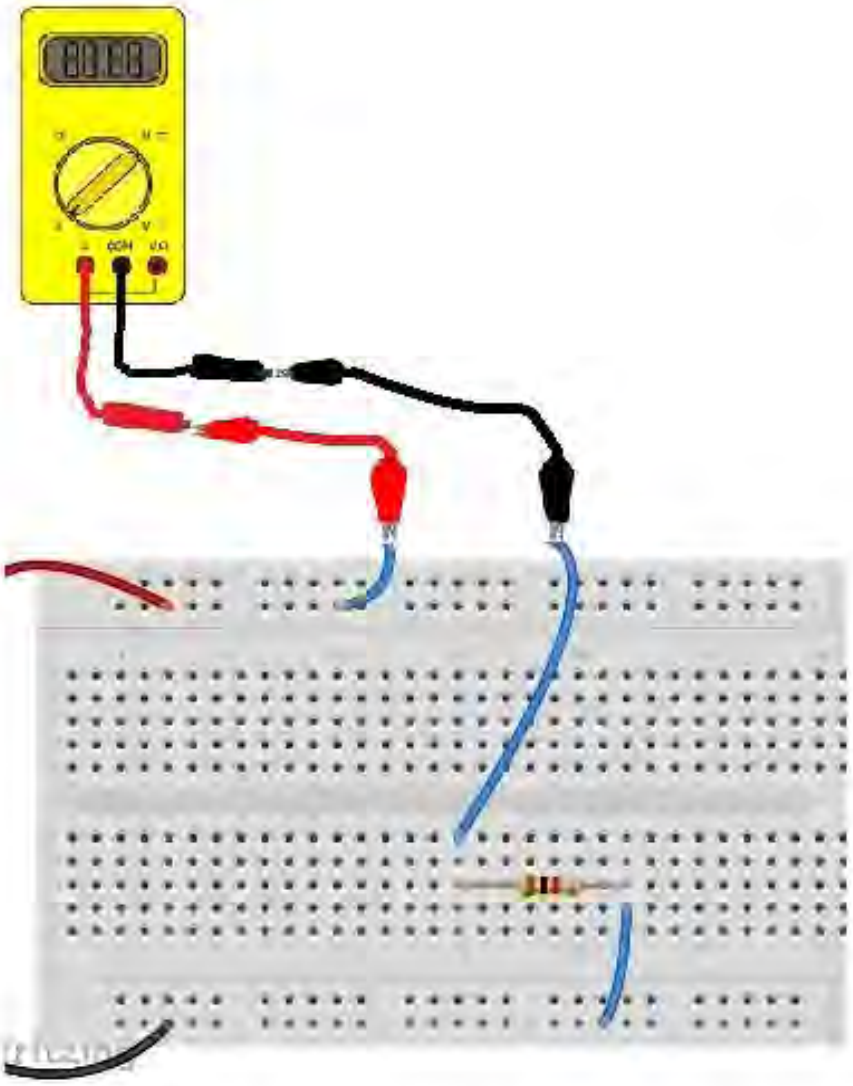
1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port.
2. Move the dial of the selector to the current section (DCA or A⎓) and place it on the 20mA range.
3. Connect the alligator clips to the probes of the multimeter
4. Set up the circuit below on you breadboard using the connection table shown below.



Ammeter Range (Ampere)	Measurable Values (Ampere)
2000µ	0A to 0.002A
20m	0A to 0.019A
200m	0A to 0.190A
10	0A to 9.99A



Component Name and Value	Component Image and Label and Label	Connection Description	Breadboard Connection	Note
Jumper wire1 (Long)		The multimeter is required to be connected in series with the device through which current is flowing when measuring voltage.	J1(A) => X9 J1(B)=> Alligator Clip	"Long" means a longer length of jumper wire will be ideal for the conection.
Jumper wire2 (Long)			J2(A) => F15 J2(B)=> Alligator Clip	
Resistor1: 1kΩ Brown, Black, Red			R1(A) => H15 R1(B) => H22	
Jumper wire3			J3(A) => I 22 J3(B) => Z18	
Battery Connector			Red(+) => X3 Black (-)=> Z3	



5. Interchange the probe of the multimeter to get a negative reading.
    - Negative reading: as with voltage measurement, it is possible to have negative reading with current measurement. This indicates that current is actually flowing in the opposite direction. A positive reading means that current is flowing through the red probe connected to the VΩmA port, through the multimeter and out through the black probe connected to the COM port.
6. Now change the selector of the multimeter to a higher range and then to a lower range.

    - Range too high: if th erange of the multimeter is too high for the current reading, its reading will display some leading zeros before the digits. To get a better reading, change the dial to lower ranges.
    - Range to low: when the range is too low for the current to be measured, it will usually show a **1 or OL(Over Load).** The two possible for this could be;
        i. If the reading is 1 or OL and the current measured is lesss than 200mA, then change the dial to a higher range to get a reading.

ii. If the range is already at the 200mA range and the reading is a 1 or OL, then it mean the measurement is to be done with the 10A DC for a maximum current of 10A flowing. You may need to replace the fuse if it is already blown by the overload measurement.

7. Replace the 1kΩ resistor and replace it with other resistor values listed in the material section of this experiment and repeat procedure 5 to 6 for each of them.

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Using the Ohm's law,

$V = I\mathrm{R}$ where V – the battery voltage.
I – current flowing in the circuit
R – Resistance of the resistor

which can be rearranged as;

$I = \frac{V}{R}$, calculate the current flowing through the circuit and compare it with the multimeter reading.

5. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 7: LIGHTING UP AN LED

AIM:

To understand how to work with an LED and how to vary the brightness with a resistor

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- Jumper wires
- 9V battery pack (1)
- Resistors: 5.6kΩ (1), 10kΩ (1), 15kΩ (1)
- LED: Red (1), Yellow (1), Green (1), White (1) , blue (1)

BACKGROUND:

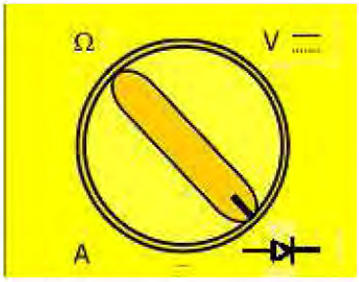
A Light Emitting Diode (LED) is a kind of diode which gives visible radiation of different colors when powered. It is a non-ohmic device, that is, it does not obey Ohm's law just like a resistor. it has two legs which are labeled anode (A) and cathode (K) respectively. For the LED to give light, then the anode must be made more positive than the cathode by amount of voltage called the forward voltage (V_F). A series resistor will be connected to the LED to limit the maximum current through it, called the forward current, (I_F). The forward voltage and the maximum current are usually give by the manufacturers in the datasheet. The value of the resistor can be calculated using Ohm's law. A typical LED will have the anode leg longer than the cathode leg but if in doubt of the identification, a multimeter can be very handy in check for the legs.

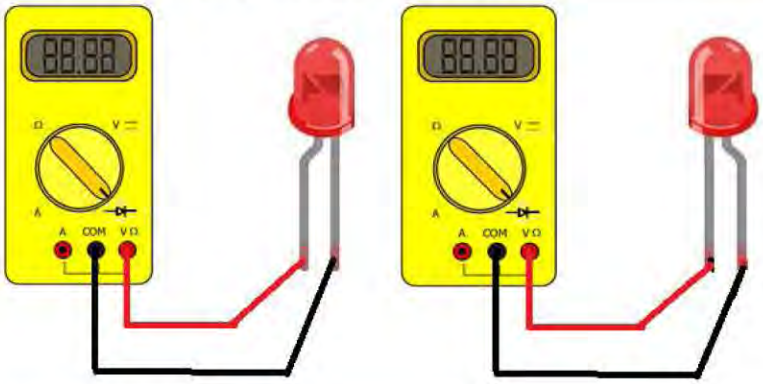
PROCEDURE:

(A) Determine the Anode And Cathode Of An LED

1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port and turn the selector to the diode tester (⊣▶⊢).
2. Connect the red probe to one of the legs and the black to the other leg. If no light comes up on the LED then interchange the probe. (The anode leg is usually longer than the cathode).
3. Once the LED give light with the probe connected, then the leg connected to the red lead is the anode (A) while the one connected to the black will be the cathode (K).
4. Use a small tape or piece of paper to mark the anode leg.

NOTE: If the LED does not give a light when the multimeter probe is connected in either ways, then, this could mean that the LED is damaged and should be replaced.





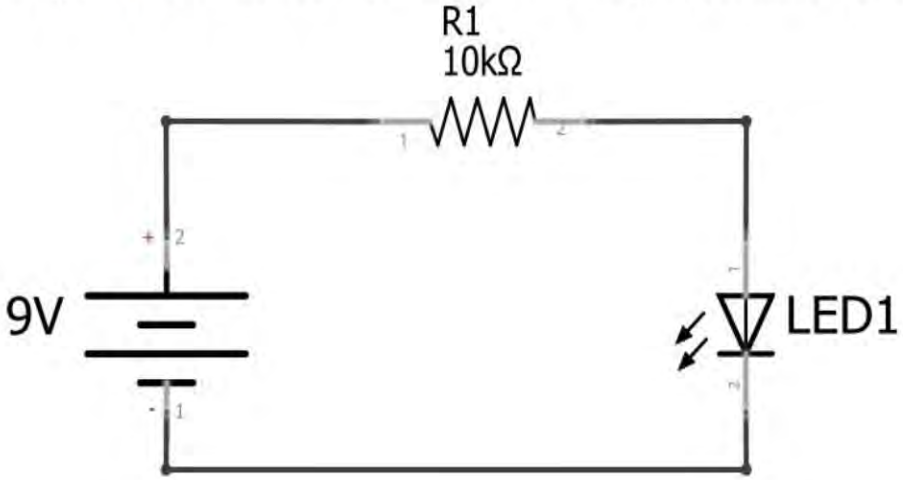
Lens Colour	Forward Voltage		Forward Current	
	Typical	Maximum	Typical	Maximum
RED	1.6Volts	2.0Volts	0.010Amp	0.020Amp
GREEN	2.2Volts	3.0Volts	0.010Amp	0.020Amp
YELLOW	2.2Volts	3.0Volts	0.010Amp	0.020Amp
"Blue" (Note)	3.8Volts	4.5Volts	0.020Amp	0.020Amp
WHITE	3.2-3.6Volts	3.8Volts	0.010Amp	0.020Amp

NOTE 1: The above Voltage and Current ratings are based on several everyday generic LEDS in the 3mm and 5mm ranges.

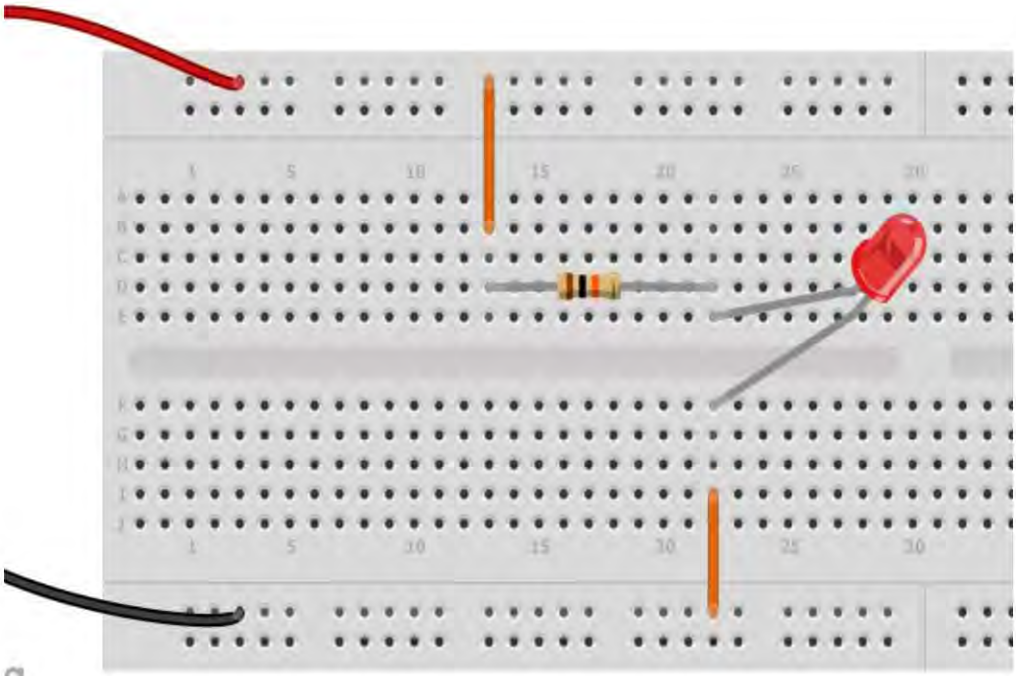
NOTE 2: Blue colour LEDS may typically have forward working voltages exceeding those used in the above example. Forward working voltages for some Blue colour LEDS may also fall in the 4.9 to 5.5Volt range.

(B) Connecting The LED In A Circuit

1. Set up the circuit below on your breadboard using the connection table below.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire1			J1(A) => W11 J1(B) => B13	The anode leg of the LED is usually longer than that of the cathode from the manufactu rer.
Resistor1: 10k Ω (Brown, Black, Orange)			R1(A) => D13 R1(B) => D22	
LED1			LED1(A) =>E22 LED1(K) =>F22	
Jumper wire2			J2(A) => H22 J2(B) => Y19	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



g

2. Remove the 10kΩ resistor and replace it with the 5.6kΩ and 15kΩ resistors and observe the brightness of the LED.
3. Replace the LED with other colors listed in the materials section of this experiment.

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.

4. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port.
5. Move the dial of the selector to the voltage section (DCV or V⎓) and place it on the 20V range.
6. Measure the voltage across the LED, that is, connect the red probe of the multimeter to the anode and the black probe to the cathode respectively. (Refer to experiment 3 for more assistance).
7. Using the equation below, calculate the current flowing through the LED;

$$I_{LED} = \frac{Battery\ voltage - LED\ voltage}{Resistance\ of\ the\ series\ resistor}$$

8. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port.
9. Move the dial of the selector to the current section (DCA or A⎓) and place it on the 20mA range.
10. Then, measure the current flowing through the circuit and compare it with your calculated value.
11. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 8: RESISTORS IN SERIES

AIM:

To learn how to construct resistors in series on a breadboard and understand the feature of a series circuit

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- Jumper wires
- Alligator clip pair (2)
- 9V battery pack (1)
- Resistors: 1kΩ (1), 5.6kΩ (1), 10kΩ (1)

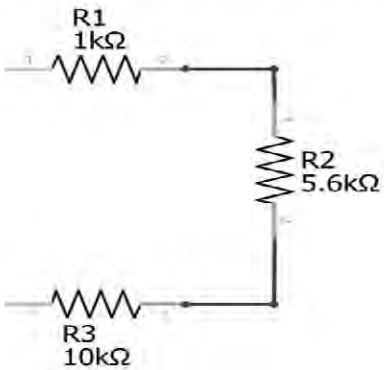
BACKGROUND:

When there is more than one resistor in a circuit, they can be arranged in either series or parallel connection. A series connection is an end-to-end arrangement which allows the same current to flow through the network while the applied voltage will be divided across the resistances in series. The total resistance for three series connected resistors will be the sum of the individual resistance connected, given by the equation;

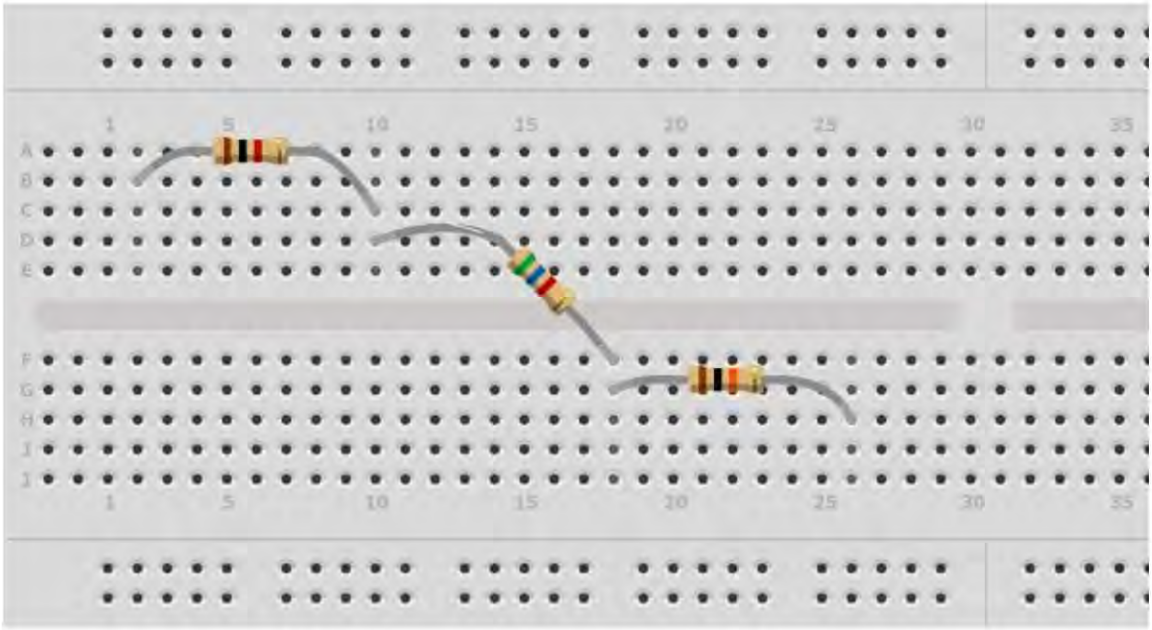
$$R_{TOTAL} = R_1 + R_2 + R_3$$ EQUAVALENT OF TWO RESISTANCES IN SERIES

PROCEDURE:

1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port.
2. Move the selector to the Ohms section (Ω) and place it on the 20kΩ range.
3. Set up the circuit below using the connection table;



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor1: 1k Ω (Brown, Black, Red)		Make connections as indicated in the breadboard connection column.	R1(A) => B2 R1(B) => C10	There is no power connection done yet. It will be introduced later in the experiment.
Resistor2: 5.6kΩ (Green, Blue, Red)			R2(A) => D10 R2(B) => F18	
Resistor3: 10k Ω (Brown, Black, Orange)			R3(A) => G18 R3(B) => H26	

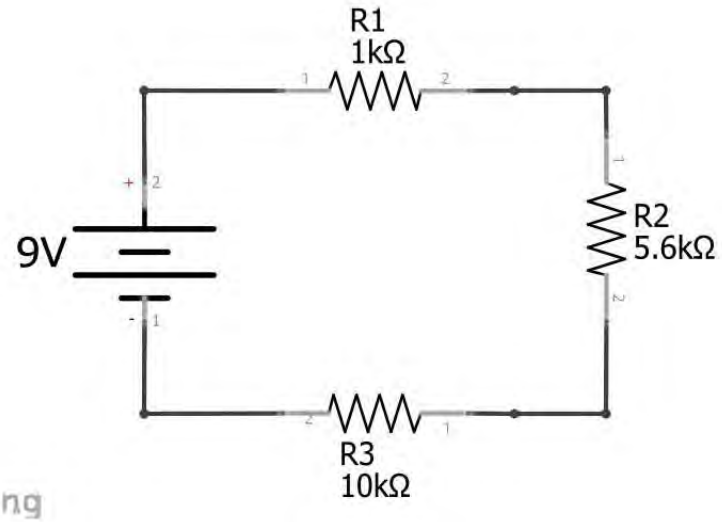


i. Measure the resistance of each of the resistors in series on the breadboard and record it in the table below

s/n	Resistor	Measured Resistances	Measured voltages
1	R1		
2	R2		
3	R3		
4	Total Measured		

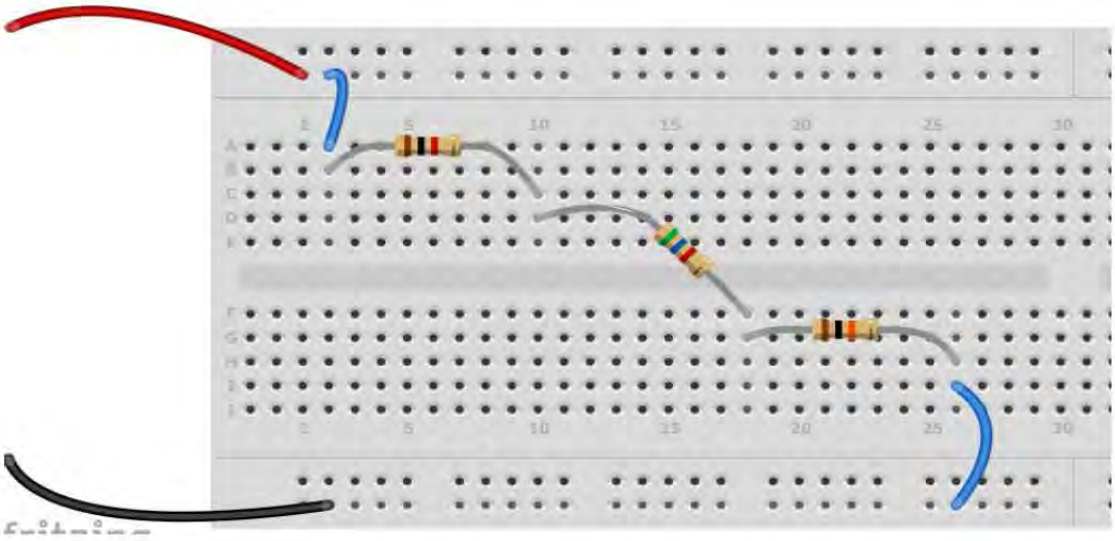
ii. Now measure the total resistance of the series connected resistors and record in the table above.

4. Complete the circuit above using the connection table below for the addition of power supply;



ng

Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper1		Make connections as indicated in the breadboard connection column.	J1(A) => X2 J1(B) => A2	This table is an addition to the previous table setup.
Jumper2			J2(A) => I 26 J2(B) => Z22	
Battery Connector			Red (+)=> X1 Black (-)=> Z2	



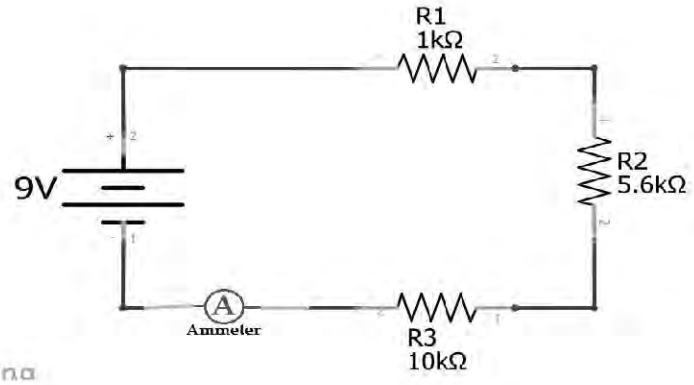
5. Move the dial of the selector to the voltage section (DCV or V⎓) and place it on the 20V range. Then measure the voltage across each of the resistors and record in the table above.

NOTE: For a series arrangement, the sum of the individual voltage drop across the resistances in series will be equal to the applied voltage (battery voltage) of the circuit. This is given by the equation;

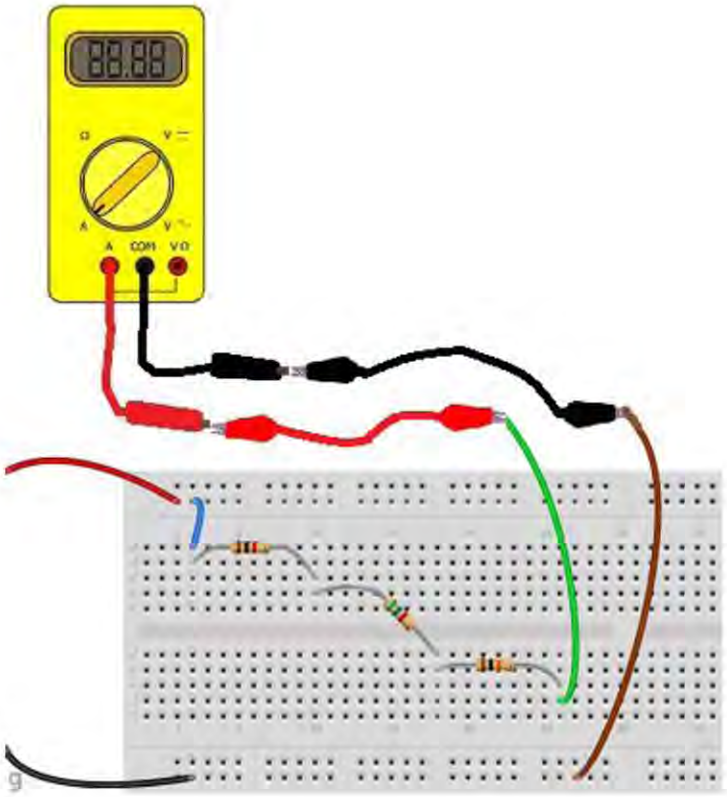
$$V_{TOTAL} = V_1 + V_2 + V_3$$

6. Set up the circuit shown below to measure the current flowing through the circuit and compare with a calculated value; Move the dial of the selector to the current section (DCA or A⎓) and place it on the 20mA range.

NOTE: For a series arrangement, the same amount of current will flow through all the connected resistances.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire3		Jumper 2 should be removed before making this adjustment.	J1(A) => I 26 J1(B) => Red Alligator Clip	Make adjustment to the setup done in the previous table.
Jumper4			J2(A) => Black Alligator Clip J2(B) => Z23	
Battery Connector			Red(+) => X1 Black (-)=> Z2	



7. Compare your current measured with the calculated value given by Ohm's law as,

$$I = \frac{V(sum\ of\ voltage\ across\ the\ resistors)}{R(Sum\ of\ the\ measured\ resistancess)}$$

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.
5. Confirm that Ohm's laws hold for the circuit by multiplying the current by each of the resistances.

i. $V_{R1} = I \times R1$

ii. $V_{R2} = I \times R2$

iii. $V_{R3} = I \times R3$

EXPERIMENT 9: RESISTORS IN PARALLEL

AIM:

To learn how to construct resistors in parallel on a breadboard and understand the feature of a parallel circuit

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- Jumper wires
- Alligator clip pair (2)
- 9V battery pack (1)
- Resistors: 5.6kΩ (1), 10kΩ (1)

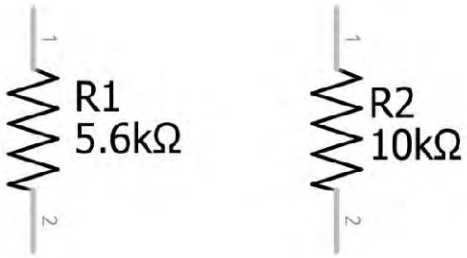
BACKGROUND:

The parallel connection has a ladder model in which there are two main supports which are then connected with branches in between. The two main supports are the positive and negative supply (or live and neutral) while the branches are the connected load (or resistances). The same voltage will be across each of the loads and only the needed current for each load will flows through the branches. The parallel connection is usually used for various types of domestic and industrial electrical installations. The total resistance in an arrangement of resistors connected in parallel for two resistors is usually smaller and given by the equation;

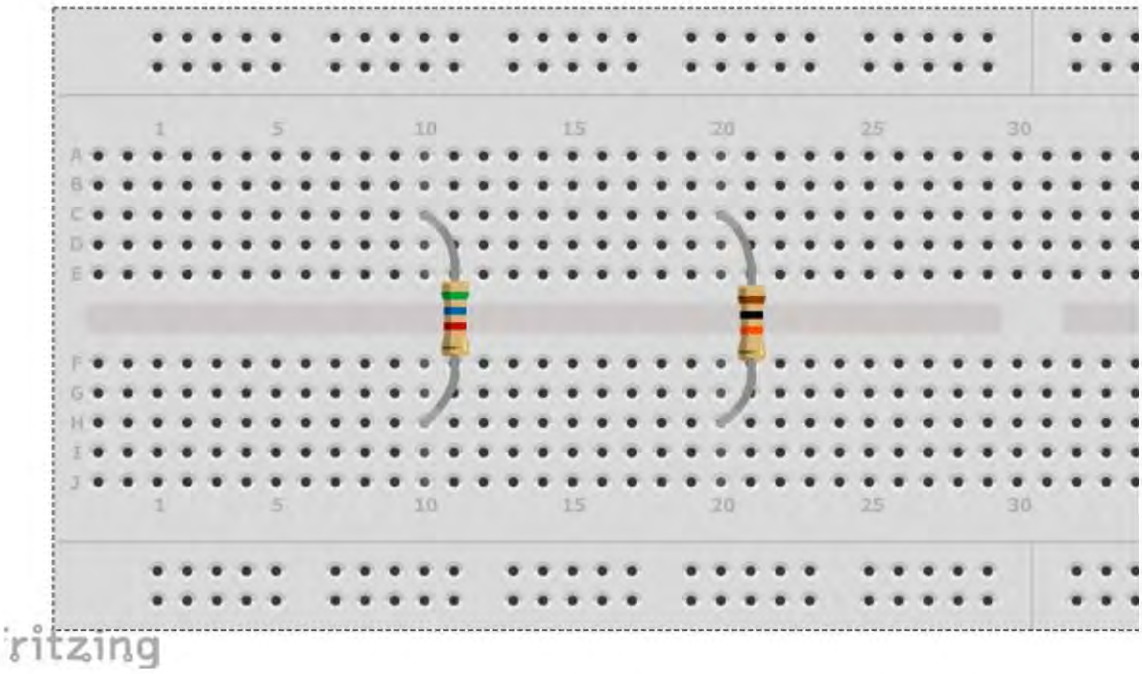
$$\frac{1}{R_{TOTAL}} = \frac{1}{R_1} + \frac{1}{R_2} \quad \ldots \text{ EQUVALENT FOR TWO RESISTANCES IN PARALLEL}$$

PROCEDURE:

1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port.
2. Move the selector to the Ohms section (Ω) and place it on the 20kΩ range.
3. Set up the circuit below using the connection table given and then measure the resistance of each of the resistors. Record your result in the table below.

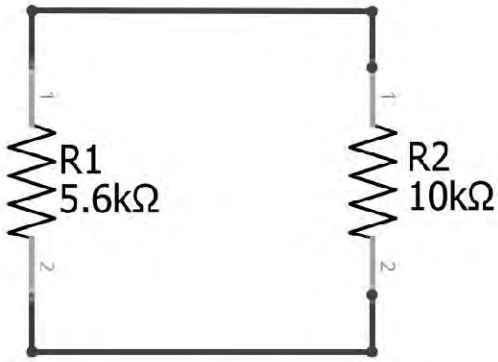


Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor1: 5.6kΩ **Green, Blue, Red**			R1(A) => C10 R1(B) => H10	There is no power connection done yet.
Resistor2: 10k Ω **Brown, Black, Orange**			R2(A) => C20 R2(B) => H20	

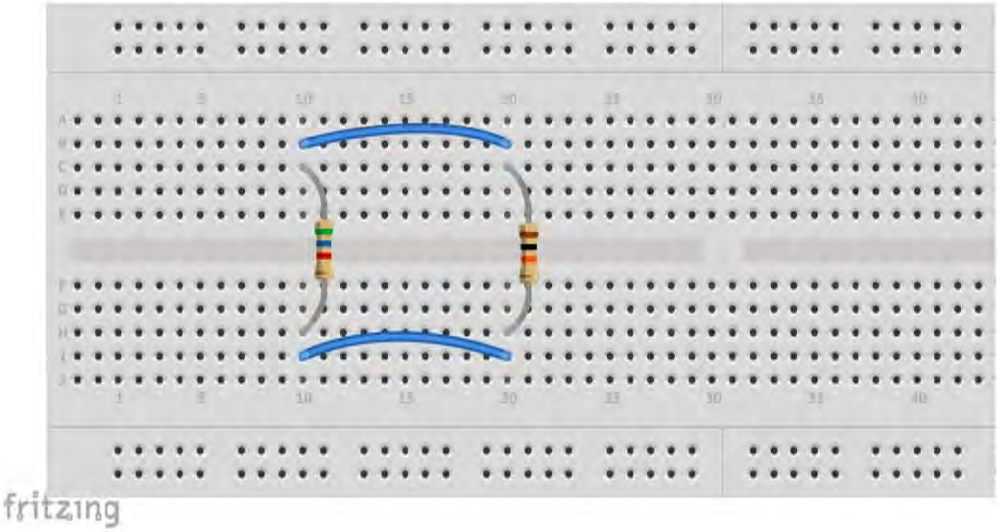


s/n	Resistor	Measured Resistances	Measured current
1	R1		
2	R2		
3	Total Measured		

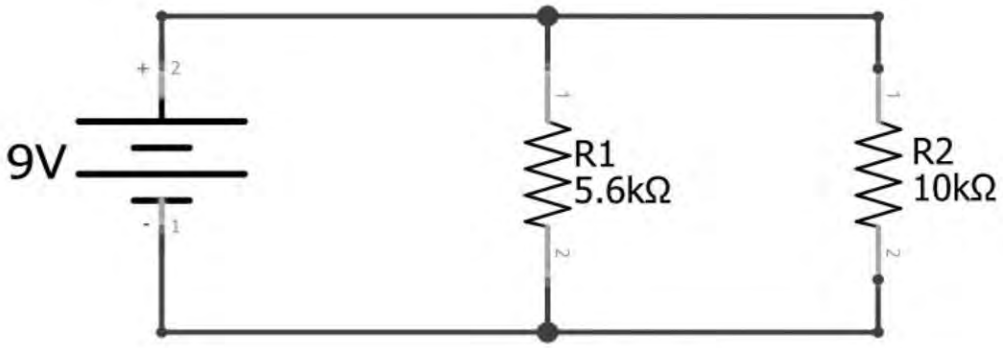
4. Use the connection table below, complete the circuit above to connect the two resistors in parallel and measure the total resistance. Record your results in the table above.

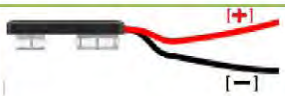


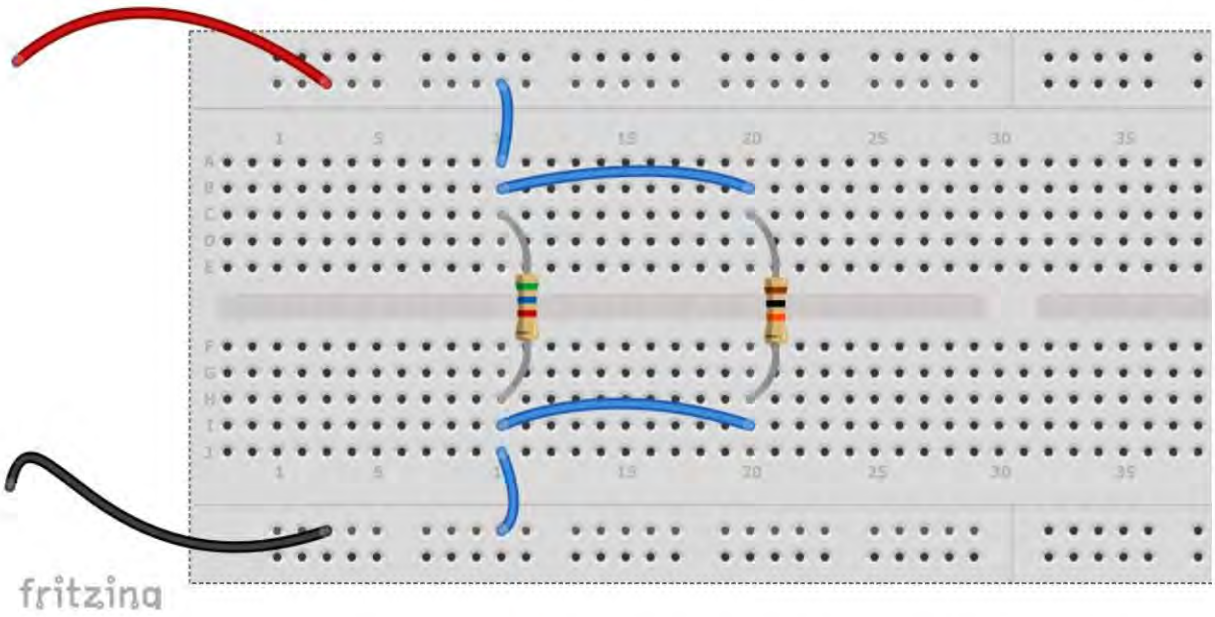
Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire1			J1(A) => B10 J1(B) => B20	This table is an addition to the previous table setup.
Jumper wire2			J2(A) => I 10 J2(B) => I 20	



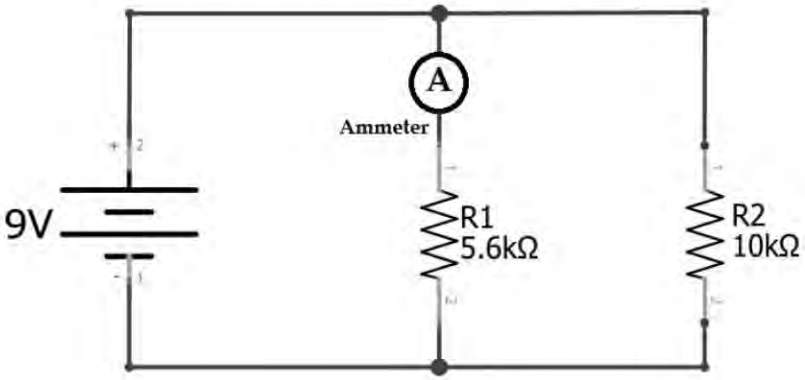
5. Connect the power supply to the network by using the additional connection table below;

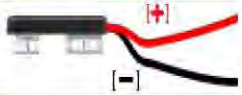


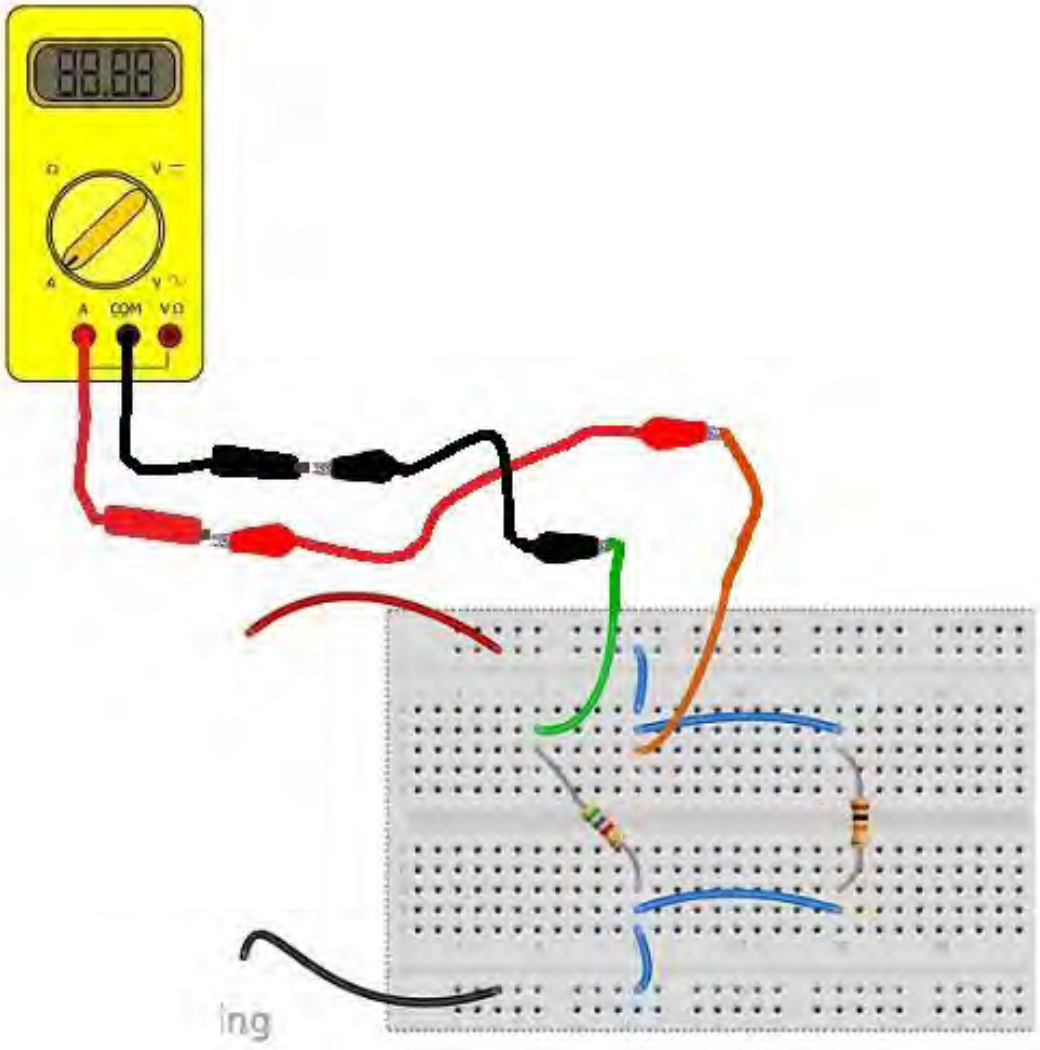
Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire3		Make connections as indicated in the breadboard connection column.	J3(A) => X9 J3(B) => A10	Further addition to the other connections already made on the breadboard.
Jumper wire4			J4(A) => J10 J4(B) => Y9	
Battery Connector			Red (+)=> X3 Black (-)=> Y3	



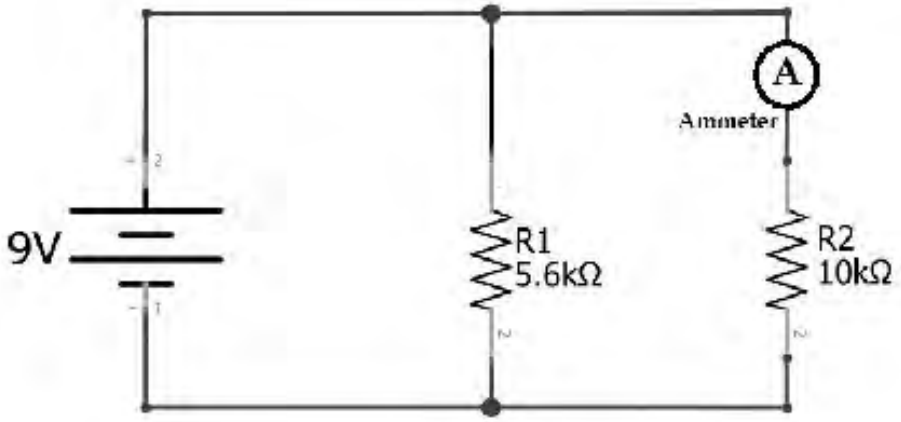
6. Move the dial of the selector to the voltage section (DCV or V⎓) and place it on the 20V range. Then measure the voltage across each of the resistors. (The voltage should be the same as the applied voltage)
7. Move the dial of the selector to the current section (DCA or A⎓) and place it on the 20mA range.
8. Set up the circuit below to be able to measure the current flowing through each of the resistors and the total current in the circuit. Use the connection table below.
   i. Current through the 5.6kΩ resistor. Record your result in the given table above.



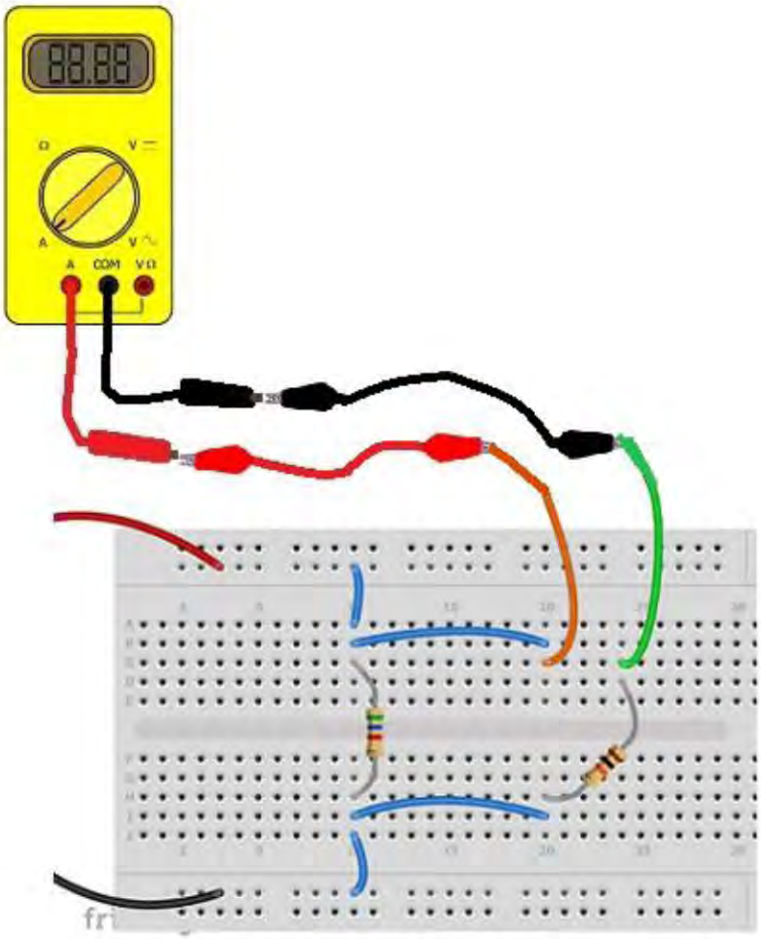
Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor1: 5.6k Ω Green, Blue, Red		Slight changes done to the position of the components.	R1(A) => C5 R1(B) => H10	Make adjustment to the arrangement on the breadboard with this table.
Jumper wire5			J5(A) => C10 J5(B) => Alligator Clip	
Jumper wire6			J6(A) => B5 J6(B) => Alligator Clip	
Battery Connector			Red (+)=> X3 Black (-)=> Y3	



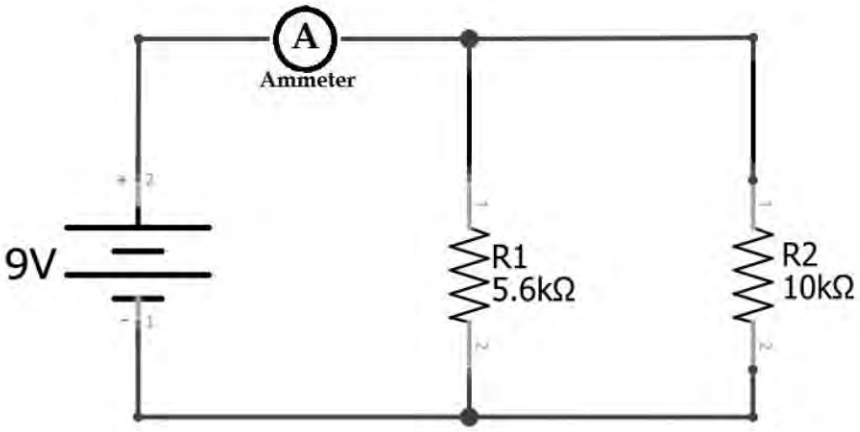
ii. Current through the 10 kΩ resistor. Record your result in the given table above.

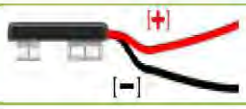


Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor1: 5.6k Ω **Green, Blue, Red**		Slight changes done to the position of the components.	R1(A) => C10 R1(B) => H10	Make adjustment to the arrangement on the breadboard with this table
Resistor2:10k Ω **Brown, Black, Orange**			R2(A) => D24 R2(B) => H20	
Jumper wire5 **(Long)**			J5(A) => C20 J5(B)=> Alligator Clip	
Jumper wire6 **(Long)**			J6(A) => C24 J6(B)=> Alligator Clip	
Battery Connector			Red(+) => X3 Black (-)=> Y3	



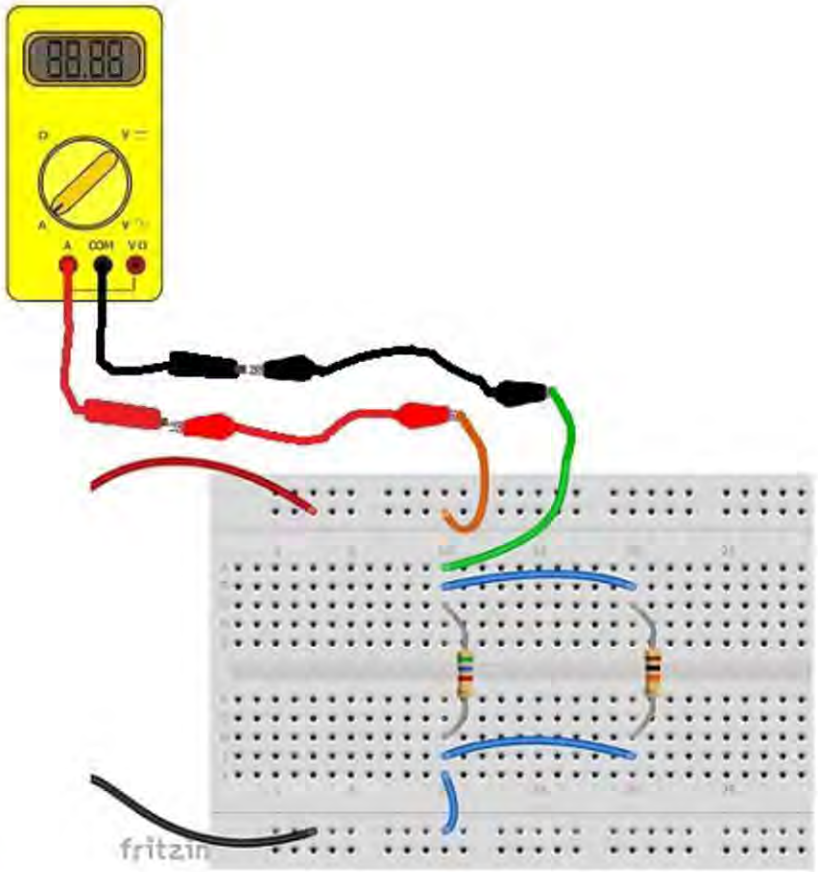
iii. Sum of current through the 5.6 kΩ and 10 kΩ resistor. Record your result in the given table above.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor2: 10k Ω Brown, Black, Orange		Jumper 3 should be removed before making this adjustment.	R2(A) => C20 R2(B) => H20	Make adjustment to the arrangement on the breadboard with this table
Jumper wire5 (Long)			J5(A) => X9 J5(B) => Alligator Clip	
Jumper wire6 (Long)			J6(A) => A10 J6(B) => Alligator Clip	
Battery Connector			Red(+) => X3 Black (-)=> Y3	

NOTE: The sum of current through the individual resistor should be equal to the total current flowing through the circuit. This is given by the equation;

$$I_{TOTAL} = I_1 + I_2$$



FUTHER ACTIVITIES:

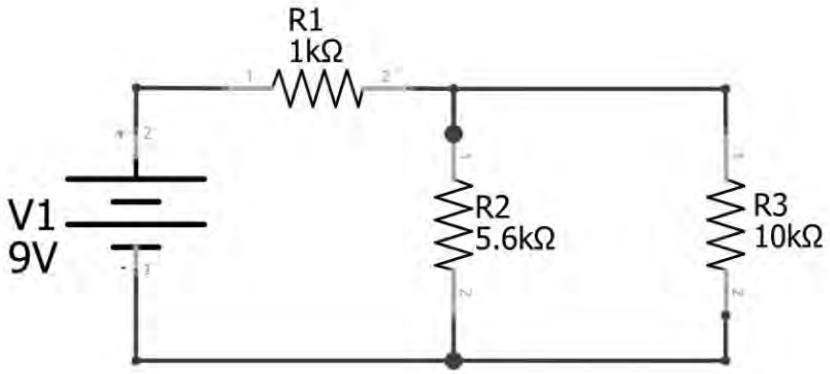
1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
1. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.
2. Calculate the total resistance with the equation and compare with your measured value;

$$R_{TOTAL} = \frac{R1 \times R2}{R1 + R2}$$

3. Calculate the total current with the equation and compare with your measured value;

$$I_{TOTAL} = \frac{V_{SUPPLY}}{R_{TOTAL}}$$

4. Make a series-parallel connection of the circuit given below and measure the voltage and current of the resistors in the circuit.


R1
1kΩ
V1
9V
R2
5.6kΩ
R3
10kΩ

EXPERIMENT 10: WORKING WITH THE POTENTIOMETERS

AIM:

To understand how a potentiometer works and how to use it in vary current in a circuit

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- Jumper wires
- Alligator clip pair (2)
- 9V battery pack (1)
- Resistors: 10kΩ (1)
- Potentiometer: 100kΩ (1)
- LED: Red (1), Yellow (1), Green (1), White (1) , blue (1)

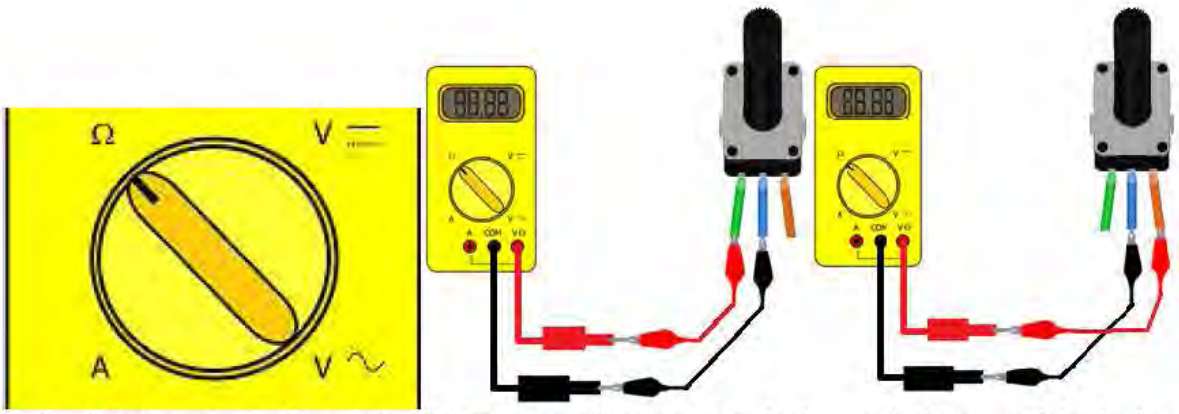
BACKGROUND:

The potentiometer (also called "Pot") is a variable resistor that can be used to smoothly vary resistance without disconnecting the circuit. It has three legs and the resistance value is usually written on its body. The middle leg is used to tap the resistance in between while the other two legs maintain a fixed resistance (that is, the resistance printed on it) across them. The resistance can be varied from zero to the maximum value printed on its body. When the middle leg is connected to any of the other two legs so that it now has two legs, it is used as a rheostat. When the three legs are used separately, it is used as a potential divider.

PROCEDURE:

(A)Testing the Potentiometer

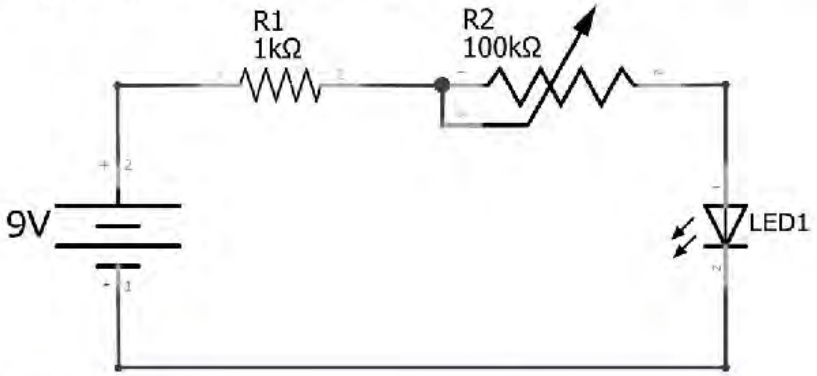
1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the selector to the Ohms section (Ω) and place it on the 200kΩ range.
2. Attach one end of one alligator clip to the red probe and another alligator clip to the black probe of your multimeter.
3. Connect the other end of the alligator clip attached to the black probe of the multimeter to the middle leg of the potentiometer and the other alligator clip to the first legs.



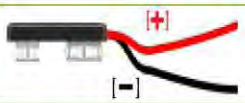
4. Gently rotate the shaft of the potentiometer clockwise and them anticlockwise and observe the reading on your multimeter.
5. Remove the red probe alligator clip and attach it to the third leg of the potentiometer and observe the reading on the multimeter.

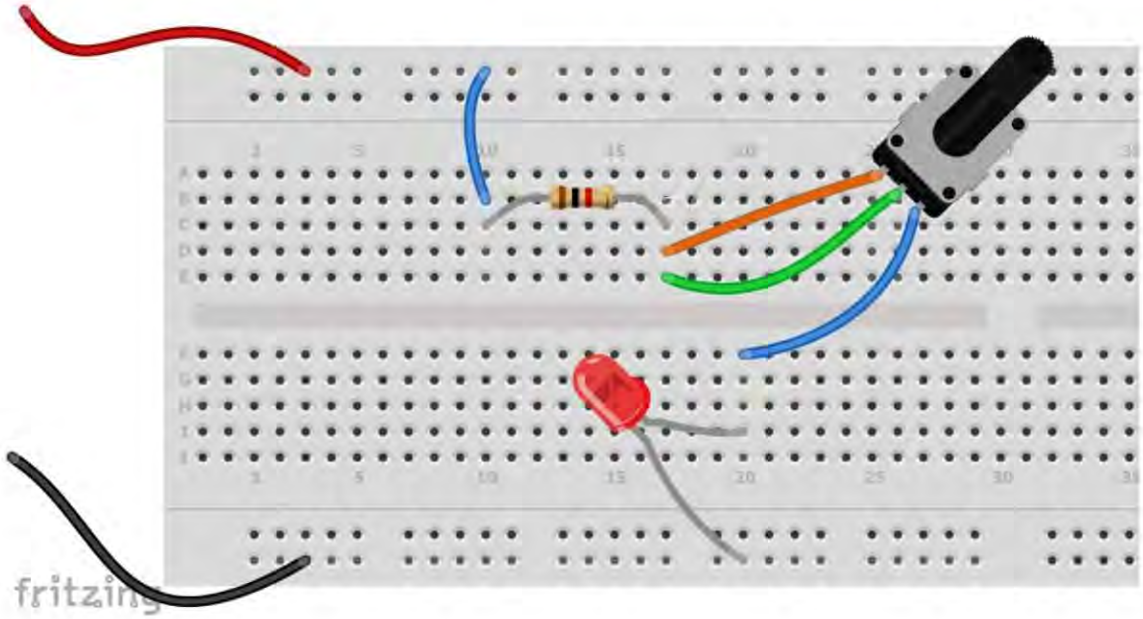
(B) Using a Potentiometer as a Rheostat

1. Set up the circuit below to connect a potentiometer to vary the brightness of and LED, using the connection table below;



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire1		Make connections as indicated in the breadboard connection column.	J1(A)=> W9 J1(B) => B10	
Resistor1: 1k Ω Brown, Black, Red			R1(A) => C10 R1(B) => C17	
Resistor2:100k Ω Potentiometer			R2(A) => D17 R2(B) => E17 R2(C) => G20	
LED1			LED1(A)=>I 20 LED1(K)=>Z17	

Battery Connector			Red(+) => W3 Black(-) => Z3	



2. Rotate the shaft of the potentiometer clockwise and anticlockwise to vary its resistance and observe how it makes the LED glow bright and dim.

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.
5. Catch some fun by using different colour of LEDs in the circuit set up.

EXPERIMENT 11: POTENTIAL DIVIDER

AIM:

To understand how a potential divider works and the different ways of making a potential divider

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Resistors: 560Ω (1), 1kΩ (2), 3.3kΩ (1)
- Potentiometer: 100kΩ (1)
- LED: Red (1), Yellow (1), Green (1), White (1) , blue (1)

BACKGROUND:

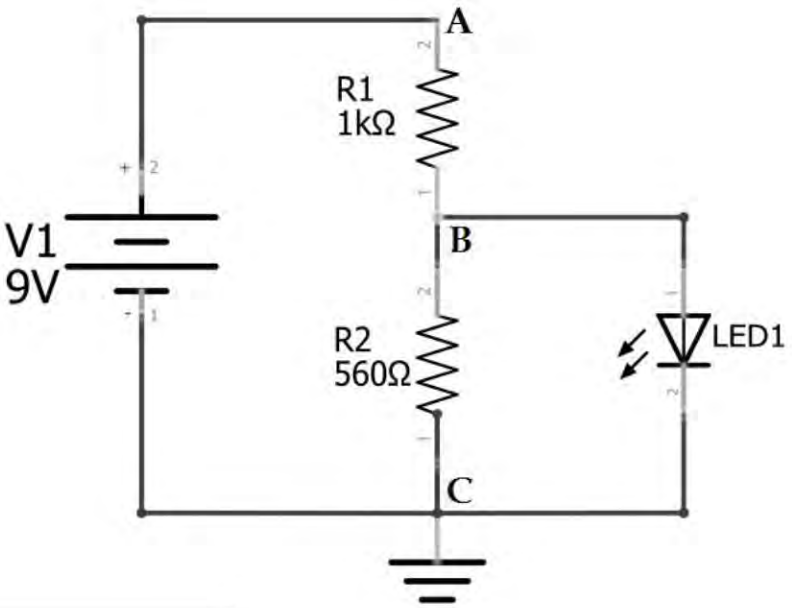
A potential divider (or voltage divider) is a useful circuit which finds application in area where low voltage is required from a high voltage supply. The main components are resistors which are connected in series so that the voltage across each resistor with respect to a reference point in the circuit is lower than the supply voltage given since the supply voltage in a series connection is divided proportionately across the resistor in relation to their resistances. That is, the larger resistances in a series connection has a higher voltage drop while smaller resistances will have a smaller voltage drop across them. The reference point in a circuit can be place at different nodes and will usually be indicated with the ground. The equation to determine the voltage across individual resistances in a two resistor series circuit is given by;

$$V_{R1} = \left(\frac{R_1}{R_1 + R_2}\right) V_{SUPPLY} \quad \text{and} \quad V_{R2} = \left(\frac{R_2}{R_1 + R_2}\right) V_{SUPPLY}$$

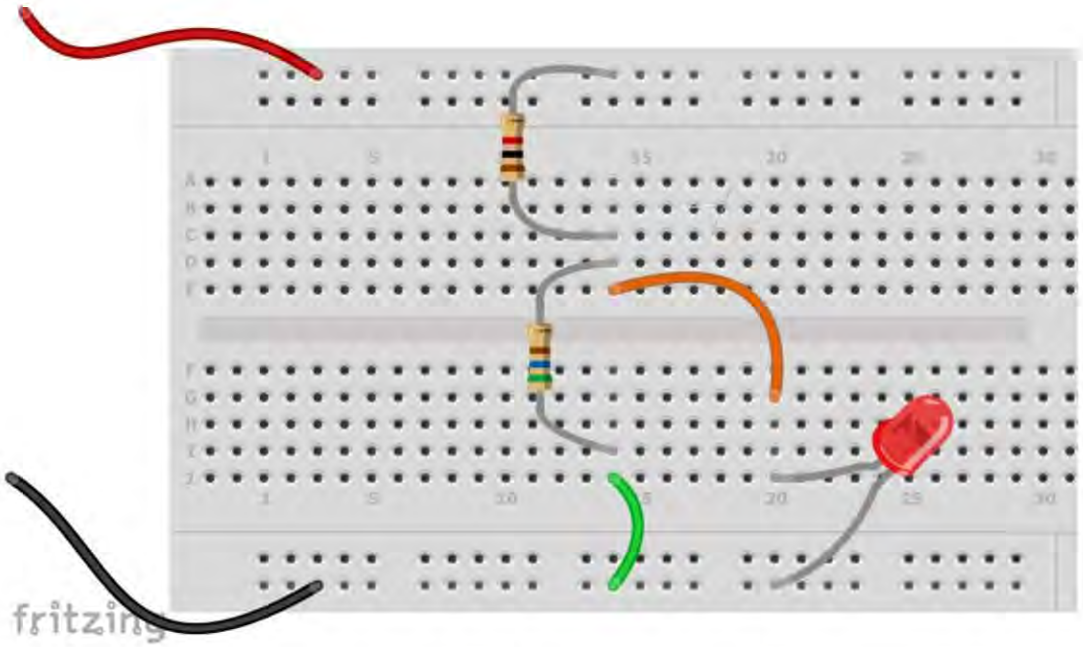
PROCEDURE:

(A) Potential Divider Using Fixed Resistors

5. Set up the potential divider circuit shown below using the breadboard connection table.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor1: 1k Ω **Brown, Black, Red**		Make connections as indicated in the breadboard connection column.	R1(A) => W12 R1(B) => C14	
Resistor2: 560Ω **Green, Blue, Brown**			R2(A) => D14 R2(B) => I 14	
Jumper wire1			J1(A) => J14 J1(B) => Z12	
Jumper wire2			J2(A) => E14 J2(B) => G20	
LED1			LED1(A)=> J20 LED1(K)=>Z17	
Battery Connector			Red(+) => W3 Black (-)=> Z3	



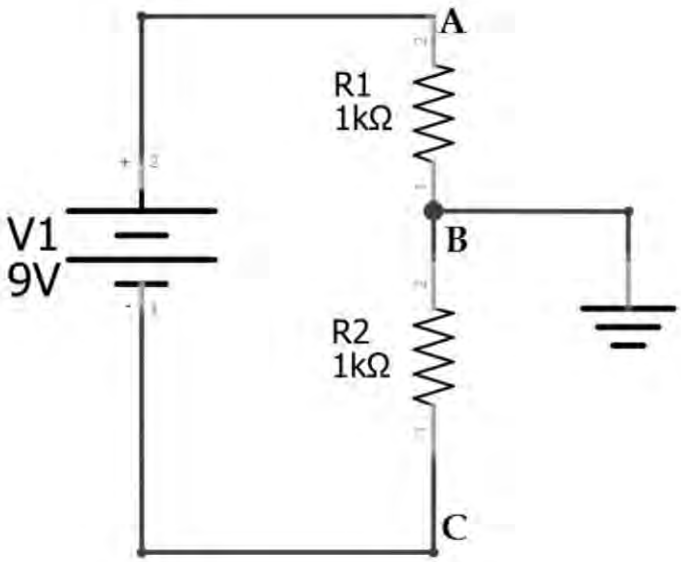
NOTE: The reference point (or ground) is placed at the point C in the circuit above, so that the output voltage (V2) is taken across resistor R2 from point B to the ground.

6. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the dial of the selector to the voltage section (DCV or V⎓) and place it on the 20V range.
7. Measure the voltage across each of the resistor with respect to the reference point C. The black probe will be kept stationary at the point C, when making the voltage measurement.

NOTE: Using the voltage divider, we have successfully reduced the supply voltage to a smaller voltage value taken across resistor (R2) which can be used to power the LED without damaging it.

(B) Using A Potential Divider To Create Positive And Negative Voltages From A Single Source

1. Replace the resistor R2 in the circuit of PART A of this experiment as shown below.

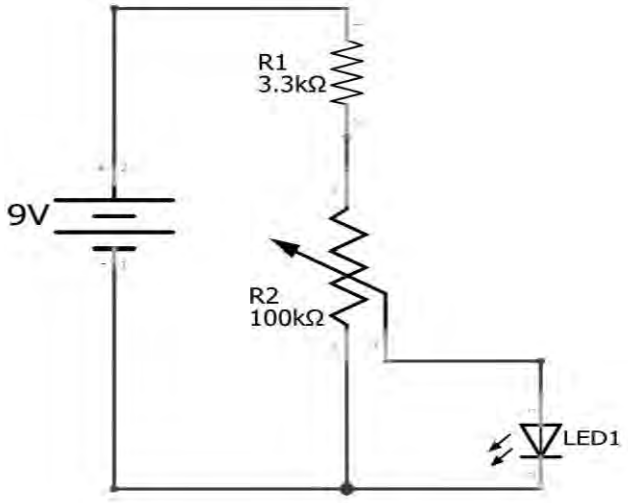


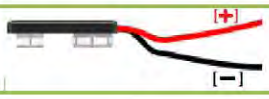
2. With your multimeter set to measure voltage as before, place the black probe at point B and the red probe at point A and observe the positive voltage output.
3. Now, with the black probe still at point B, place the red probe at point C and observe the negative voltage output.

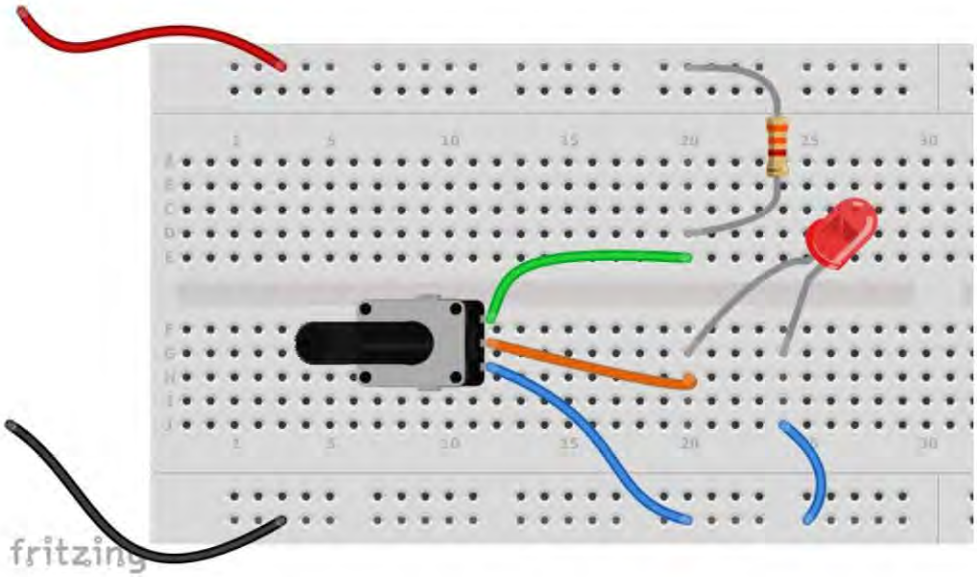
NOTE: The voltage reading should give you +4.5V and -4.5V respectively.

(C) Potential Divider Using a Potentiometer

1. Set up the potential divider circuit shown below using the breadboard connection table.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor1: 3.3kΩ Orange, Orange, Red		Make connections as indicated in the breadboard connection column.	R1(A) => W17 R1(B) => D20	
Resistor2:100k Ω Potentiometer			R2(A) => Z17 R2(B) => H20 R2(C) => E20	
LED1			LED1(A)=>G20 LED1(K)=> G24	
Jumper wire1			J1(A) => H24 J1(B) => Z21	
Battery Connector			Red(+) => W3 Black (-)=> Z3	



2. Turn the shaft of the potentiometer clockwise and anticlockwise to vary the output voltage from the potential divider. (The LED should glow bright and dim as the voltage varies across it.)

NOTE: The voltage from the power supply will be divided across the fixed resistance (R1) and the potentiometer. This circuit can allow you create a smaller variable voltage output without having to disconnect the circuit.

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Use different colour of LEDs in the circuits.
5. Calculate the voltage drop across resistor R1 and R2 for all the circuits above using the equation below and compare it with your measure values.

$$V_{R1} = \left(\frac{R_1}{R_1 + R_2}\right) V_{SUPPLY} \quad \text{and} \quad V_{R2} = \left(\frac{R_2}{R_1 + R_2}\right) V_{SUPPLY}$$

6. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 12: LEDs IN SERIES

AIM:

To understand how to combine LEDs in series and the features of such arrangement

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Alligator clip pairs (2)
- Resistors: 220Ω (1)
- LED: Red (3), Yellow (3), Green (3), White (3) , blue (3)

BACKGROUND:

Setting up a series connection of LEDs is similar to that of resistors. For LEDs connected in series, the polarity of each LED must be in the correct order; that is, current must flow through the anode (A) to the cathode (k) of each LED. Some of the features include;

- Same current flows through all the LEDs
- Each LED will have a forward voltage drop across it and may be different for different colours
- The supply voltage will be divided across any series resistor and the LEDs.
- If one LED is removed or wrongly placed, the entire circuit will not work
- Addition of more LEDs in series will lead to dim light from each LED.
- Series connection of LEDs does not drain battery.

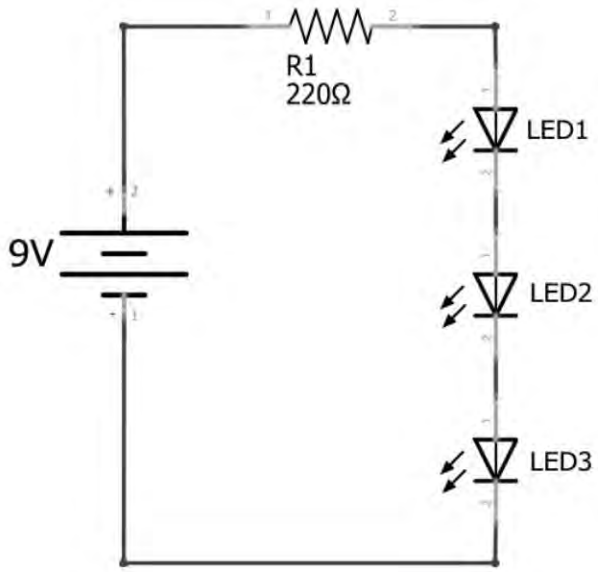
The series connected resistance can be calculated using the equation;

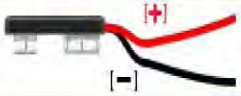
$$R = \frac{V_{SUPPLY} - nV_{FORWARD}}{I_{FORWARD}}$$

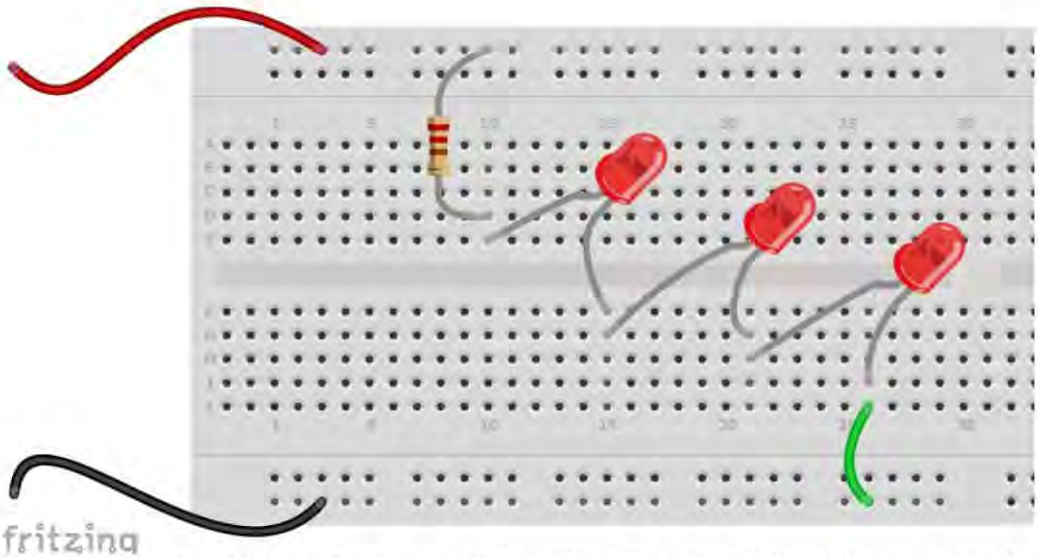
n- number of LEDs in series

PROCEDURE:

1. Set up the series connected LEDs circuit below using the connection table;



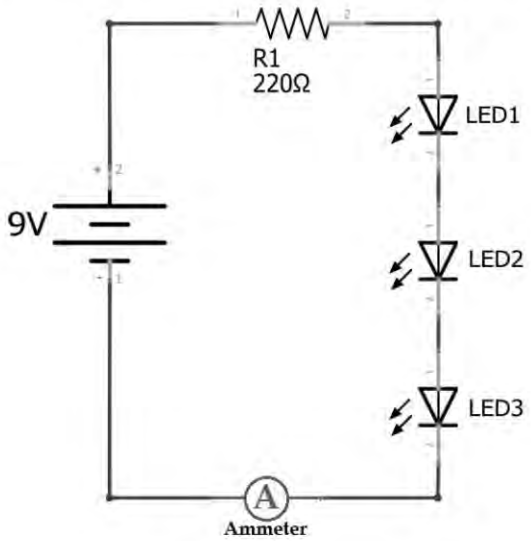
Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor1: 220Ω **Red, Red, Brown**		Make connections as indicated in the breadboard connection column.	R1(A) => W9 R1(B) => D10	
LED1			LED1(A) => E10 LED1(K) => F15	
LED2			LED2(A) =>G15 LED2(K) =>G21	
LED3			LED3(A) =>H21 LED3(K) => I 26	
Jumper wire1			J1(A) => J26 J1(B) => Z22	
Battery Connector			Red(+) => W3 Black (-)=> Z3	

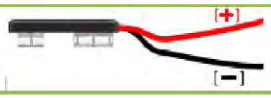


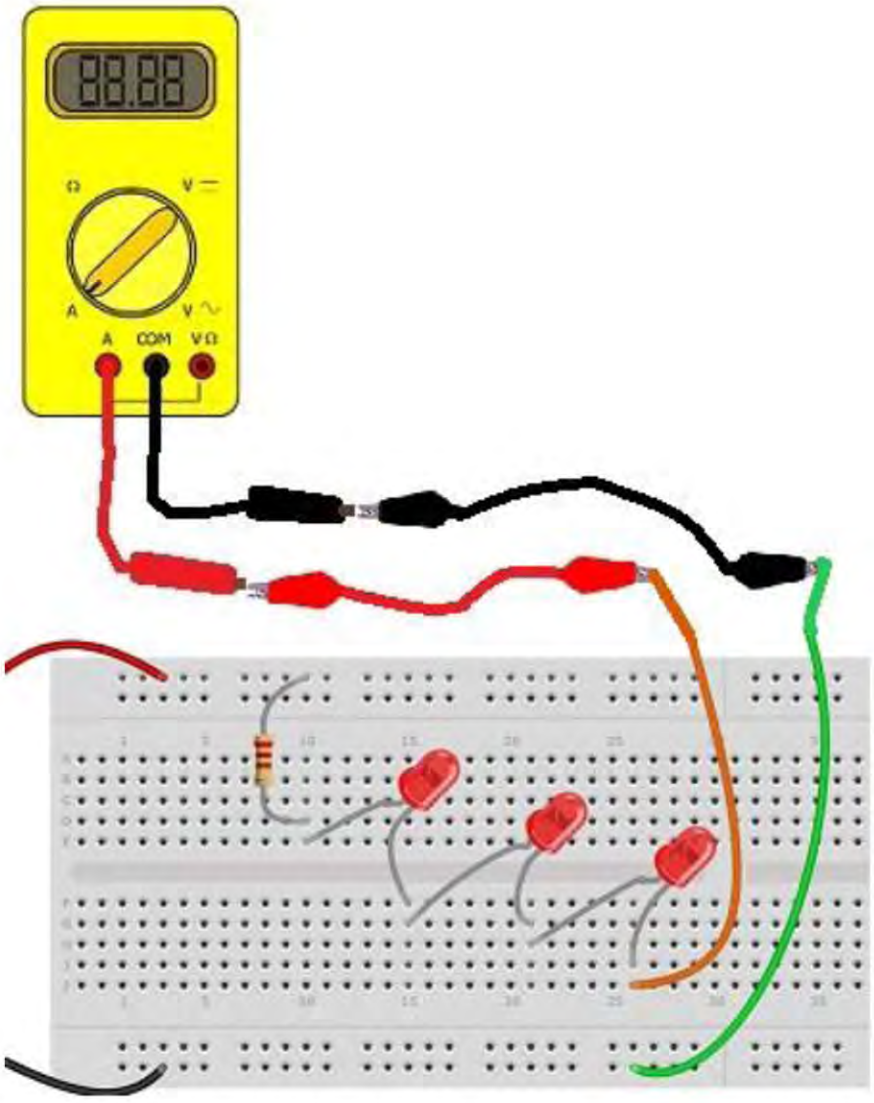
2. Remove one LED and you will observe that the rest of the LEDs will go off.
3. Now interchange the polarity of one of the LEDs as well. That is, place the anode at the position of the cathode and the cathode to the position of the anode
4. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the dial of the selector to the voltage section (DCV or V⎓) and place it on the 20V range. Then measure the voltage across the series resistor and each of the LEDs.

NOTE: Adding up all the measured voltages should be equal to the supply voltage of the battery

5. Move the dial of the selector to the current section (DCA or A⎓) and place it on the 20mA range.
6. Now set up the circuit below to allow you measure the current flowing through the circuit.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire2 (Long)		Jumper 1 should be removed before making this adjustment.	J2(A) => J26 J2(B)=> Alligator Clip	Make adjustment to the setup done in the previous table.
Jumper wire3 (Long)			J3(A) => Z22 J3(B)=> Alligator Clip	
Battery Connector			Red (+)=> W3 Black (-)=> Z3	



FUTHER ACTIVITIES:

1. Use different colour of LEDs in the circuits.
2. Calculate for the series resistor using the equation below;

$$R = \frac{V_{SUPPLY} - nV_{FORWARD}}{I_{FORWARD}}$$

Where n- number of LEDs in series

V – Measured forward voltage across one LED (for same colours in series)

I- Measured current flowing through the circuit.

3. Learn how to draw the circuit diagram(s) in this experiment.
4. Practice the circuit set up on your own without using the connection table guide.
5. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
6. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 13: LEDs IN PARALLEL

AIM:

To understand how to combine LEDs in parallel and the features of such arrangement

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Alligator clip pairs (2)
- Resistors: 1kΩ (3)
- LED: Red (3), Yellow (3), Green (3), White (3) , blue (3)

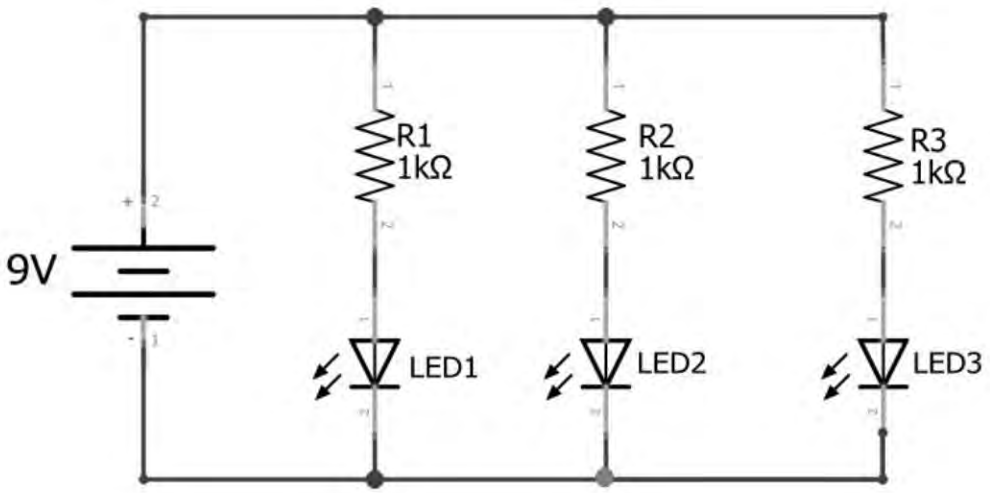
BACKGROUND:

In a parallel connection, the LEDs are independent of each other and can have different amount of current flowing through them. There will usually be a series resistor connected to each branch of the LEDs in parallel. Some of the features of parallel connected LEDs include;

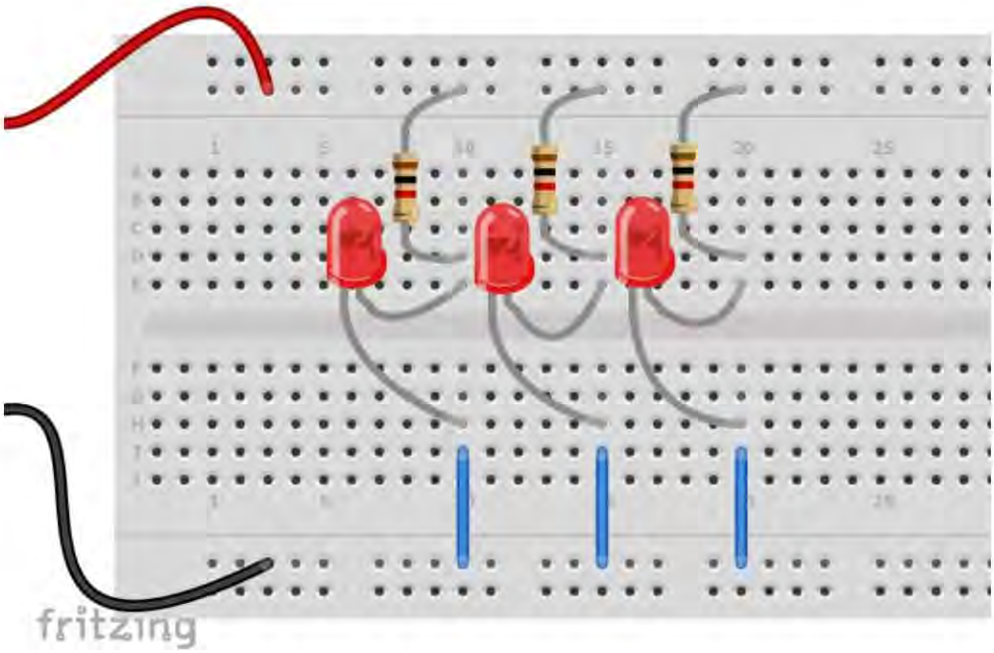
- The voltage across each LED is the same
- The total circuit current is the sum of current through each LED branch
- If one LED is removed or wrongly placed, the rest of the circuit will still function well
- Addition a few more LEDs in parallel will not affect the brightness of the entire circuit
- Parallel connections of LEDs drain battery faster.

PROCEDURE:

1. Set up the parallel connected LEDs circuit below using the connection table;



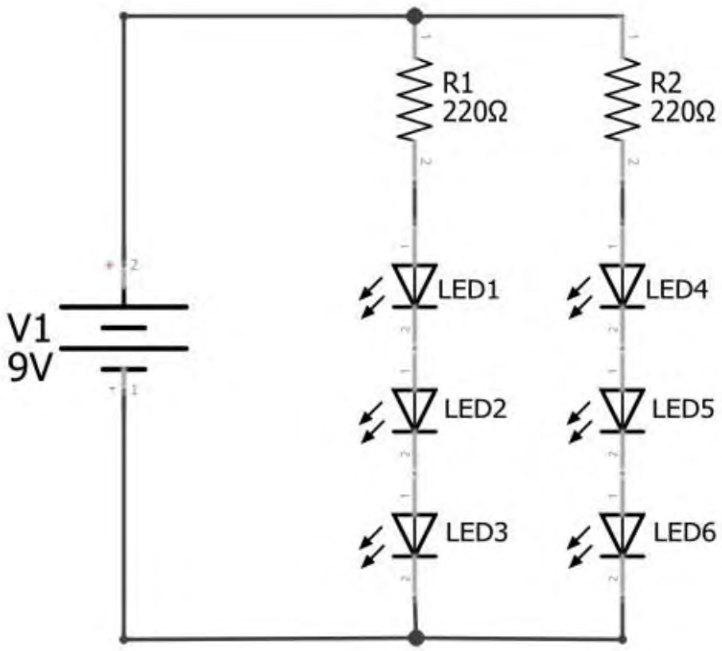
Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor1: **1k Ω** **Brown, Black, Red**		Make connections as indicated in the breadboard connection column.	R1(A) => X9 R1(B) => D10	
Resistor2: **1k Ω** **Brown, Black, Red**			R2(A) => X13 R2(B) => D15	
Resistor3: **1k Ω** **Brown, Black, Red**			R3(A) => X17 R3(B) => D20	
LED1			LED1(A) => E10 LED1(K) =>H10	
LED2			LED2(A) =>E15 LED2(K) =>H15	
LED3			LED3(A) =>E20 LED3(K) =>H20	
Jumper wire1			J1(A) => I 10 J1(B) => Y9	
Jumper wire2			J2(A) => I 15 J2(B) => Y13	
Jumper wire3			J3(A) => I 20 J3(B) => Y17	
Battery Connector			Red(+) => X3 Black (-)=> Y3	

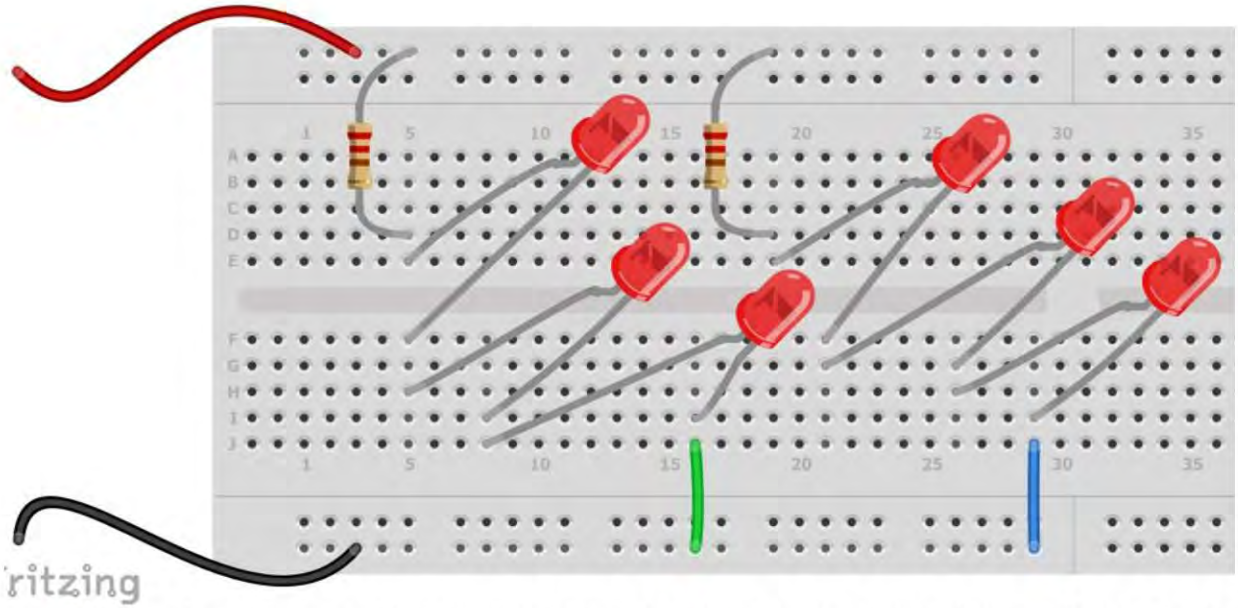


2. Remove one LED and reverse the polarity of the other and the rest of the LED circuit will still glow.
3. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the dial of the selector to the voltage section (DCV or V⎓) and place it on the 20V range.
4. Measure the voltage across each of the LED and their series resistor. The voltage of the two should give you the supply voltage.

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Using the knowledge gained in experiment 9, measure the current in each branch and the total current flowing through the circuit.
5. Construct the series-parallel circuit shown below;





6. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 14: CELLS/BATTERIES IN SERIES AND PARALLEL

AIM:

To understand how to combine cells and batteries in series and parallel and their features

MATERIALS:

- Digital Multimeter (1)
- Alligator clip pairs (2)
- AA Cells (4)
- Terminal Connecting wire (4)

BACKGROUND:

Cells and batteries can also be combined in series, parallel or series/parallel as already done for resistors and LEDs. Any of the combinations can be used as determined by the application in which it is to be used. A single cell has a rated voltage and amperage (or current capacity) which may not be sufficient for some applications. When cells are combined in series, the overall voltage of the combination is increase while the amperage remains the same as that of one cell. When cells are combined in parallel, the overall voltage is the same as that of one cell but the amperage is increased. So, for higher current, you use series combination while for higher current capacity, we use parallel combination. For both voltage and current increase, we use a series-parallel combination. A damaged cell in series will affect the whole connection and could make the output become reduced. A damaged cell in parallel will not usually affect the entire voltage but could reduce the capacity of the connection.

PROCEDURE:

(A) Cells in Series

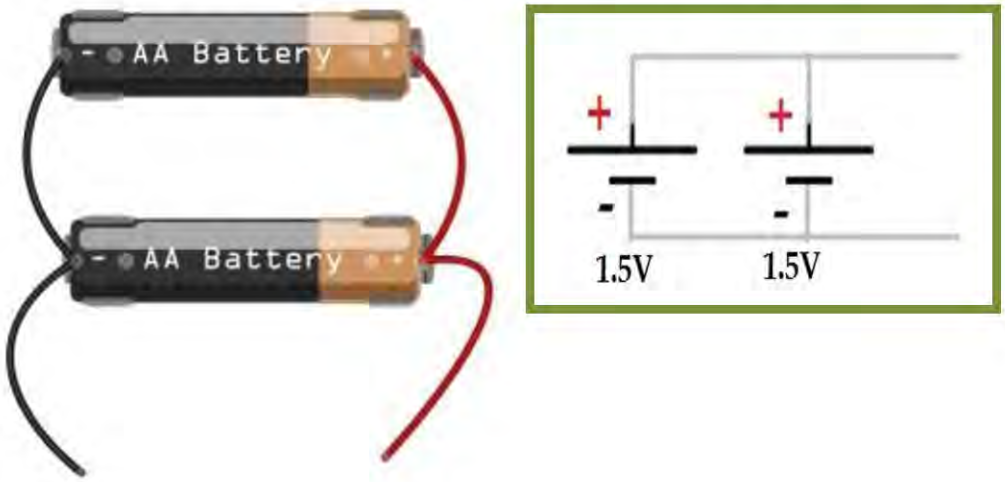
1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the dial of the selector to the voltage section (DCV or V⎓) and place it on the 20V range.
2. Using the terminal connection wire, connect two cells in series so that the **positive terminal of one is connected to the negative terminal of the other** as shown below;

CELL TYPE	VOLTAGE OF CELL	AMPERAGE OF CELL
AA CELL 1	1.5V	2000mAh
AA CELL 2	1.5V	2000mAh
TOTAL IN SERIES	**3.0V**	**2000mAh**

3. Measure the total voltage across the two cells in series and compare your reading with the table above.

(B) Cells in Parallel

1. Using the terminal connection wire, connect two cells in parallel so that the **positive terminal of one is connected to the positive terminal of the other** and the **negative terminals of one is connected to the negative terminal of the other**, as shown below;

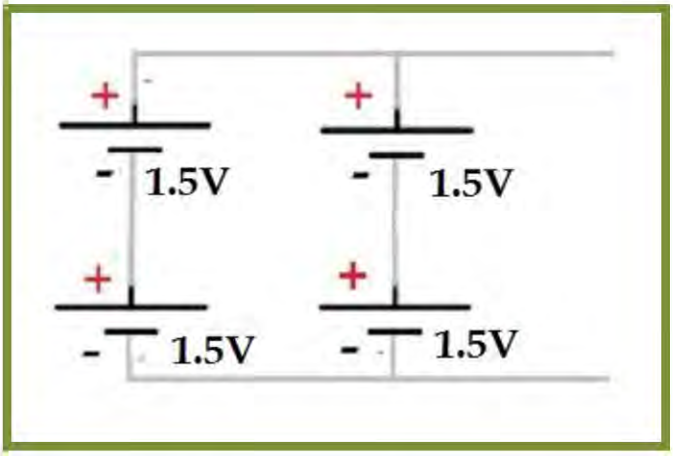


CELL TYPE	VOLTAGE OF CELL	AMPERAGE OF CELL
AA CELL 1	1.5V	2000mAh
AA CELL 2	1.5V	2000mAh
TOTAL IN PARALLEL	**1.5V**	**4000mAh**

2. Measure the voltage across each of the two cells in parallel and compare your reading with the table above.

(C) Cells in Series-Parallel

1. Using the terminal connecting wires, connect **two cells in series** and another **two cells in series**. Then connect the **two separate series combinations in parallel connection** as shown below;



CELL TYPE	VOLTAGE OF CELL	AMPERAGE OF CELL	
AA CELL 1	1.5V	2000mAh	FIRST SERIES COMBINATION
AA CELL 2	1.5V	2000mAh	
TOTAL IN SERIES	**3.0V**	**2000mAh**	
AA CELL 3	1.5V	2000mAh	SECOND SERIES COMBINATION
AA CELL 4	1.5V	2000mAh	
TOTAL IN SERIES	**3.0V**	**2000mAh**	
TOTAL IN SERIES-PARALLEL	**3.0V**	**4000mAh**	**PARALLEL CONNECTION OF THE TWO SERIES COMBINATION**

2. Measure the voltage across the combination in series-parallel and compare your reading with the table above.

FUTHER ACTIVITIES:

1. Construct a series connection of 1.5V cells to make up 9V battery.
2. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 15: WORKING WITH SWITCHES

AIM:

To understand the working of a switch and its application

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Alligator clip pairs (2)
- Resistors: 1kΩ (2)
- LED: Red (2), Yellow (2), Green (2), White (2) , blue (2)
- Press button Switch (2
- Toggle switch (2)
- Rocker SPDT (1)

BACKGROUND:

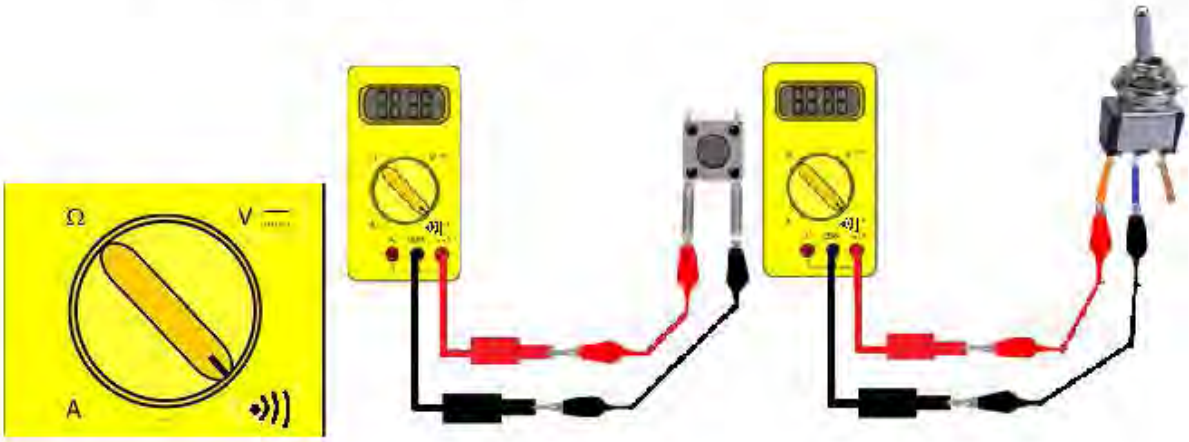
Switches are required in electrical circuit for enforcing control and for maintaining safety of devices and the human alike. When a switch is placed in a circuit, it can be used to connect and disconnect a circuit path, that is, a making a close or open circuit. Switches come in various sizes and form and can be combined in different way to achieve desired control. Some of the features of a switch is the Pole (P) and the Throw (T) and it could also be considered as a normally open (NO) or normally closed (NC) switch.

PROCEDURE:

(A) Testing A Switch

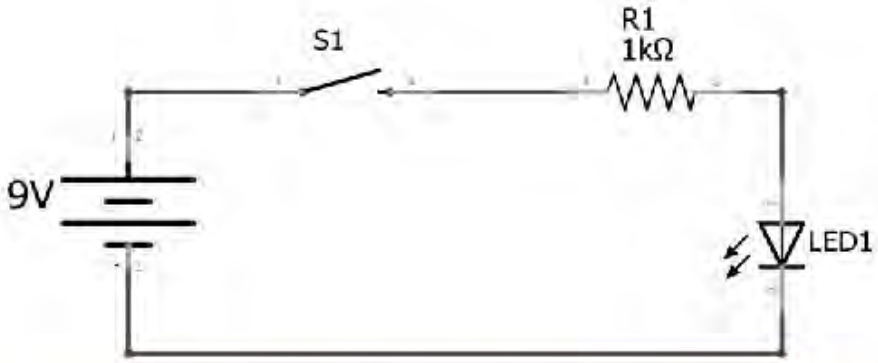
1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the dial of the selector to the continuity tester, .
2. Attach on end of your alligator clips to the probe of your multimeter and then attach the other ends of the alligator clips to legs of the press button switch.
3. Now press the button on the switch to make contact within the switch and you should hear a beep from the multimeter whenever the switch is closed (ON) and the beep stops when the contact within the switch is open (OFF).

4. Pick a toggle switch and connect one alligator clip to the middle leg and another to first leg of the switch.
5. Push the switch control to one end and the other and you should hear a beep when a contact is made for that leg. Remove the alligator clip attached to the red probe to the third leg and observe likewise.

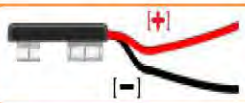


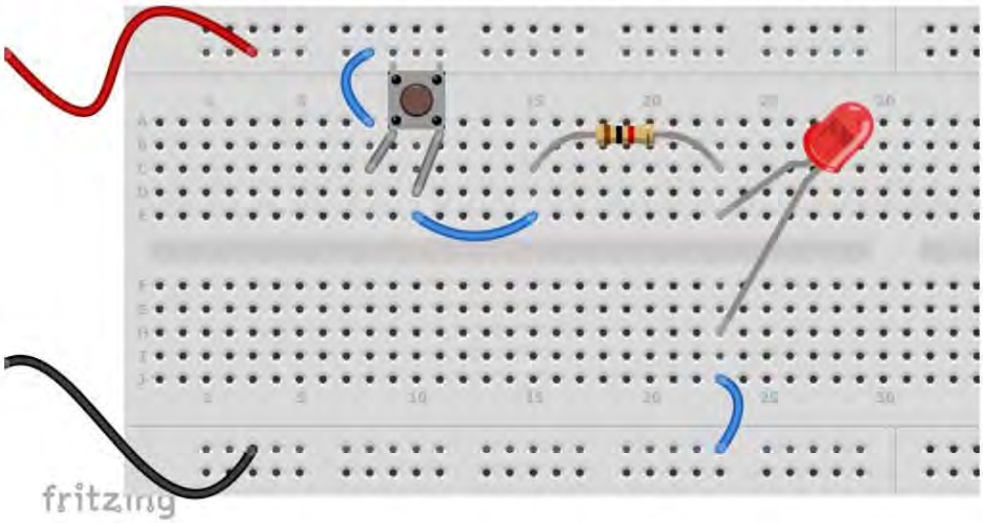
(B) Switching Circuits

1. Set up the switch connected circuit below using the connection table;



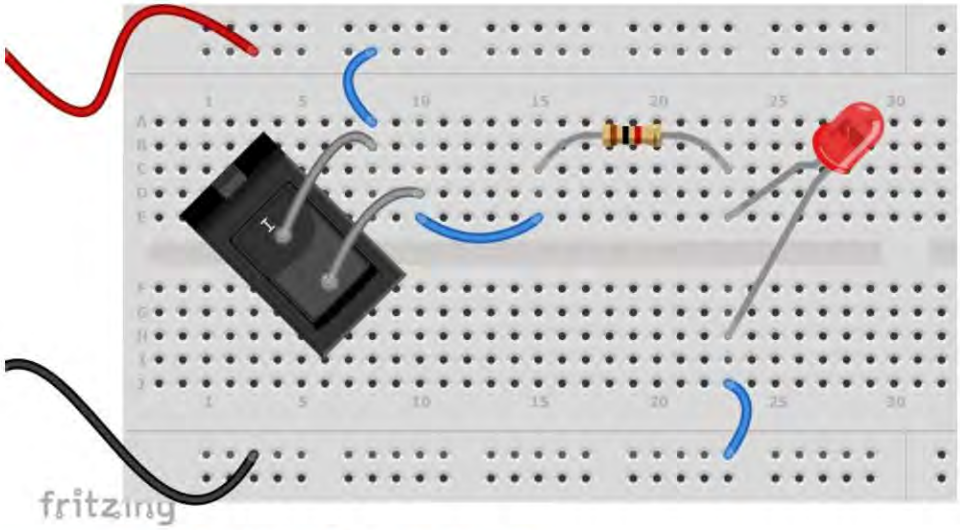
Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire1		Make connections as indicated in the breadboard connection column.	J1(A) => X7 J1(B) => A8	
Switch1 (Press Button)			S1(A) => C8 S1(B) => D10	
Jumper wire2			J2(A) => E10 J2(B) => E15	
Resistor1: 1k Ω Brown, Black, Red			R1(A) => C15 R1(B) => C23	

LED 1			LED 1(A) => E23 LED 1(K) =>H23	
Jumper wire3			J3(A) => I 23 J3(B) => Y20	
Battery Connector			Red(+) => X3 Black (-)=> Y3	



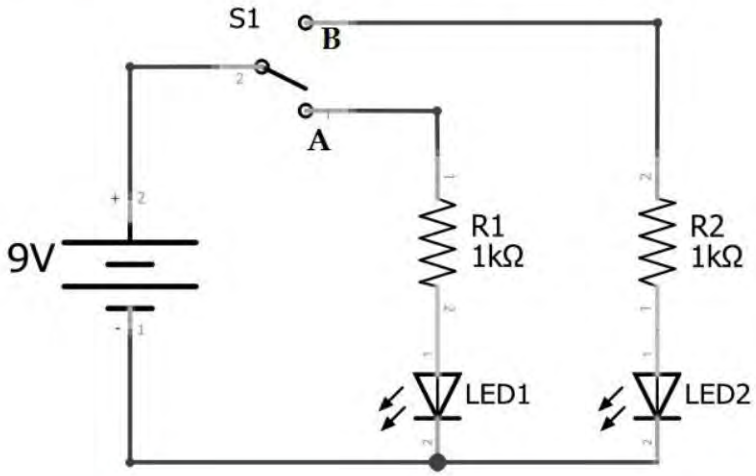
2. Press the button the switch and observe the circuit closed. The LED should give a light whenever the switch is pressed.
3. Replace the press button switch with the SPDT rocker switch provided using the connection table as shown below;

Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Switch2 (Rocker)		The switch 1 should be removed before making this adjustment.	S2(A) => E8 S2(B) => D10	Make adjustment to the setup done in the previous table.
Battery Connector			Red(+) => X3 Black (-)=> Y3	

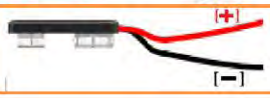


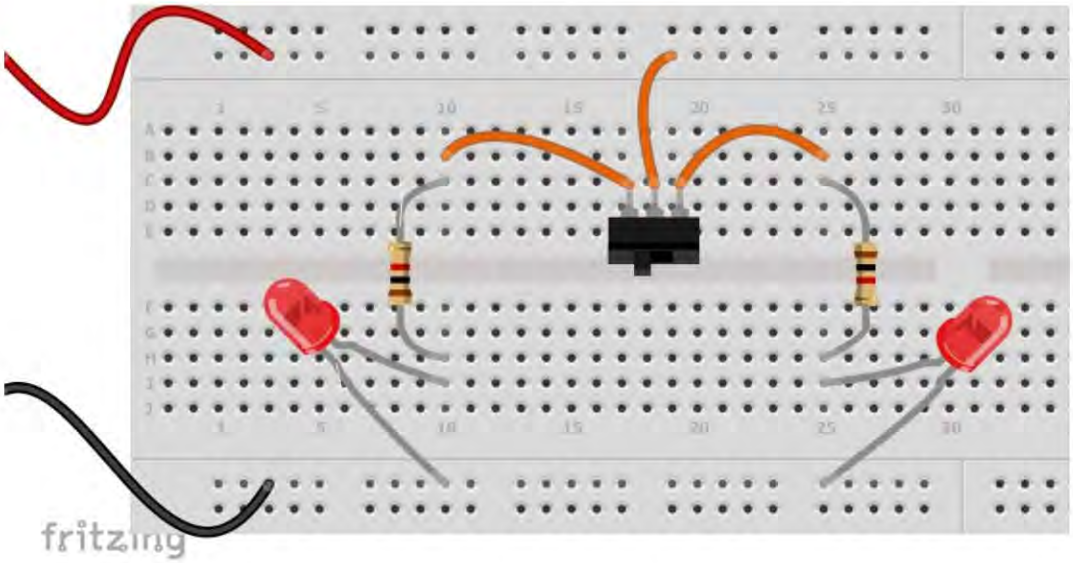
(C) Two way Switching Using A Toggle Switch

1. Set up the switching circuit below using the connection table;



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Switch1 (Toggle)		Make connections as indicated in the breadboard connection column.	S1(A) => B10 S1(B) =>X16 S1(C) => B25	
Resistor1: **1k Ω** **Brown, Black, Red**			R1(A) => C10 R1(B) => H10	
Resistor2: **1k Ω** **Brown, Black, Red**			R2(A) => C25 R2(B) => H25	

LED1			LED1(A) => J10 LED1(K) => Y9	
LED2			LED2(A) =>J25 LED2(K) => Y21	
Battery Connector			Red(+) => X3 Black (-)=> Y3	

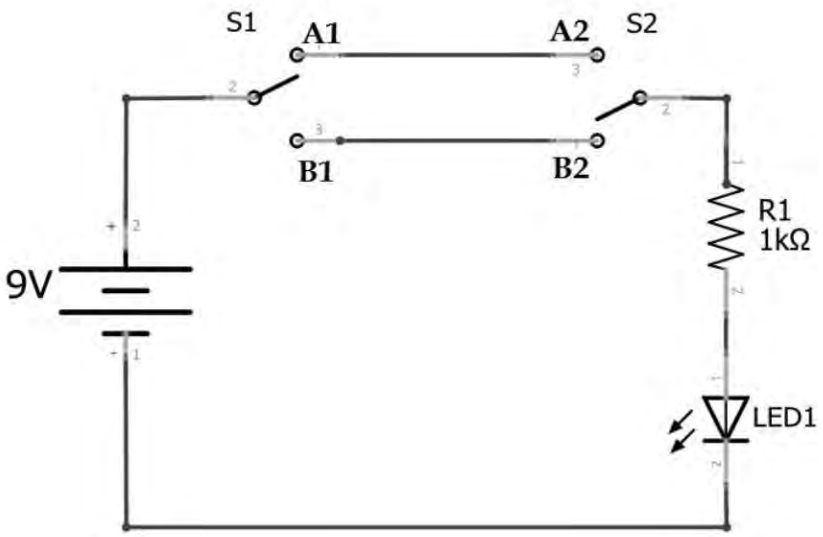


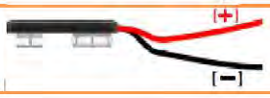
2. Push the shaft of the switch to one side and the other and observe how the toggle switch alternates the lighting of the LEDs as shown in the table below;

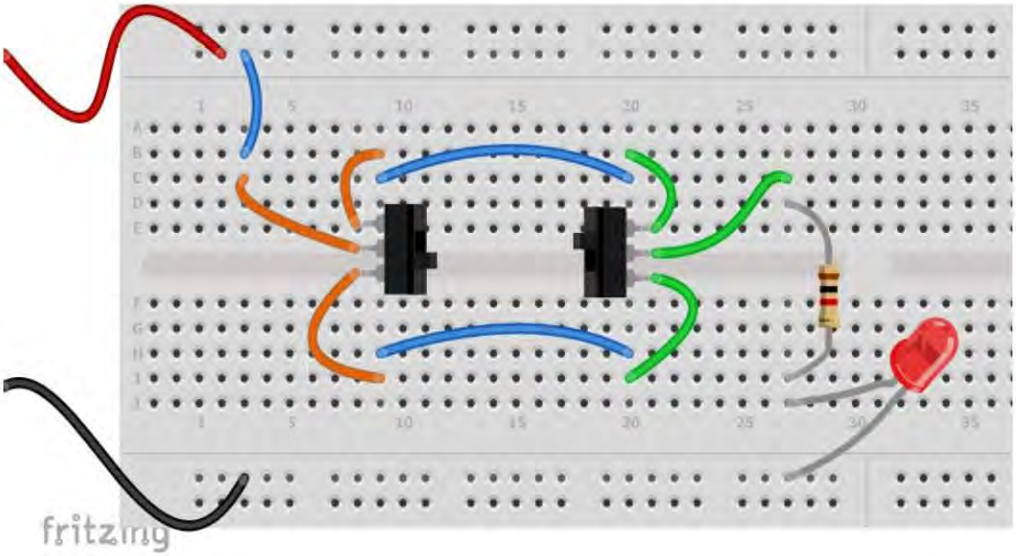
SWITCH	LED 1	LED2
A	ON	OFF
B	OFF	ON

(D) Three-Way Switching Using two Toggle Switches

1. Set up the switching circuit below using the connection table;



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire1		Make connections as indicated in the breadboard connection column.	J1(A) => X4 J1(B) => B3	
Jumper wire2			J2(A) => C9 J2(B) => C20	
Jumper wire3			J3(A) => H9 J3(B) => H20	
Resistor1: 1k Ω **Brown, Black, Red**			R1(A) => D27 R1(B) => I 27	
LED1			LED1(A) => J27 LED1(K) => Y23	
Switch1 **(Toggle)**			S1(A) => B9 S1(B) =>D3 S1(C) => I 9	
Switch2 **(Toggle)**			S2(A) => B20 S2(B) =>C27 S2(C) => I 20	
Battery Connector			Red(+) => X3 Black (-)=> Y3	



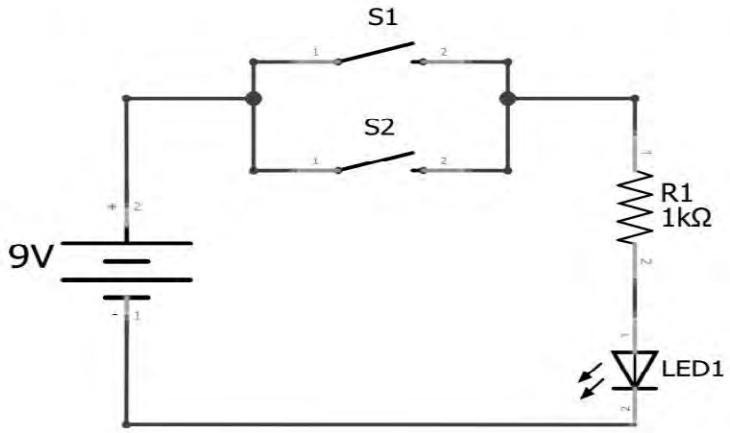
2. Push the shaft on switch 1 to one end and the shaft of switch 2 to another end and observe its operation as shown in the table below;

NOTE: With the three-way switching, a point of light can be independently controlled from two different locations.

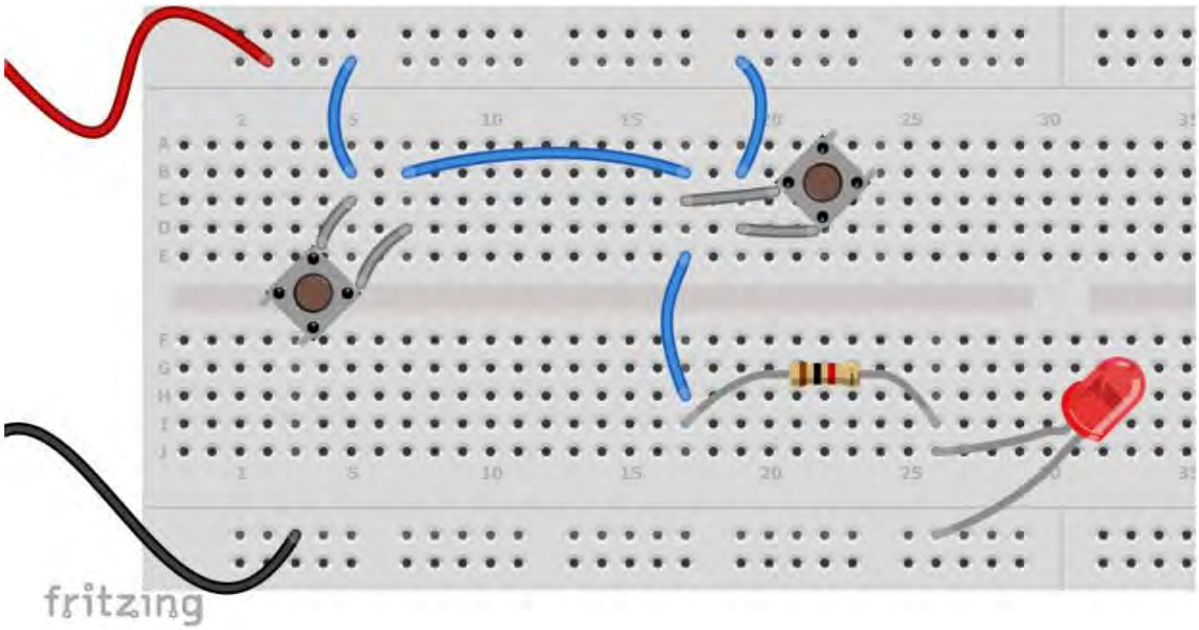
SWITCH 1	SWITCH 2	LED
A1	A2	ON
B1	A2	OFF
A1	B2	OFF
B1	B2	ON

(E) OR Gate And AND GATE With Switches

1. Set up the OR gate circuit below using the connection table;



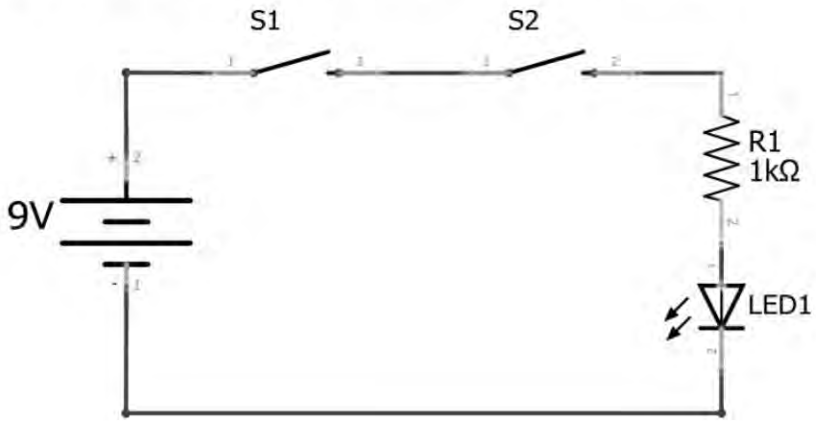
Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire1		Make connections as indicated in the breadboard connection column.	J1(A) => X5 J1(B) => B5	
Jumper wire2			J2(A) => B7 J2(B) => B17	
Jumper wire3			J3(A) => X16 J3(B) => B19	
Jumper wire4			J4(A) => E17 J4(B) => H17	
Resistor1: 1k Ω **Brown, Black, Red**			R1(A) => I 17 R1(B) => I 26	
LED1			LED1(A) => J26 LED1(K) => Y22	
Switch1 **(Press Button)**			S1(A) => C5 S1(B) => D7	
Switch2 **(Press Button)**			S2(A) => C17 S2(B) => D19	
Battery Connector			Red(+) => X3 Black (-)=> Y3	



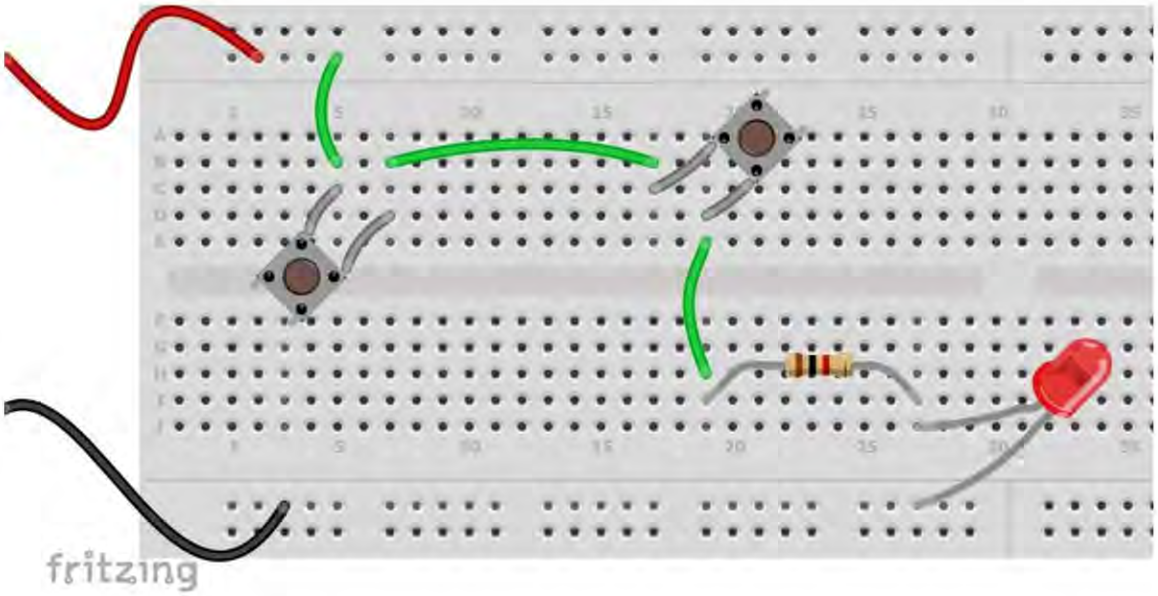
2. Press the buttons on the switch 1 and then switch 2. Then press both switches together and observe the operation of the OR gate as shown in the table below;

SWITCH 1	SWITCH 2	LED
OFF	OFF	OFF
ON	OFF	ON
OFF	ON	ON
ON	ON	ON

3. Set up the AND gate circuit below using the connection table;



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire1		Make connections as indicated in the breadboard connection column.	J1(A) => X5 J1(B) => B5	
Jumper wire2			J2(A) => E7 J2(B) => E17	
Jumper wire3			J3(A) => E19 J3(B) => H19	
Switch1 (Press Button)			S1(A) => C5 S1(B) => D7	
Switch2 (Press Button)			S2(A) => C17 S2(B) => D19	
Resistor1: 1k Ω Brown, Black, Red			R1(A) => I 19 R1(B) => I 27	
LED1			LED1(A) => J27 LED1(K) => Y23	
Battery Connector			Red(+) => X3 Black (-)=> Y3	



4. Press the buttons on the switch 1 and then switch 2. Then press both switches together and observe the operation of the AND gate as shown in the table below;

SWITCH 1	SWITCH 2	LED
OFF	OFF	OFF
ON	OFF	OFF
OFF	ON	OFF
ON	ON	ON

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Expand the gate to three (3) switches and draw the table of its operation.
5. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 16: WORKING WITH CAPACITORS

AIM:

To understand the working of a capacitor and its application

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Resistors: 10kΩ (1), 15kΩ (1), 22kΩ (1)
- Capacitor: 1000μF (1)
- LED: Red (1), Yellow (1), Green (1), White (1) , blue (1)
- Press button Switch (1)
- Rocker SPDT (1)

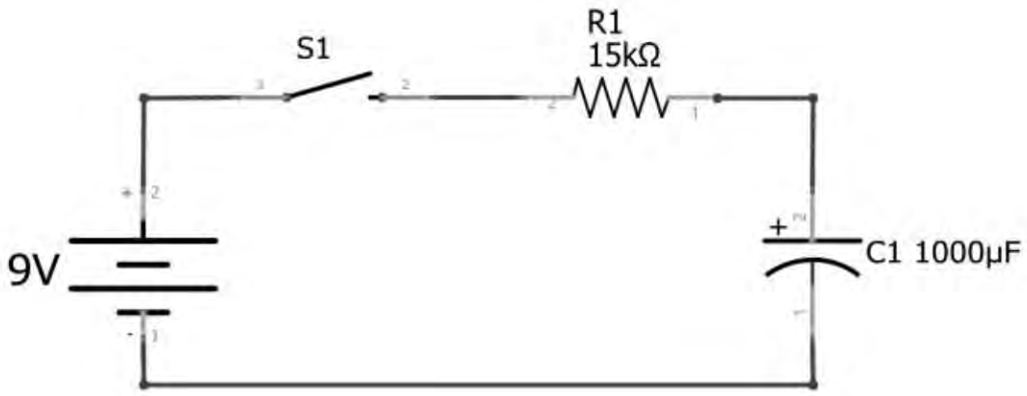
BACKGROUND:

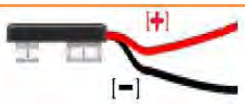
The capacitor has the capacity to store charges. It can be charge and discharged quickly as opposed to a battery. The charging and discharging process of a capacitor is usually associated with a time constant (τ = RC unit in second) which is the product of the resistance connected in series to the capacitor and the capacitance of the capacitor. Without a series resistor, the capacitor will charge up quickly without any delay, since R=0 and then τ = 0 seconds. The time constant is the time taken for the capacitor to charge or discharge to 63% of the applied voltage charging the capacitor. The time taken for the capacitor to be fully charged or discharged is approximately equal to five (5) times the time constant (= 5 τ).

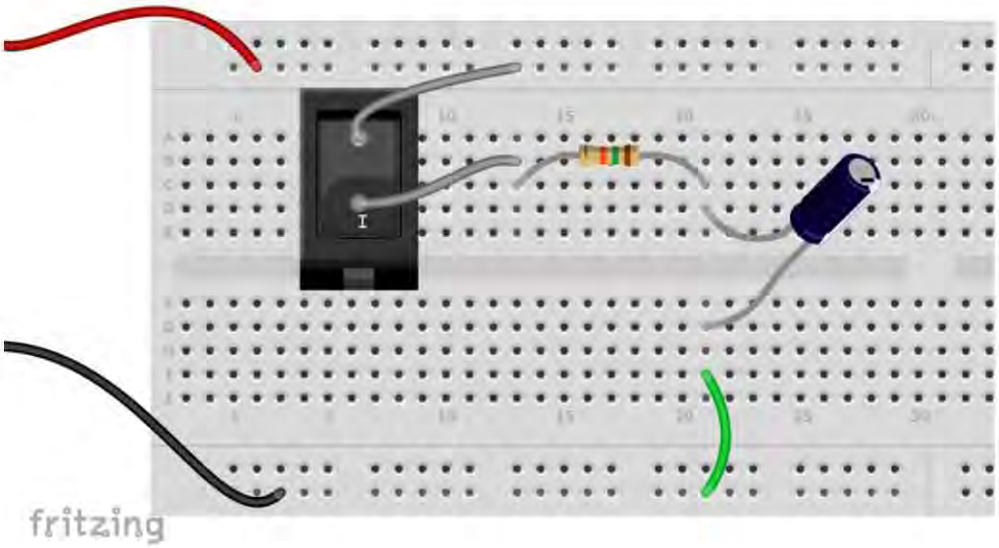
PROCEDURE:

(A) Charging A Capacitor

1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the dial of the selector to the voltage section (DCV or V⎓) and place it on the 20V range.
2. Set up the circuit show below for the charging of a capacitor, using the connection table;



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Switch1 (Rocker)		Observe the polarity of the electrolytic capacitor; the negative lead is marked on its side.	S1(A) => X11 S1(B) => B13	Ensure to keep to the timing for this experiment in order to get an accurate result.
Resistor1:15k Ω Brown, Green, Orange			R1(A) => C13 R1(B) => C21	
Capacitor1:1000*µF* 25V			C1(+) => D21 C1(-) => G21	
Jumper wire1			J1(A) => I 21 J1(B) => Z18	
Battery Connector			Red(+) => X3 Black (-)=> Z3	



3. With the aid of a stopwatch, keep the switch ON for exactly $1RC$ (or 15sec).
4. Once the switch is OFF after the time elapses, measure the voltage across the capacitor and record it in the table for the 15kΩ below;

NOTE: Ensure the capacitor is fully discharged before using it in the circuit. To discharge the capacitor, connect a jumper wire across the two legs to bridge them.
WARNING: You may notice sparks from the capacitor when trying to discharge it with the jumper wire.

Resistance (R)	**Capacitance (C)**	**Time constant ($\tau = R \times C$)**
10kΩ	1000µF	10 sec
15kΩ	1000µF	15 sec
22kΩ	1000µF	22 sec

Value of Resistance	**Multiples of Time Constant**	**Charging Time**	**Capacitor Voltage(V_C) -OLD**	**Capacitor Voltage (V_C) -NEW**
10kΩ	$1RC$	10 sec		
	$2RC$	20 sec		
	$3RC$	30 sec		
	$4RC$	40 sec		
	$5RC$	50 sec		

Value of Resistance	Multiples of Time Constant	Charging Time	Capacitor Voltage(V_C) -OLD	Capacitor Voltage (V_C) -NEW
15kΩ	$1RC$	15 sec		
	$2RC$	30 sec		
	$3RC$	45 sec		
	$4RC$	60 sec		
	$5RC$	75 sec		

Value of Resistance	Multiples of Time Constant	Charging Time	Capacitor Voltage(V_C) -OLD	Capacitor Voltage (V_C) -NEW
22kΩ	$1RC$	22 sec		
	$2RC$	44 sec		
	$3RC$	66 sec		
	$4RC$	88 sec		
	$5RC$	110 sec		

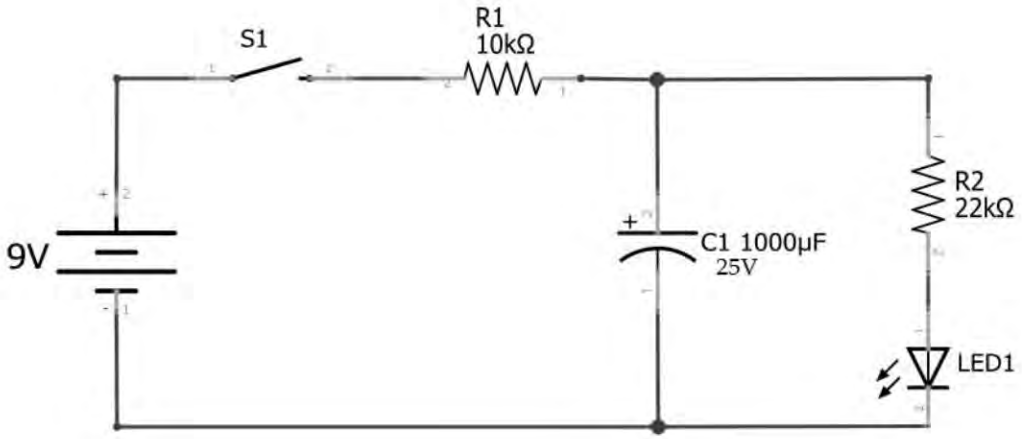
NOTE: The old capacitor voltage for the 1RC is zero while the measured value is recorded for the new. For the 2RC, the old capacitor value is the value recorded in the new for 1RC and so on.

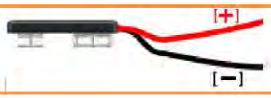
5. Discharge the capacitor and then repeat the procedure number 3 and 4 for 2RC, 3RC, 4RC and 5RC respectively.
6. Now replace the 15kΩ with the 10k and the 22k and repeat the procedure number 3 and 4 for 1RC, 2RC, 3RC, 4RC and 5RC respectively and record your results in the tables above.

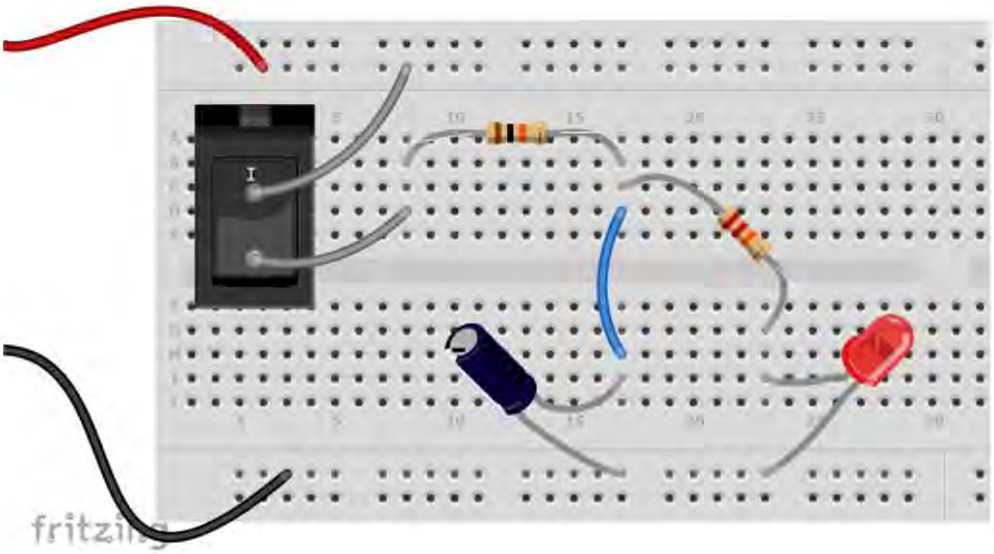
NOTE: The smaller the series resistance value, the faller the capacitor charges. Higher series resistance means a longer time to charge up

(B) Capacitor Discharging and Delay Application

1. Set up the circuit shown for the discharging and delay feature of a capacitor, using the connection table below;



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Switch1 (Rocker)		Make connections as indicated in the breadboard connection column.	S1(A) => X7 S1(B) => D8	
Resistor1: 10k Ω Brown, Black, Orange			R1(A) => B8 R1(B) => B17	
Resistor2: 22k Ω Red, Red, Orange			R2(A) => C17 R2(B) => G23	
Jumper wire1			J1(A) => D17 J1(B) => H17	
Capacitor1:1000*µF* 25V			C1(+) => I 17 C1(-) => Y15	
LED1			LED1(A) => I 23 LED1(K)=> Y20	
Battery Connector			Red(+) => X3 Black (-)=> Y3	



2. Turn ON the switch so that the capacitor starts charging up and observe how the LED gradually starts to light up as the capacitor charging causes a delay.
3. Once the LED is bright enough, turn the switch OFF and then observe how the capacitor discharges through the LED; the capacitor keeps the LED ON and does not switch off immediately.
4. Replace the 10kΩ resistor with the 15kΩ and repeat the procedures 2 and 3 above.

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Calculate for the capacitor voltage for each charging to time, use the equation below and compare your result with your measured values.

$$V_{CAP\,(NEW)} = V_{CAP\,(OLD)} + \{0.63 \times (V_{APPLIED} - V_{CAP\,(OLD)})\}$$

NOTE: The old capacitor voltage for the 1RC is zero while the measured value is recorded for the new. For the 2RC, the old capacitor value is the value recorded in the new for 1RC while the old capacitor voltage for the 3RC, is the value recorded for the 2RC new and so on.

5. Plot a graph of the capacitor voltages (new) for 1RC, 2RC, 3RC, 4RC and 5RC respectively against charging time and observe that it will give a result similar to the graph below;

6. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 17: WORKING WITH RELAYS

AIM:

To understand the working of a relay and its application

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Alligator clips pair (2)
- Resistors: 470Ω (1)
- Relay: SPDT (1)
- LED: Red (2), Yellow (2), Green (2), White (2) , blue (2)
- Press button Switch (1)

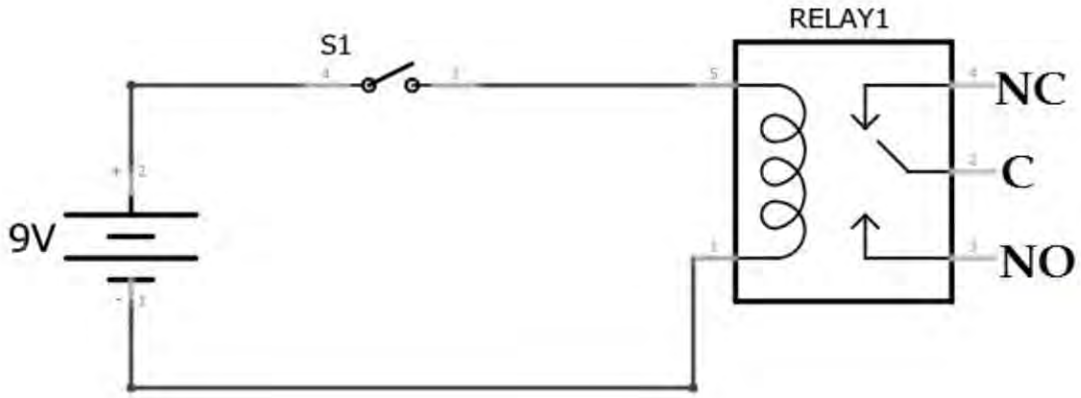
BACKGROUND:

Electromechanical relays are switches are operated both electrically and mechanically. It comes in various types depending on the application in which it is required. With a relay, a small voltage or current can be used to effectively operate a large voltage of current. The main part of a relay is an electromagnet armature, movable point contact and the restoring spring. Other features of the relay are the number of poles (P) and throws (T) it has. Also, we consider the terminals to know if it is a normally open (NO) or normally closed (NC). The relay used in this experiment is Single Pole Double Throw (SPDT) relay.

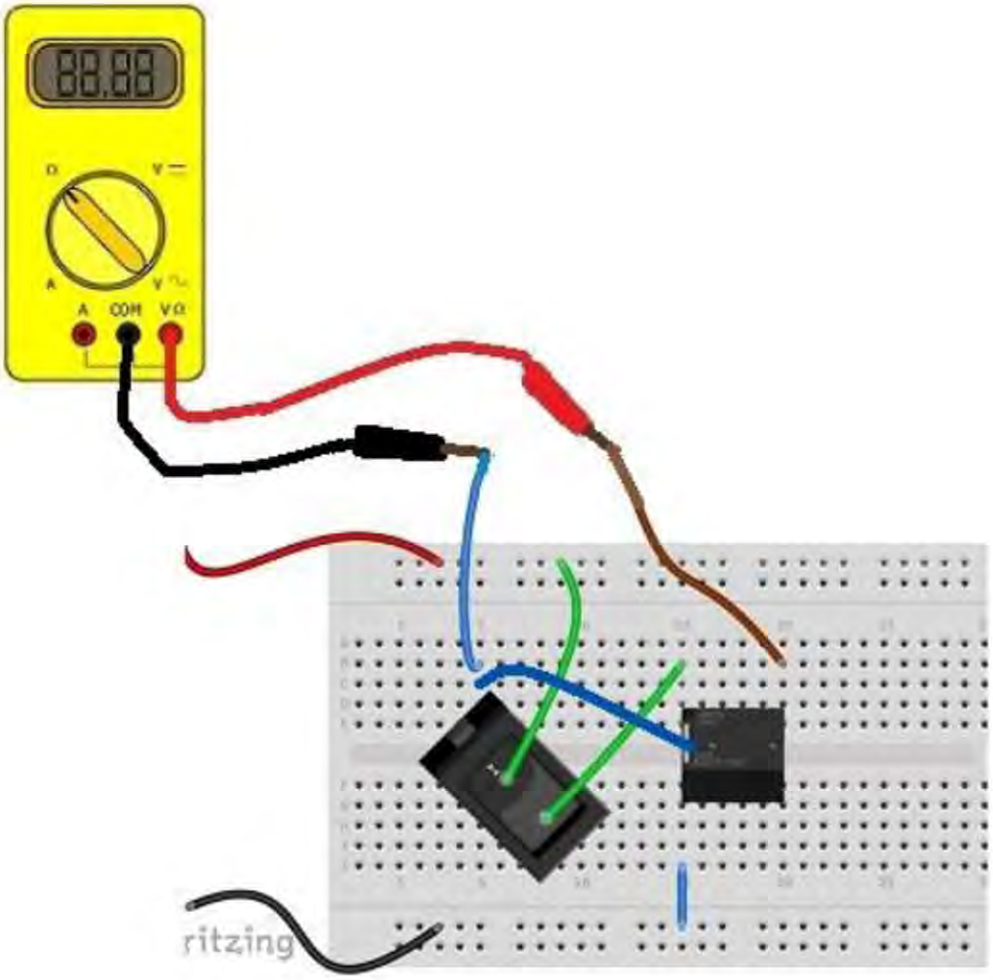
PROCEDURE:

(A) Testing a Relay

1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the dial of the selector to the continuity tester, •)||.
2. To be able to identify the pins and their working, set up the circuit shown below using the connection table provided.

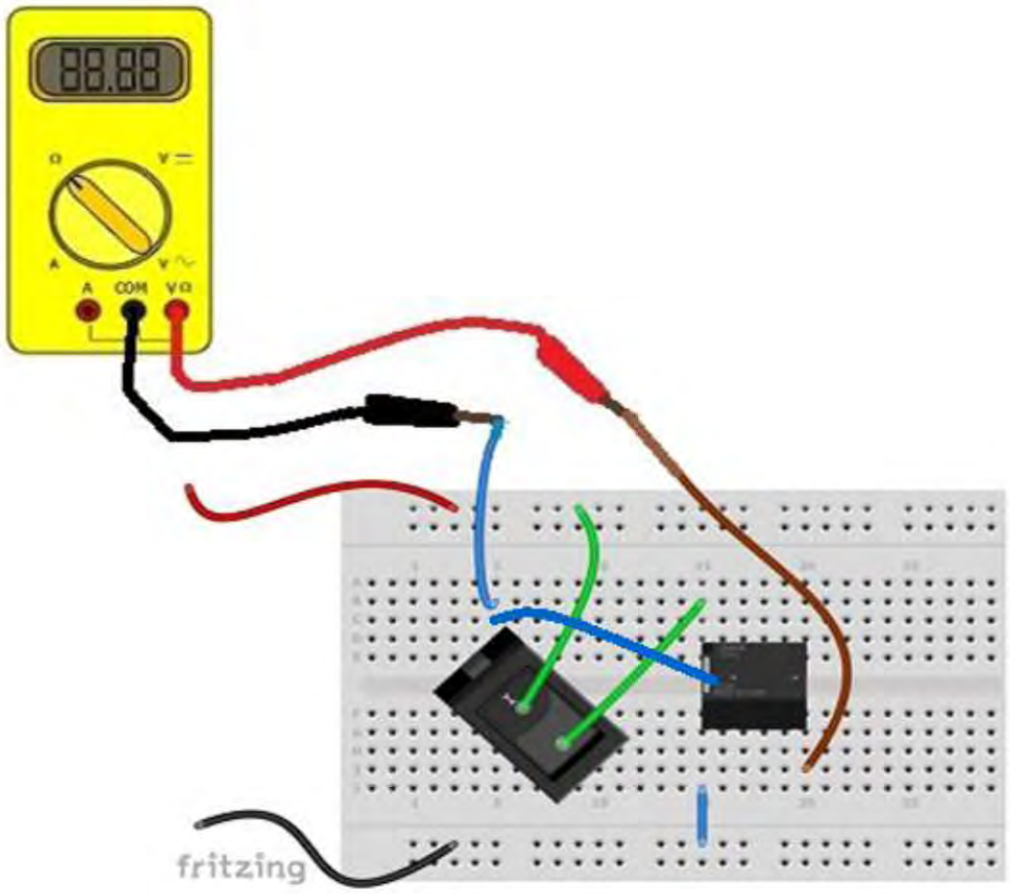


Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Relay1: SPDT		The relay pins are no shown. The labeled shown for the relay is gotten by placing the relay on the breadboard so that the small groove on in is at your left hand side when looking from above.	E1(A) => D15 E1(B) => G15 E1(C) => D5 E1(NC) => D20 E1(NO) => G20	The coils are labeled A and B while the common is the C.
Switch1 (Rocker)			S1(A) => W8 S1(B) => B15	
Jumper wire1			J1(A) => B5 J1(B) => Alligator Clip	
Jumper wire2			J2(A) => I 15 J2(B) => Y13	
Jumper wire3			J3(A) => B20 J3(B) => Red Alligator Clip	
Jumper wire4			J4(A) => I 20 J4(B) => Alligator Clip	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



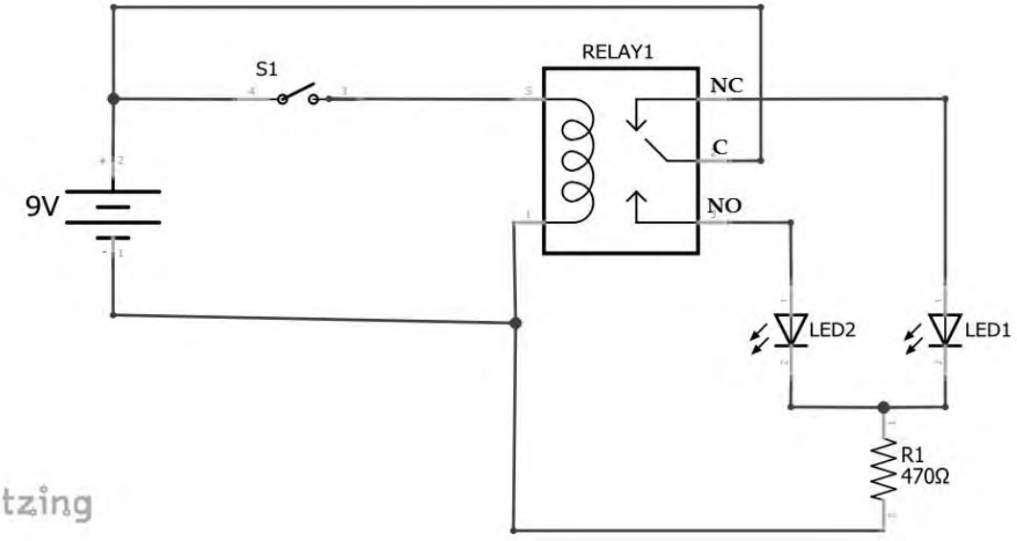
3. Turn the switch OFF and observe that the multimeter gives a beep when connected to the NC terminal. This means that the NC and the common (C) are already connected without the relay being powered.
4. To check for the NO terminal, make the connection to the vertical slot connected to the NO terminal as shown below.
5. With the switch still turned OFF, there will be no beep from your multimeter which indicates that there is no connection yet between the common (C) and the NC terminal.
6. Now press the switch ON and you should hear a beep indicating a connection between them.

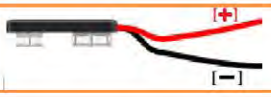
NOTE: You will usually hear a click from the relay whenever the power connected and disconnected to the coils activating the contacts.

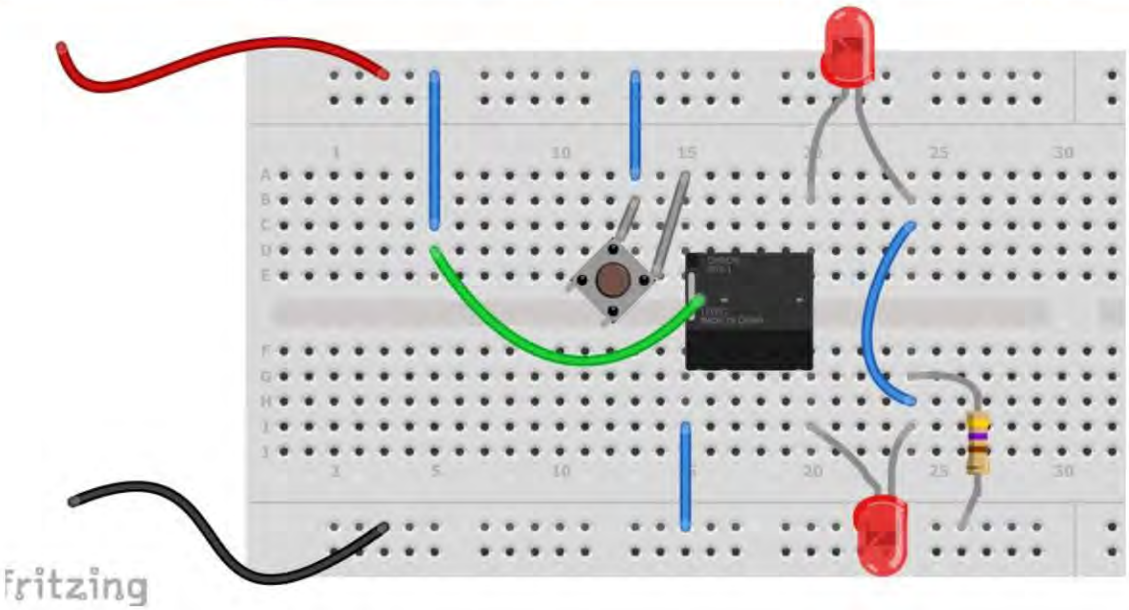


(B) Using Relay For Alternate Switching

1. Set up the circuit shown below to allow you switch between two points using a relay. Use the connection table below for setting up.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Relay1: SPDT		Make connections as indicated in the breadboard connection column.	E1(A) => D15 E1(B) => G15 E1(C) => D5 E1(NC) => D20 E1(NO) => G20	
LED1			LED1(A)=>B20 LED1(K)=> B24	
LED2			LED2(A)=> I 20 LED2(K)=> I 24	
Jumper wire1			J1(A) => C5 J1(B) => W5	
Jumper wire2			J2(A) => A13 J2(B) => W11	
Jumper wire3			J3(A) => I 15 J3(B) => Y13	
Jumper wire4			J4(A) => C24 J4(B) => H24	
Switch1 **(Press Button)**			S1(A) => B13 S1(B) => A15	
Resistor1:470 Ω **Yellow,Purple, Brown**			R1(A) => G24 R1(B) => Y22	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



2. Press the button to the switch and observe that the relay could disconnect one LED to connect the other whenever it is powered.

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Use a different capacitance value and observe how it affects the switching rate.
5. Connect a 1k Ω, 10k Ω and 100k Ω resistor in series with the capacitor and observe how it affects the switching.
6. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 18: WORKING WITH DIODES

AIM:

To understand the working of a diode and its application

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Resistors: 1kΩ (1)
- Diode (2)
- LED: Red (1), Yellow (1), Green (1), White (1) , blue (1)
- Press button Switch (2)

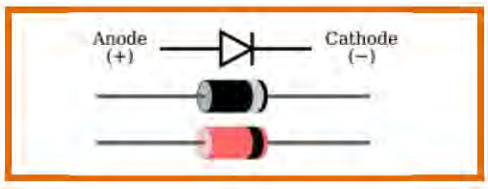
BACKGROUND:

The rest of the experiments in this section will be focused on semiconductor materials. The diode acts as a one-way switch, allowing current to flow from the anode (A) to the cathode (K) only. When forward biased, it requires a minimum voltage called, diode forward voltage V_F (or barrier voltage) across the anode and the cathode to turn it ON. When the diode is reversed biased, that is, the cathode is made more positive than the anode, then it behaves like an open switch and will not allow current to flow through that circuit path. One of the applications of the diode is in the conversion of alternating current to direct current, a process called rectification (not covered in this book).

PROCEDURE:

(A) Testing A diode

1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port and turn the selector to the diode tester (⊣▶⊢).
2. Identify the anode and the cathode of the diode as shown in the diagram below. The cathode is usually marked with a solid band by its edge.



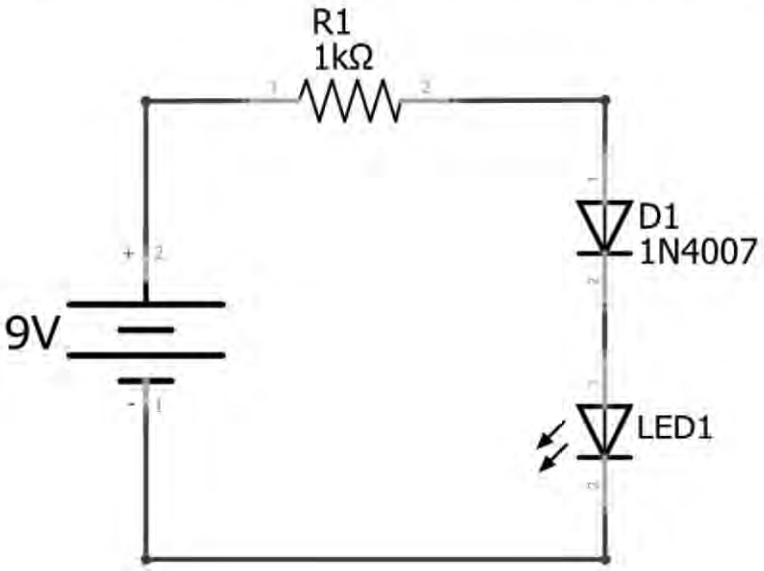
3. Connect the red multimeter probe to the anode and the black probe to the anode and observe the resistance reading. This is a forward bias measurement reading for the diode. Compare your reading with that of the table below.
4. Reverse the probes, so that the red probe is on the cathode while the black probe is on the anode and observe the resistance reading. This is the reverse bias measurement reading for the diode. Compare your reading with that of the table below.

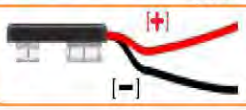
NOTE: The resistance diode test is a quick way to check if the diode is still good, open circuit or short circuit.

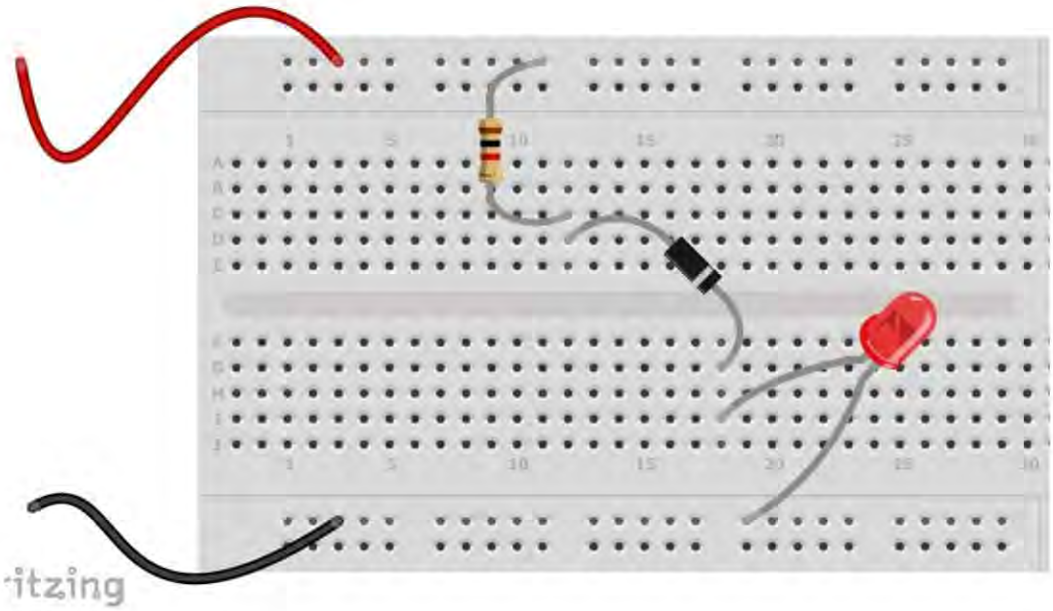
Diode State	Forward Bias (Ω)	Reverse Bias (Ω)
Good	LOW	HIGH
Open Circuit	HIGH	HIGH
Short Circuit	LOW	LOW

(B) Diode Forward and Reverse Bias

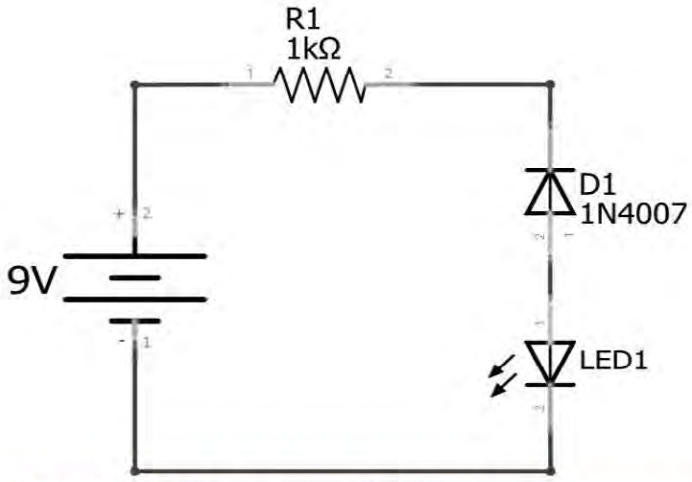
1. Set up the circuit below for the forward bias of a diode using the connection table.



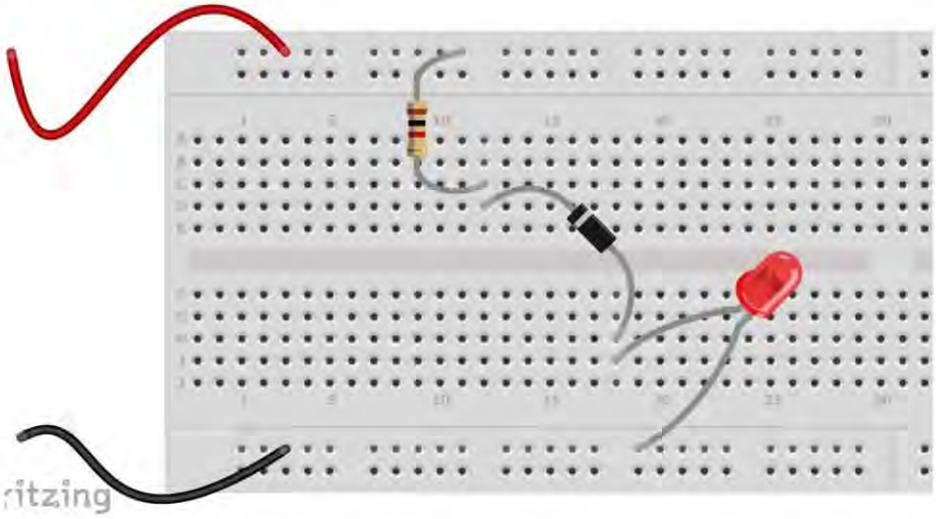
Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor1: 1k Ω **Brown, Black, Red**		Make connections as indicated in the breadboard connection column.	R1(A) => C11 R1(B) => W10	To quickly identify the cathode, the mark on the diode is nearer to the cathode lead.
Diode 1 **(Rectifier)**			D1(A) => D11 D1(K) => G18	
LED1			LED1(A) => I 18 LED1(K) => Y16	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



2. Move the dial of the selector to the voltage section (DCV or V⎓) and place it on the 20V range.
3. Place the red probe on the anode leg and the black probe on the diode cathode leg and take a reading of the forward voltage drop across the diode. Compare your reading with the table below.
4. Now, disconnect the diode for the previous set up and place the anode where the cathode was placed and the cathode to the location of the anode.



NOTE: The LED should not glow once the diode has been reversed bias.

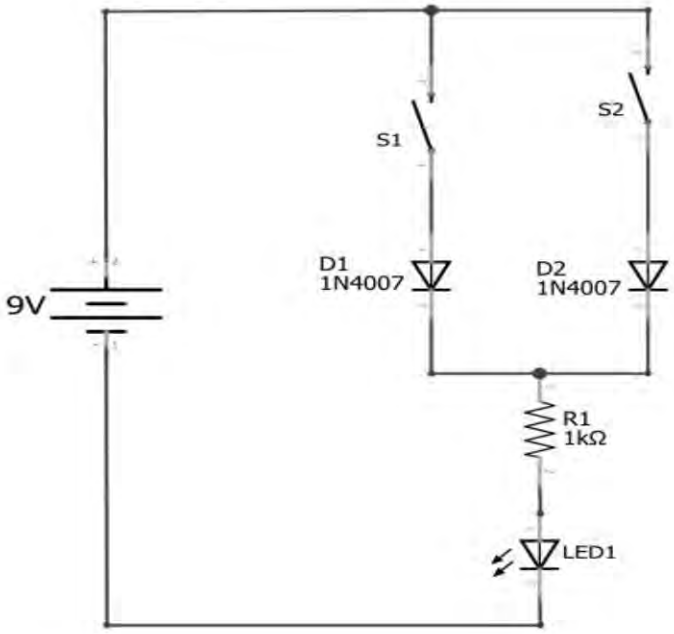


5. To measure the voltage across the diode, disconnect the LED and replace it with a jumper wire. Place the red probe on the anode and the black probe on the diode cathode when reversed bias and observe the reading. (Your reading should equal to the applied voltage, which means the diode is like an opened switch)

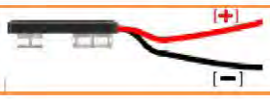
Diode State	Forward Bias (V)	Reverse Bias (V)
Good	Silicon diode: 0.5V to 0.8V Germanium diode: 0.2V to 0.4V	$V_{APPLIED}$
Open Circuit	$V_{APPLIED}$	$V_{APPLIED}$
Short Circuit	0V to 0.4V	0V to 0.4V

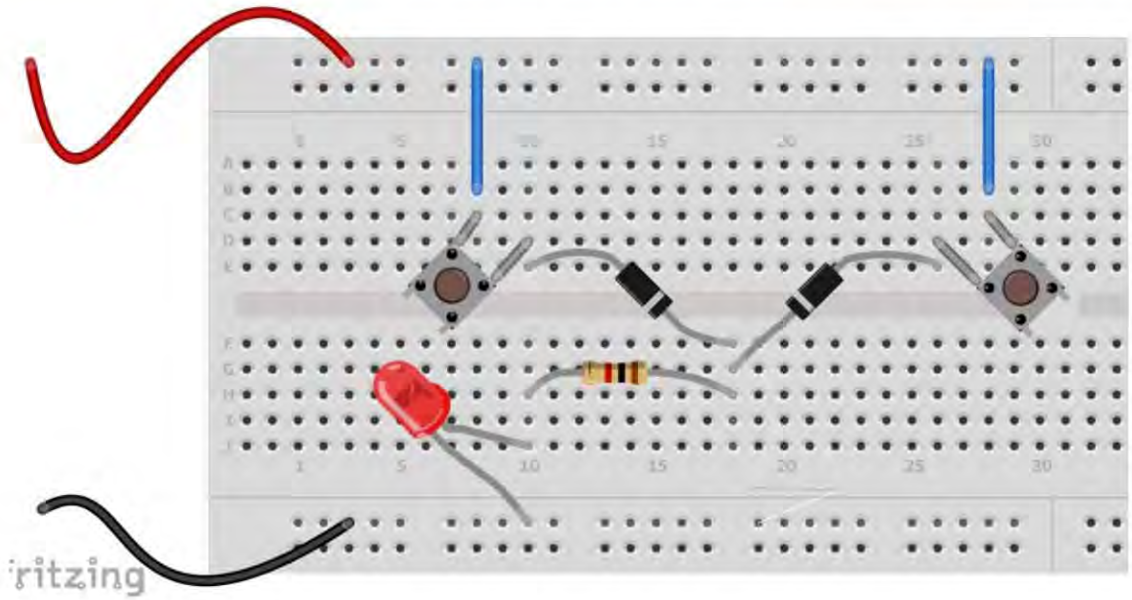
(C) Diode OR and AND logic circuit

1. Set up the circuit below to construct diode OR gate using the connection table below.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire1		Make connections as indicated in the breadboard connection column.	J1(A) => B8 J1(B) => W7	
Jumper wire2			J2(A) => B28 J2(B) => W24	
Switch1 (Press Button)			S1(A) => C8 S1(B) => D10	
Switch2 (Press Button)			S2(A) => D26 S2(B) => C28	
Diode 1 (Rectifier)			D1(A) => E10 D1(K) => F18	
Diode 2 (Rectifier)			D2(A) => E26 D2(K) => G18	
Resistor1: 1k Ω Brown, Black, Red			R1(A) => H10 R1(B) => H18	
LED1			LED1(A) => J10 LED1(K) => Y9	

Battery Connector			Red (+) => W3 Black (-)=> Y3	



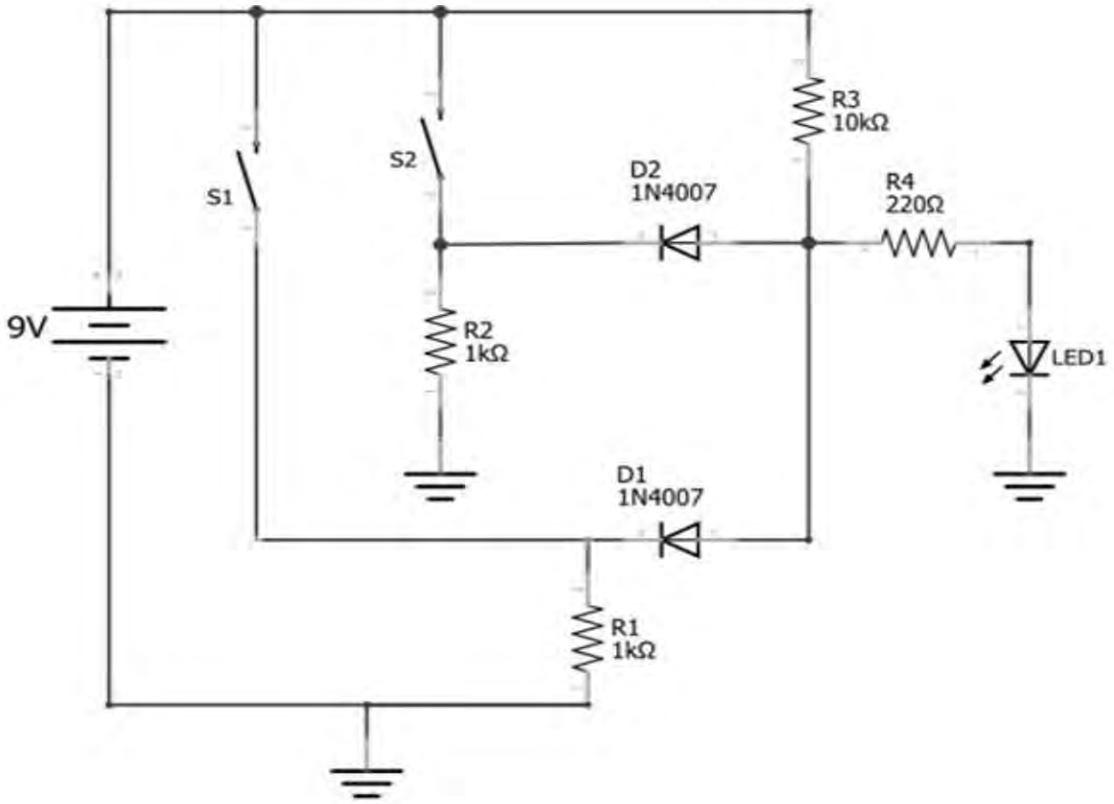
2. Press the button on the switch 1 and then the button on the switch 2 and press both switches together and observe what happens as the LED light up. Compare your observation with the table given below.

DIODE 1	DIODE 2	LED
OFF	OFF	OFF
ON	OFF	ON
OFF	ON	ON
ON	ON	ON

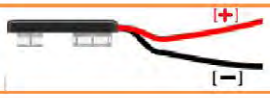
A	B	X
0	0	0
1	0	1
0	1	1
1	1	1

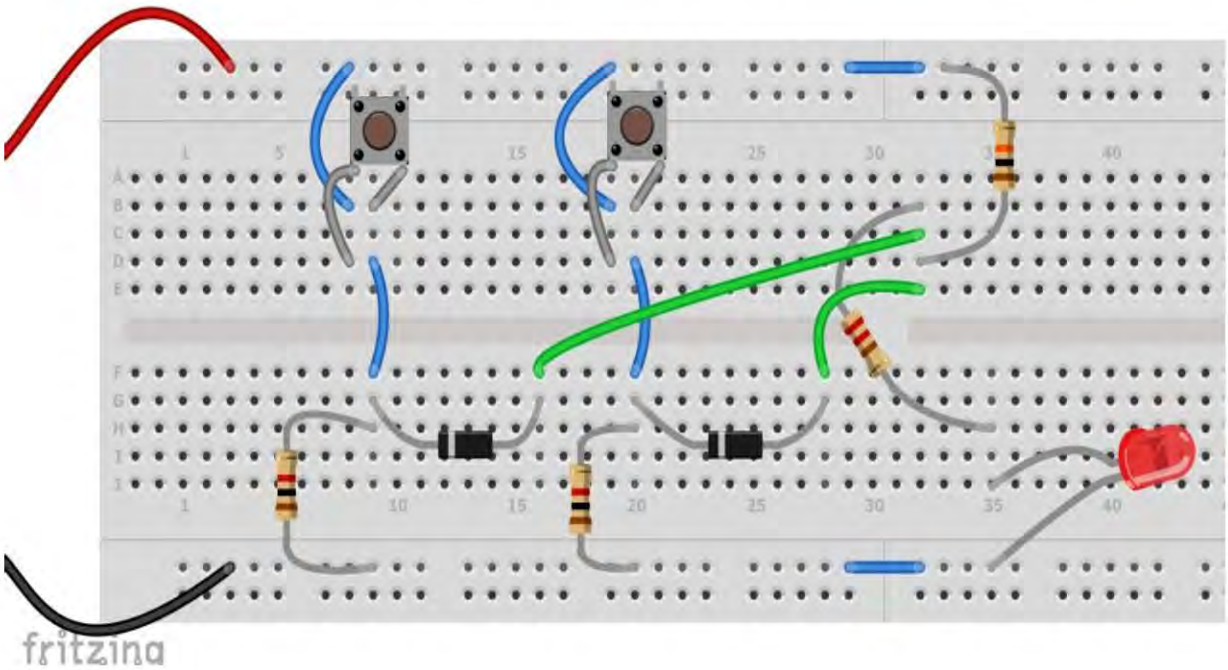
NOTE: The LED lights up when either of the switches are closed or when both switches are closed. When the diode is OFF, it is considered as a logical 0 state while when the diode is ON, it is considered as a logical 1 state.

3. Set up the circuit below to construct diode AND gate using the connection table below.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire1		Make connections as indicated in the breadboard connection column.	J1(A) => W7 J1(B) => B8	
Jumper wire2			J2(A) => W16 J2(B) => B19	
Jumper wire3			J3(A) => D9 J3(B) => F9	
Jumper wire4			J4(A) => D20 J4(B) => F20	
Jumper wire5			J5(A) => F16 J5(B) => C32	
Jumper wire6			J6(A) => F28 J6(B) => E32	
Jumper wire7			J7(A) => W25 J7(B) => W26	
Jumper wire8			J8(A) => Y25 J8(B) => Y26	
Diode 1 (Rectifier)			D1(A) =>G16 D1(K) =>G9	

Diode 2 **(Rectifier)**			D2(A) =>G28 D2(K) =>G20	
Switch1 **(Press Button)**			S1(A) =>D8 S1(B) =>B9	
Switch2 **(Press Button)**			S2(A) => D19 S2(B) => B20	
Resistor1: 1k Ω **Brown, Black, Red**			R1(A) => H9 R1(B) => Y8	
Resistor2: 1k Ω **Brown, Black, Red**			R2(A) => H20 R2(B) => Y17	
Resistor3: **10k Ω** **Brown, Black, Orange**			R3(A) => D32 R3(B) => W27	
Resistor4: **220 Ω** **Brown, Black, Red**			R4(A) => B32 R4(B) => H35	
LED1			LED1(A) => J35 LED1(K) =>H35	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



4. Press the button on switch 1 and then switch 2 and then press both switches and observe what happens as the LED lights up. Compare your observation with the table below.

DIODE 1	DIODE 2	LED
ON	ON	OFF
ON	OFF	OFF
OFF	ON	OFF
OFF	OFF	ON

A	B	X
0	0	0
1	0	0
0	1	0
1	1	1

NOTE: The LED lights up only when both switches are closed. When either or both of the switches are open the LED will be OFF. When the diode is ON, it is considered as a logical 0 state while when the diode is OFF, it is considered as a logical 1 state.

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 19: WORKING WITH TRANSISTORS

AIM:

To learn the basic usage of a bipolar transistor and its features

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Alligator clip pairs (2)
- Resistors: 560Ω (1), 330kΩ (1)
- Transistor: BC547 (1)

BACKGROUND:

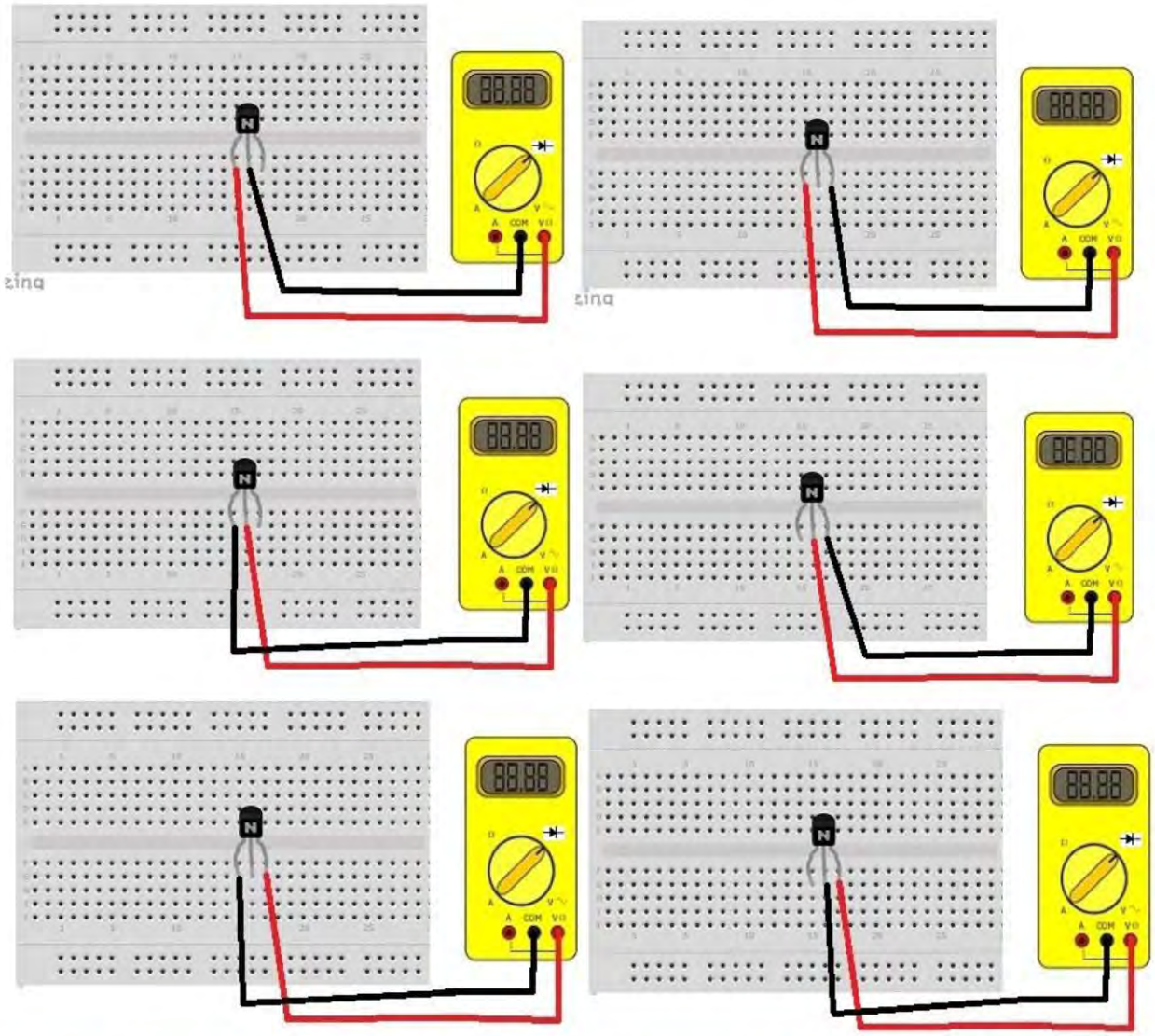
The bipolar transistor is a semiconductor device with three legs namely; Base (B), Emitter (E) and Collector (C). Transistor can control current and voltage and consequently the power in a circuit. By using the base current, it can control the devices to cut-off, active or saturation modes. The small voltage current can also control a large current or voltage change at the emitter and collector of the device. The ratio of the collector DC current to base DC current is called the DC current gain ($\beta_{DC} = I_C/I_B$) which is usually given by the manufacturer. In order to turn the transistor ON, the base voltage is to be made about 0.7V greater than the emitter voltage for NPN while for a PNP, the base voltage is made about 0.7V lesser than the emitter voltage. When in cut-off mode, the collector-emitter voltage will equal to the applied voltage across it while in the saturation mode, the collector-emitter voltage will equal to about 0.2V. The transistor can be used for two main applications namely, switching and amplification.

PROCEDURE:

(A) Testing A transistor

1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port and turn the selector to the diode tester (⊣▶⊢).
2. Place the BC547 transistor on the breadboard so that the labeled part is facing you as shown below.
3. Place the red multimeter probe on the first pin and the black touching the second and the third pin. Then move the red probe to the second pin and touch the first

and third pins with the red probe as shown in the diagram below. Observe the reading on the multimeter when touching the pins with the black probe.



NOTE: Whenever you get a reading for the other two pin when touch by the black probe, then the pin with the red probe is the base while the other two will be either the collector or the emitter.

NPN: Red probe (+) is fixed on a pin while the black probe (-) gives reading for the other pins.	PNP: Black probe (-) is fixed on a pin while the red probe (+) gives reading for the other pins.

4. Compare the transistor pin test with the table given below.

NPN	B (-)	E (-)	C (-)
B (+)	------	R_{BE}	R_{BC}
E (+)	1	------	1
C (+)	1	1	------

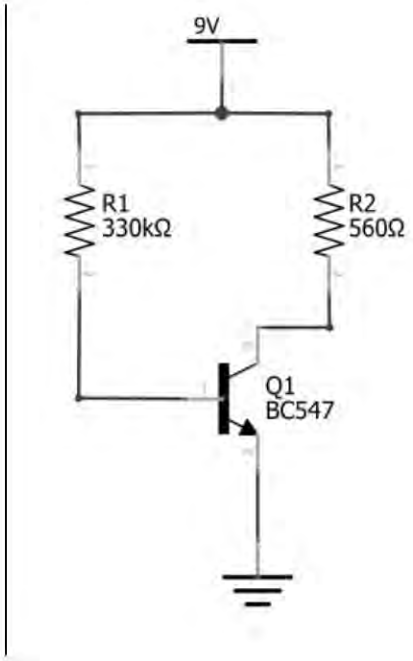
PNP	B (+)	E (+)	C (+)
B (-)	------	R_{BE}	R_{BC}
E (-)	1	------	1
C (-)	1	1	------

- **Short circuit transistor**; 0Ω or very low resistance for forward and reverse diode test on the pins
- **Open circuit transistor**; 1 or very high resistance on multimeter reading for both forward and reverse diode test on pins.

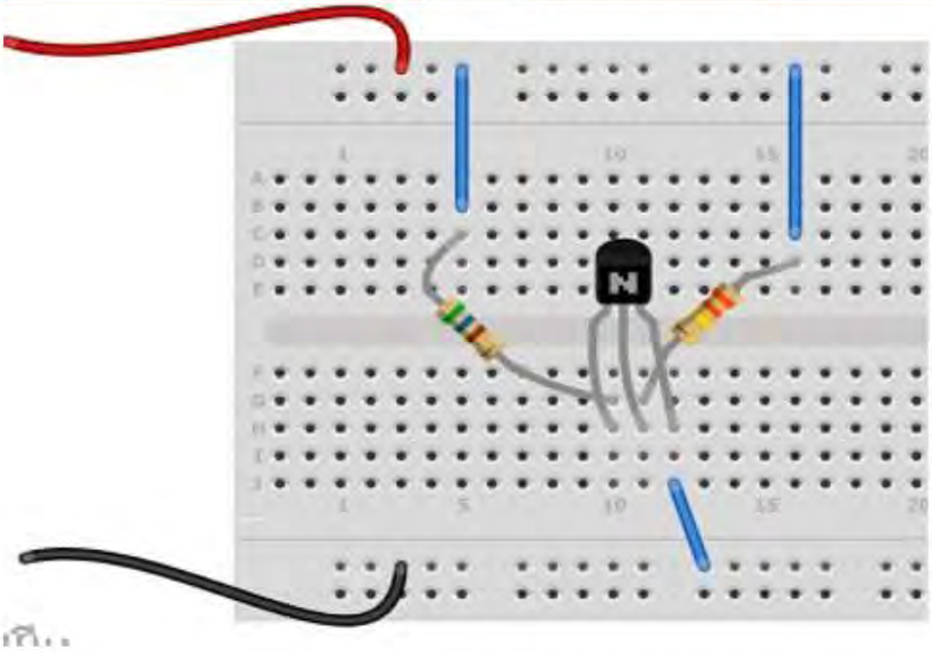
NOTE: The base-emitter resistance (R_{BE}) is greater than the base-collector resistance (R_{BC}) by a few ohms. The pin with the greater resistance with respect to the base is the emitter pin while that with the lesser resistance is the collector pin $(R_{BE} > R_{BC})$.

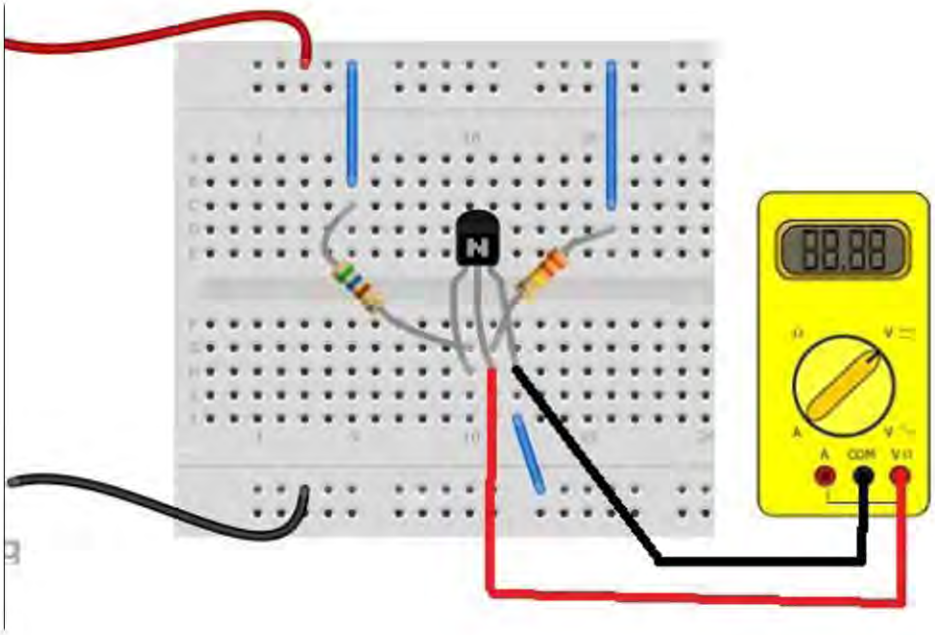
(B) Transistor Biasing

1. Set up the circuit showing a transistor with base transistor bias, using the connection table.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: BC547		To identify the pins of the transistor as labeled, hold the transistor such that the flat side is facing you. In this position, the pins from left to right are as follows; collector (C), base (B) and emitter (E).	Q1(C) => H10 Q1(B) => H11 Q1(E) => H12	Also, confirm the pins with the help of your multimeter.
Resistor1:330k Ω Orange,Orange, Yellow			R1(A) => G11 R1(B) => D16	
Resistor2: 560Ω Green, Blue, Brown			R2(A) => C5 R2(B) => G10	
Jumper wire1			J1(A) => B5 J1(B) => W5	
Jumper wire2			J2(A) => C15 J2(B) => W14	
Jumper wire3			J3(A) => J12 J3(B) => Y11	
Battery Connector			Red(+) => W3 Black (-)=> Y3	





2. Move the dial of the selector to the voltage section (DCV or $\mathbf{V}\overline{\overline{\mathbf{=}}}$) and place it on the 20V range.
3. Measure the following voltages across the transistor pin;
   i. Base-Emitter voltage (V_{BE})
   ii. Collector-Emitter voltage (V_{CE})
   iii. Voltage across collector resistor (V_{R_C})
   iv. Voltage across base resistor (V_{R_B})

NOTE: The voltage relationship for the transistor bias done above will equal to:

- $V_{R_C} + V_{CE} = V_{APPLIED}$
- $V_{R_B} + V_{BE} = V_{APPLIED}$

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 20: TRANSISTOR LOGIC GATES

AIM:

To construct transistor logic gates to perform the OR, AND and the INVERTER functions

MATERIALS:

- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Switch: Press button (2), SPDT Rocker (1)
- LED: Red (1), Yellow (1), Green (1), White (1) , blue (1)
- Resistors: 220Ω (1), 1kΩ (1), 10kΩ (1), 1MΩ (2)
- Transistor: BC547 (2), D882 (1)

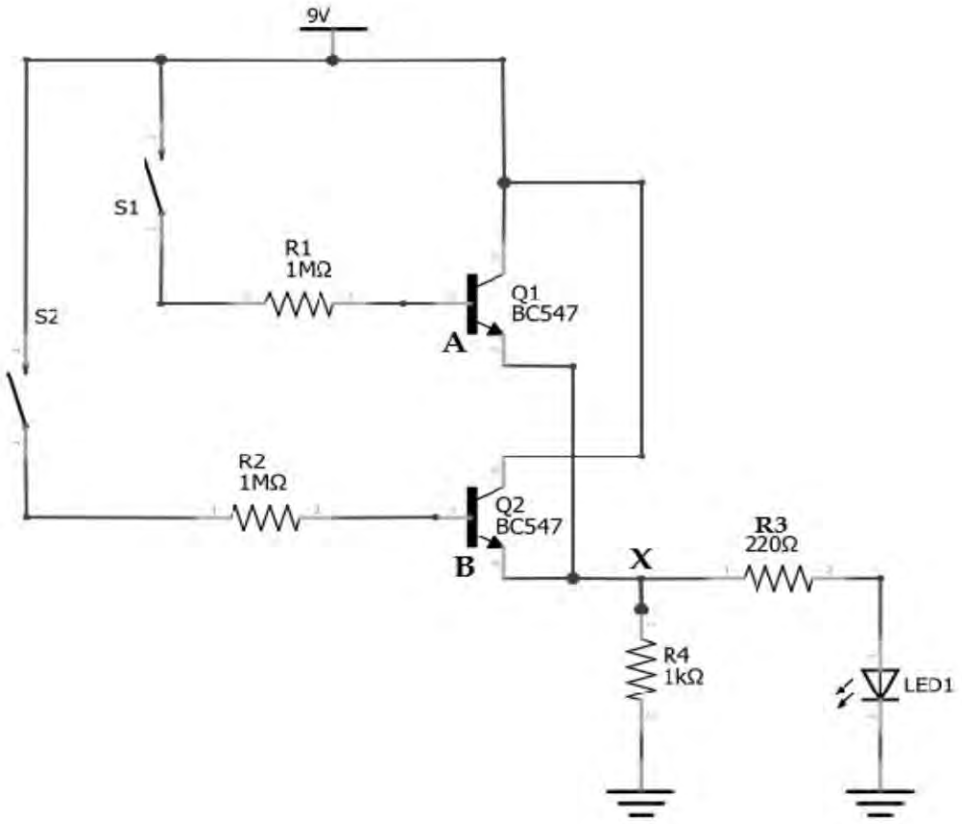
BACKGROUND:

Transistor are be used for constructing logic gates when used as a switch. The input signal sent through the base so that it can turn ON the base-emitter junction of the transistor and drive it into saturation. In this experiment, for the OR gate, the transistors are connected in parallel with their collectors joined together and their emitters joined together. The transistors are connected in series for achieving the AND gate, in such a way that the emitter of one is connected to the collector of the other. A single transistor will be used for the INVERTER such that, when the transistor is ON then the output will be OFF when the transistor is OFF, the output will be ON.

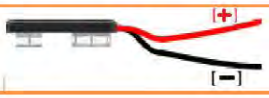
PROCEDURE:

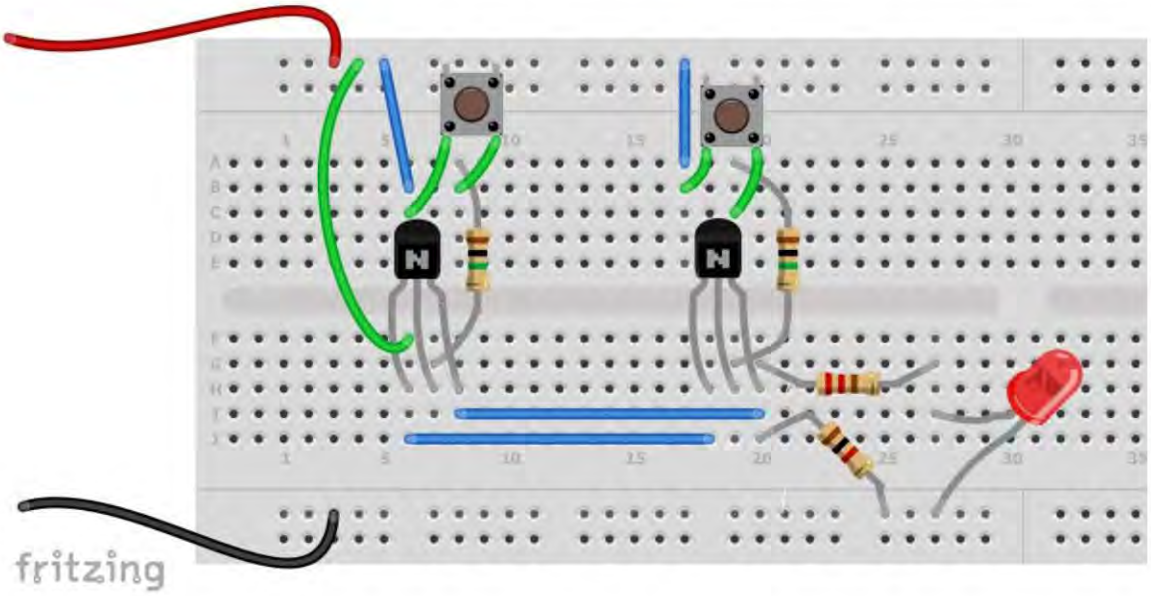
(A) Transistor OR Gate

1. Set up the circuit for the OR gate shown below using the connection table.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: BC547		Make connections as indicated in the breadboard connection column.	Q1(C) => H6 Q1(B) => H7 Q1(E) => H8	
Transistor 2: BC547			Q2(C) => H18 Q2(B) => H19 Q2(E) => H20	
Jumper wire1			J1(A) => J6 J1(B) => J18	
Jumper wire2			J2(A) => I 8 J2(B) => I 20	
Jumper wire3			J3(A) => B6 J3(B) => W5	
Jumper wire4			J4(A) => A17 J(B) => W15	
Resistor1: 1MΩ Brown, Black, Green			R1(A) => G7 R1(B) => A8	

Resistor2: 1MΩ **Brown, Black, Green**			R2(A) => A19 R2(B) => G19	
Switch1 **(Press Button)**			S1(A) => C6 S1(B) => B8	
Switch2 **(Press Button)**			S2(A) => B17 S2(B) => C19	
Resistor3: 220Ω **Red, Red, Brown**			R3(A) => G20 R3(B) => G27	
Resistor4: 1kΩ **Brown, Black, Red**			R4(A) => J20 R4(B) => Y21	
LED1			LED1(A) => I 27 LED1(K) => 23	
Jumper wire5			J5(A) => F6 J5(B) => W4	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



2. Press the button the switch 1 alone and release it. Now press the button on switch 2 alone and release it. Finally press both switches.
3. Compare your result with the table shown below.

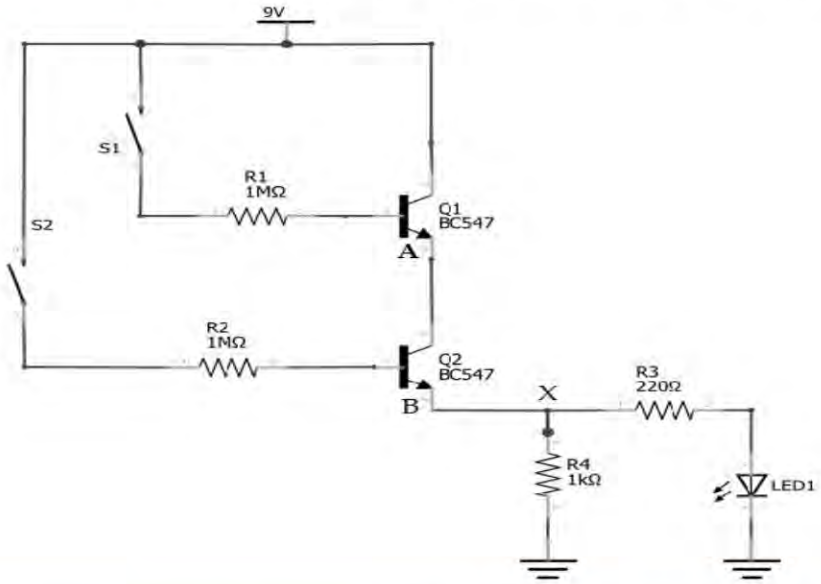
TRANSISTOR 1	TRANSISTOR 2	LED
OFF	OFF	OFF
ON	OFF	ON
OFF	ON	ON
ON	ON	ON

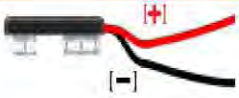
A	B	X
0	0	0
1	0	1
0	1	1
1	1	1

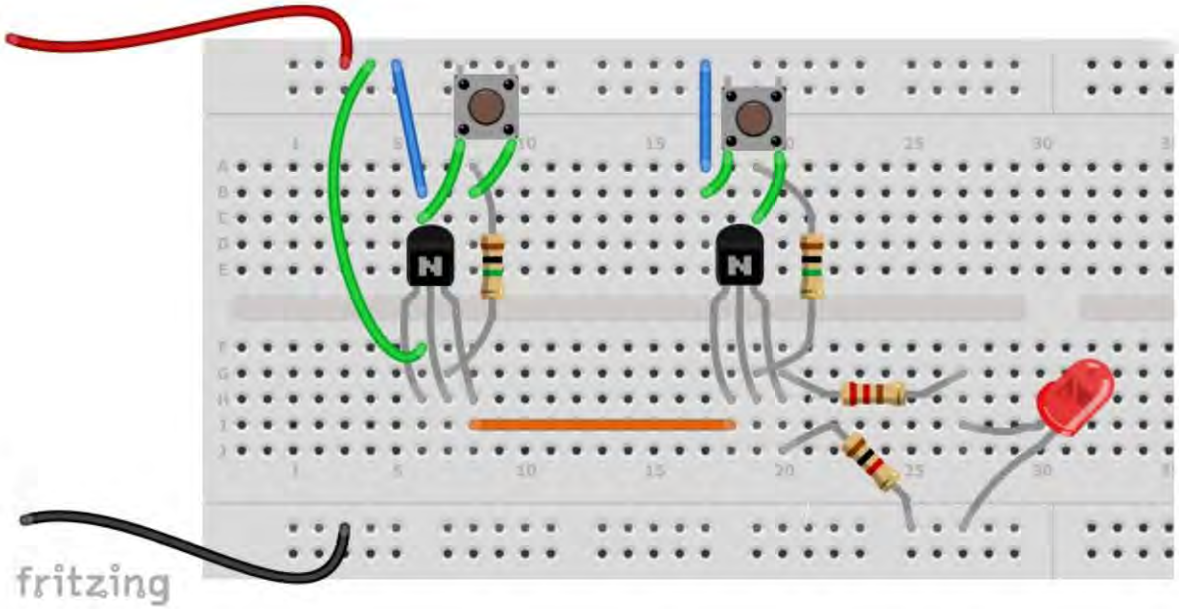
NOTE: The OR gate function operates such that if one or both transistors are turned ON, then the output will be turn ON as well.

(B) Transistor AND gate

1. Set up the circuit for the AND gate shown below using the connection table.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Jumper wire2		Remove jumper wire 1 and place jumper wire 2 in this new position.	J2(A) => I 8 J2(B) => I 18	This table is an adjustment to the previous table in section A.
Battery Connector			Red(+) => W3 Black (-)=> Y3	



2. Press the button the switch 1 alone and release it. Now press the button on switch 2 alone and release it. Finally press both switches.

1. Compare your result with the table shown below.

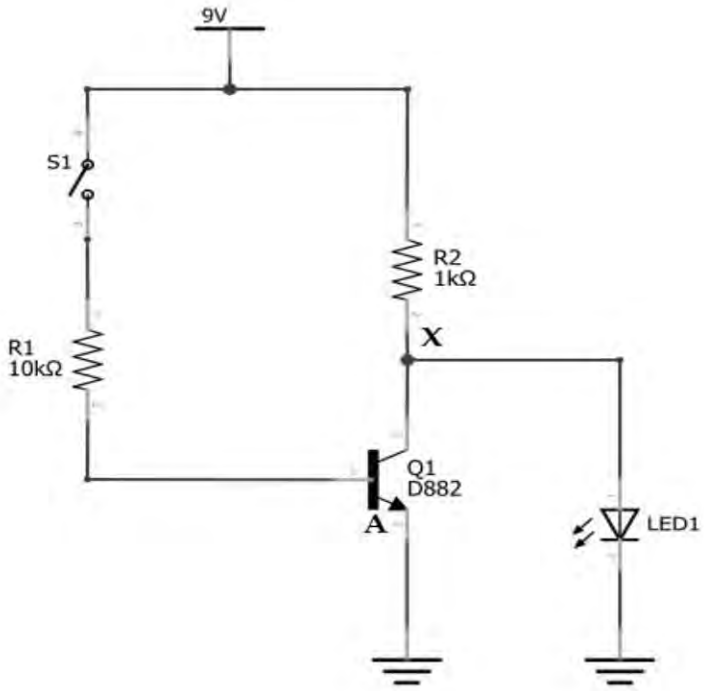
TRANSISTOR 1	TRANSISTOR 2	LED
OFF	OFF	OFF
ON	OFF	OFF
OFF	ON	OFF
ON	ON	ON

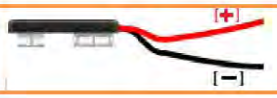
A	B	X
0	0	0
1	0	0
0	1	0
1	1	1

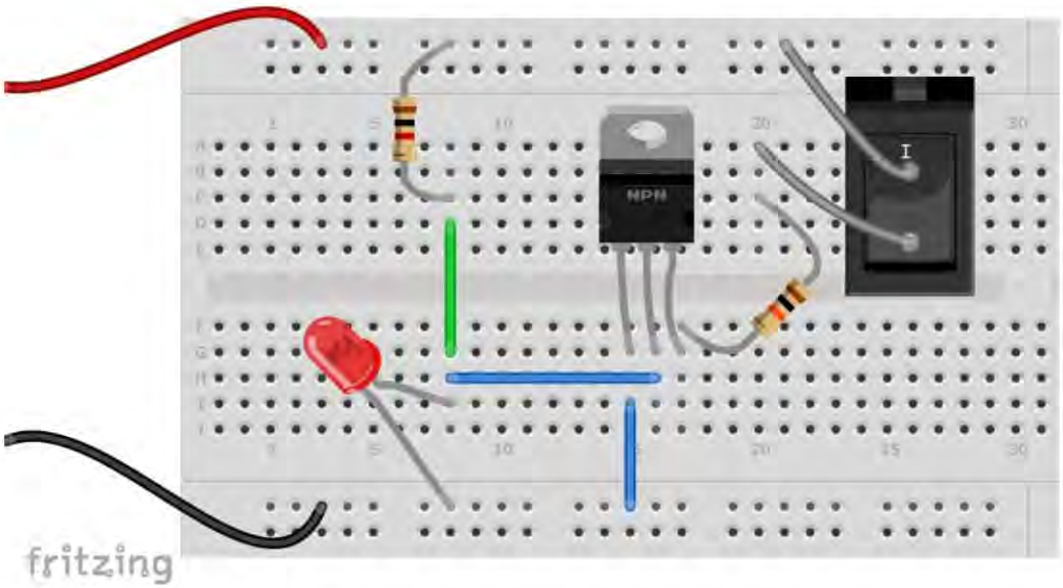
NOTE: The AND gate function operates such that only when both transistors are turned ON, then the output will be turn ON as well.

(C) Transistor INVERTER Gate

1. Set up the circuit for the INVERTER gate shown below using the connection table.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: D882		To identify the pins of the transistor as labeled, hold the transistor such that the side with transistor name is facing you. In this position, the pins from left to right are as follows; emitter (E), collector (C), base (B) and	Q1(E) => G15 Q1(C) =>G16 Q1(B) =>G17	
Switch1 (Rocker)			S1(A) => A20 S1(B) => W18	
Resistor1: 1kΩ Brown, Black, Red			R1(A) => C8 R1(B) => W7	
Resistor2: 10kΩ Brown, Black, Orange			R2(A) => F17 R2(B) => B20	
LED1			LED1(A) => I 8 LED1(K) =>Y7	
Jumper wire1			J1(A) => H8 J1(B) => H16	
Jumper wire2			J2(A) => I 15 J2(B) => Y13	
Jumper wire 3			J3(A) => D8 J3(B) => G8	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



2. Press the button the switch and release it. Compare your result with the table shown below.

SWITCH 1	LED
OFF	ON
ON	OFF

A	X
0	1
1	0

NOTE: The INVERTER gate function operates such that when the transistor is turned ON, then the output will be turn OFF but if the transistor is then OFF, the output will be ON.

FUTHER ACTIVITIES:

1. Expand the OR and the AND gates to three transistor inputs and draw out the table of its operation.
2. Learn how to draw the circuit diagram(s) in this experiment.
3. Practice the circuit set up on your own without using the connection table guide.
4. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
5. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 21: TRANSISTOR SWITCH WITH RELAY

AIM:

To construct a transistor switch for controlling an LED and a relay.

MATERIALS:

- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Switch: SPDT Rocker (1)
- Relay (1)
- Diode (1)
- LED: Red (1), Yellow (1), Green (1), White (1) , blue (1)
- Resistors: 1kΩ (1), 10kΩ (1)
- Transistor: D882 (1)
- DC motor (1)

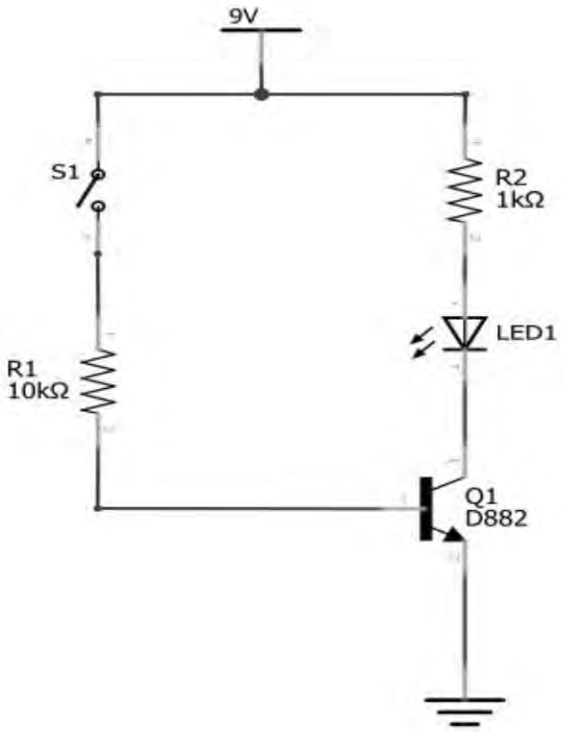
BACKGROUND:

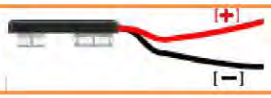
Transistors can be used as switches by operating it between the cut-off and saturation modes. At the cut-off mode, the base-emitter junction is not forward bias and so the collector-emitter junction voltage should be equal to the supply voltage. At the saturation mode, the base-emitter is forward bias, such that the current is high enough to allow the maximum current flowing through the collector. The collector-emitter voltage will be about 0.2V in the saturation mode. The load (LED and Relay) will be connected in series with the collector. A diode connected in reverse across the relay coil is called the flywheel diode. It prevents the relay from sending high current through the transistor during switching process.

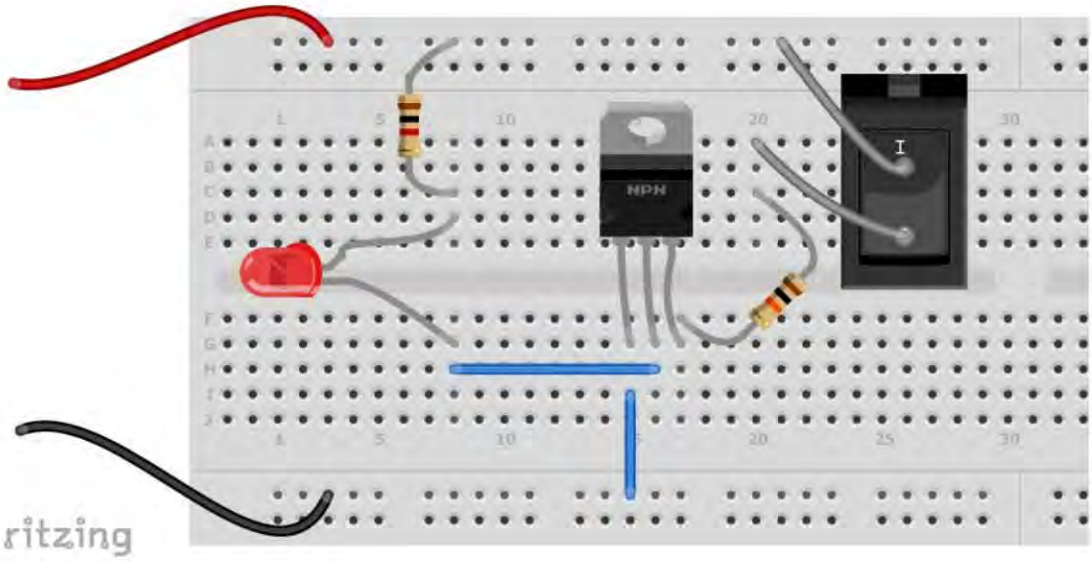
PROCEDURE:

(A) Transistor LED Switch

1. Set up the circuit for switching an LED using the transistor using the connection table.



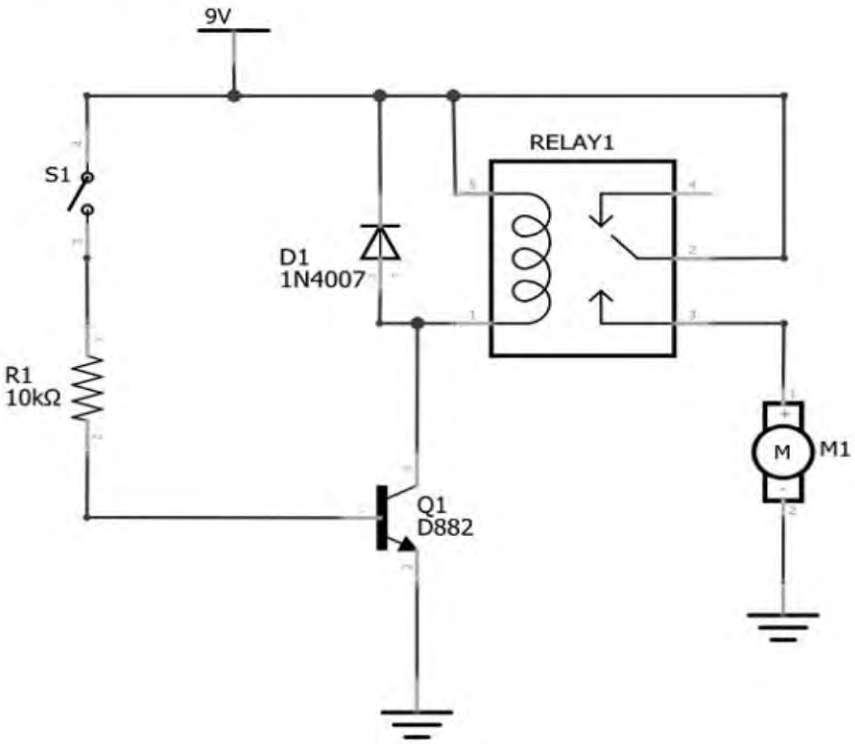
Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: D882		Make connections as indicated in the breadboard connection column.	Q1(E) => G15 Q1(C) =>G16 Q1(B) =>G17	
Switch1 (Rocker)			S1(A) => A20 S1(B) => W18	
Resistor1: 1kΩ Brown, Black, Red			R1(A) => C8 R1(B) => W7	
Resistor2: 10kΩ Brown, Black, Orange			R2(A) => F17 R2(B) => B20	
LED1			LED1(A) => D8 LED1(K) => G8	
Jumper wire1			J1(A) => H8 J1(B) => H16	
Jumper wire2			J2(A) => I 15 J2(B) => Y13	
Battery Connector			Red(+) => W3 Black (-)=> Y3	

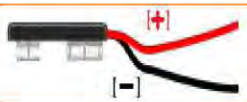


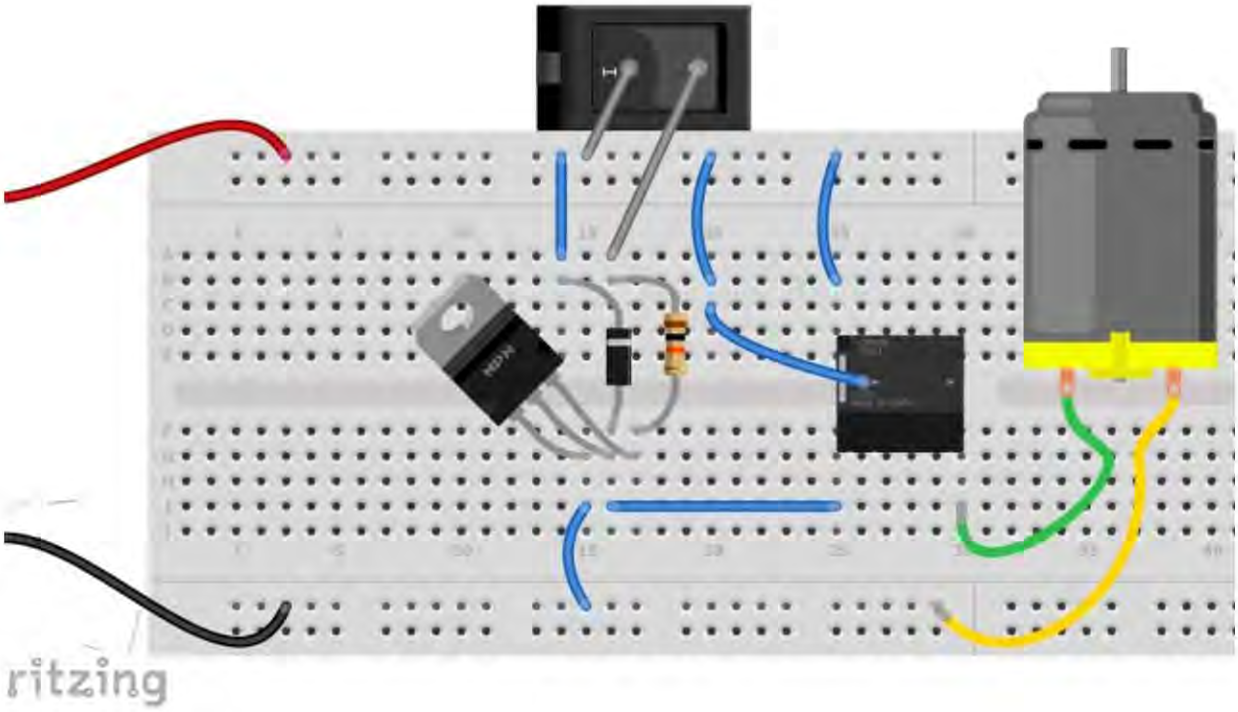
2. Press the switch button to switch ON so that the transistor will become ON and will start conducting. The LED should give a light once the transistor is turned ON.

(B) Transistor Relay Switching

1. Set up the circuit for switching a relay controlled by the transistor using the connection table.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: D882		Make connections as indicated in the breadboard connection column.	Q1(E) => G15 Q1(C) =>G16 Q1(B) =>G17	
Switch1 (Rocker)			S1(A) => A16 S1(B) => W13	
Resistor1: 10kΩ Brown, Black, Orange			R1(A) => B16 R1(B) => F17	
Diode 1 (Rectifier)			D1(A) => F16 D1(K) => B14	
Relay1: SPDT			E1(A) => D25 E1(B) => G25 E1(C) => C20 E1(NC) => D30 E1(NO) => G30	
DC motor 1			M1(+) => I 30 M1(-) =>Y25	
Jumper wire1			J1(A) => A14 J1(B) => W12	
Jumper wire2			J2(A) => I 15 J2(B) => Y13	
Jumper wire3			J3(A) => B20 J3(B) => W17	
Jumper wire4			J4(A) => I 16 J4(B) => I 25	
Jumper wire5			J5(A) => B25 J5(B) => W21	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



2. Press the button on the switch and observe that the relay is energized and then the DC motor starts rotating. Once the power is stopped, the relay is de-energized which makes the DC motor come to a stop.

FUTHER ACTIVITIES:

1. Connect the DC motor positive wire to the NC (B30) terminal on the breadboard and observe that the operation will be opposite. That is, when the transistor is ON, the DC motor is OFF and when the transistor is OFF, the DC motor will be ON.
2. Learn how to draw the circuit diagram(s) in this experiment.
3. Practice the circuit set up on your own without using the connection table guide.
4. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
5. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 22: TRANSISTOR VOLTAGE REGULATOR

AIM:

To learn how to construct a voltage source, using a transistor circuit.

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Zener Diode: 5.1V (1)
- Resistors: 1kΩ (3), 5.6kΩ (1), 15kΩ (1), 47kΩ (1), 100kΩ (1)
- Transistor: D882 (1)

BACKGROUND:

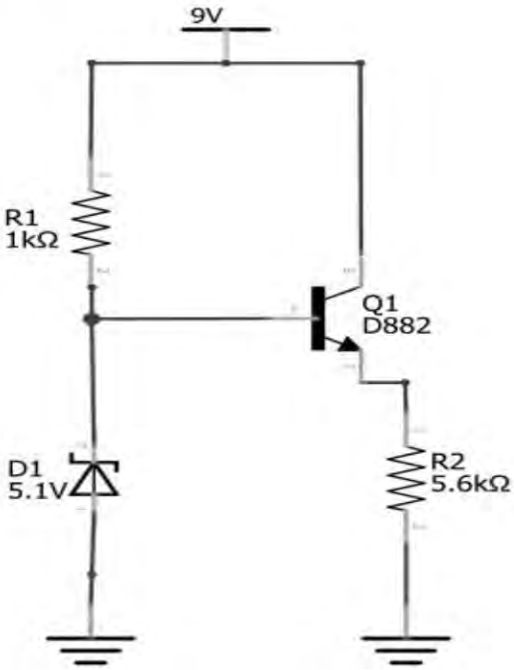
A voltage source is a circuit capable of providing constant voltage across a connected load. A good voltage source will keep the output voltage stable even when supply voltage fluctuates. The output from a voltage source is usually regarded as a regulated voltage. Transistors are used for constructing efficient voltage regulator when compared with those made from resistor network only. The transistor in this experiment is used in the common-emitter configuration also called **emitter follower.** Also, a Zener diode was introduced at the base to bias the transistor and enforce voltage stability. The Zener diode is usually operated in the reverse bias for providing constant voltage across it when the applied voltage is greater than a required amount. A resistor may also be used in place of the Zener diode.

PROCEDURE:

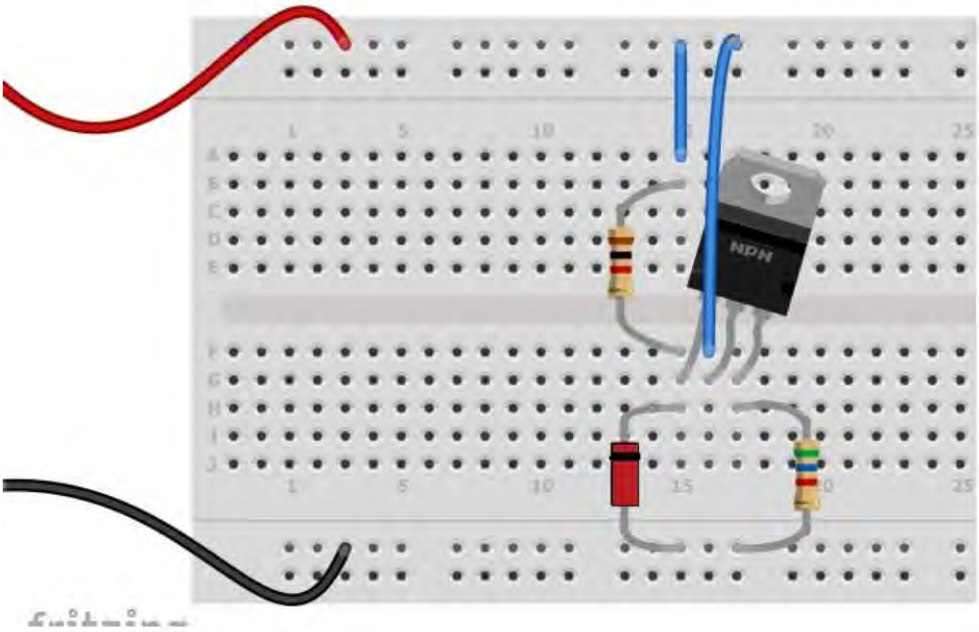
(A) Voltage Source with Zener diode bias

1. Set up the circuit for the transistor voltage source using the connection table below.
2. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the dial of the selector to the voltage section (DCV or V⎓) and place it on the 20V range.
3. Measure the voltage of your battery and check if it is within ±9V, that is, between 10V maximum and 8V minimum.

4. Measure the voltage across the Zener diode with the red probe on the cathode while the black probe will be on the anode.



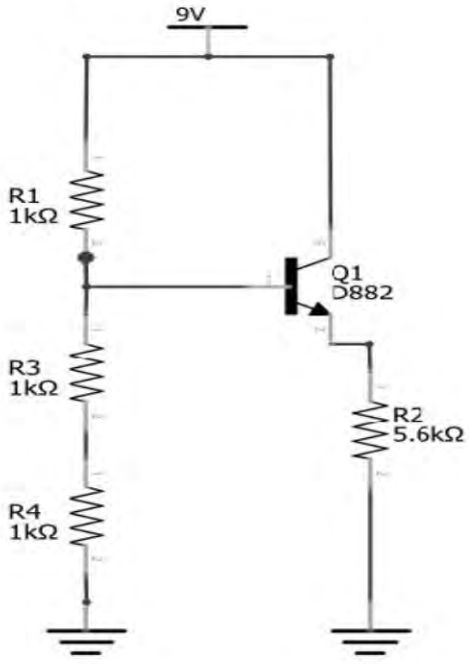
Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: D882		Make connections as indicated in the breadboard connection column.	Q1(B) => G15 Q1(C) =>G16 Q1(E) =>G17	
Resistor1: 1kΩ **Brown, Black, Red**			R1(A) => B15 R1(B) => F15	
Resistor2:5.6k Ω **Green, Blue, Red**			R2(A) => H17 R2(B) => W7	
Diode1: Zener (5.1V)			D1(A) => Y13 D1(K) => H15	
Jumper wire1			J1(A) => A15 J1(B) => W13	
Jumper wire2			J2(A) => F16 J2(B) => W15	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



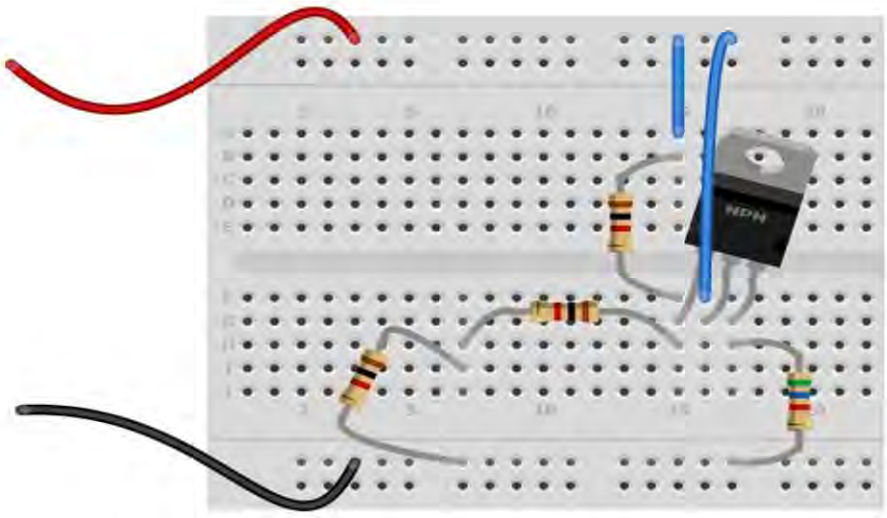
5. Measure the voltage across the load resistor $R_2$and observe the reading.
6. Now, replace the 5.6kΩ with the other resistors 15kΩ, 47kΩ, and 100kΩ. Measure the voltage across the resistors and observe your reading.

(B) Voltage Source With A Voltage Divider Bias

1. Set up the circuit for the voltage source having the base bias from a voltage divider, using the connection table below.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor3: 1kΩ **Brown, Black, Red**	A B	The Zener diode should be removed before making this adjustment.	R3(A) => H7 R3(B) => H15	This table is an adjustment to the previous table in section A.
Resistor4: 1kΩ **Brown, Black, Red**	A B		R4(A) => I 7 R4(B) => Y6	
Battery Connector	[+] [−]		Red(+) => W3 Black (-)=> Y3	



2. Repeat the procedure 5 and 6 from section A above and observe your reading.

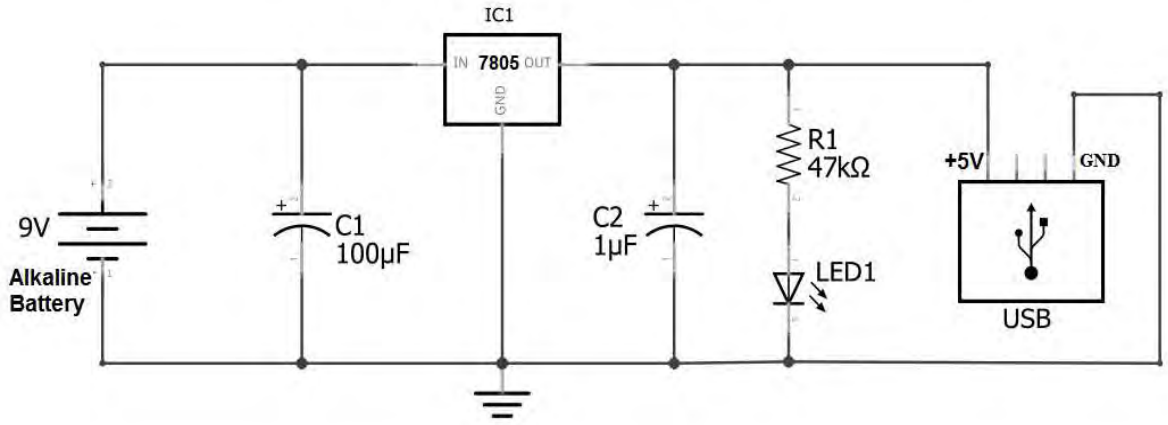
FUTHER ACTIVITIES:

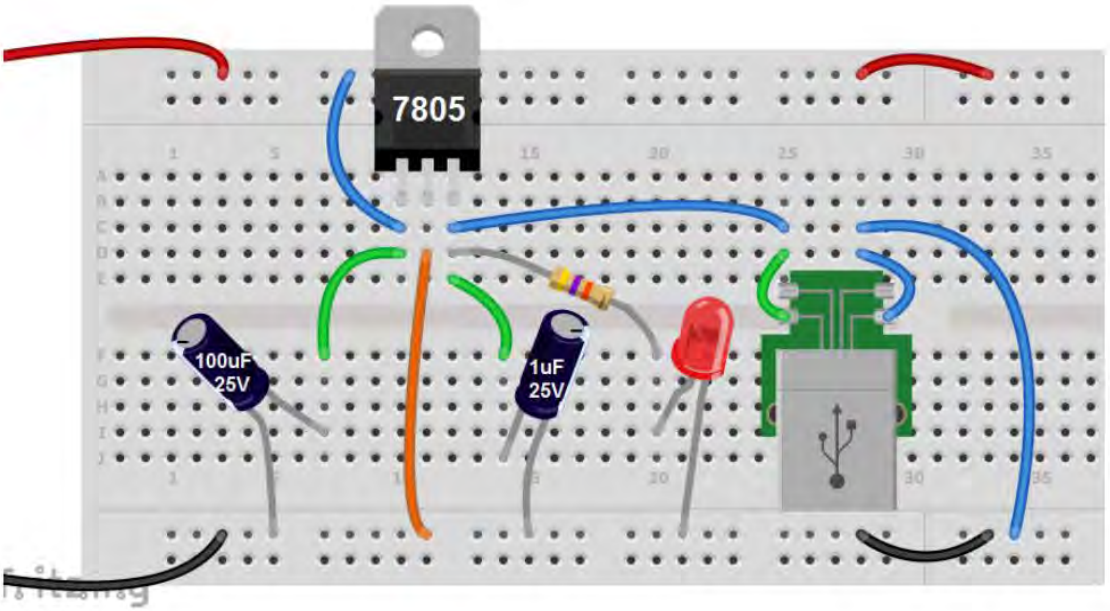
1. Set up the portable phone charger circuit and the breadboard diagram show below. The main component in the circuit is the fixed +5V voltage regulator IC (7805). At the input, 9V is supplied so that the IC can produce a voltage of +5V at its output. The output voltage is then connected to the USB connector.

NOTE: In order the get the best result from the charger circuit, use a **9V ALKALINE BATTERY** to power the circuit

2. Learn how to draw the circuit diagram(s) in this experiment.
3. Practice the circuit set up on your own without using the connection table guide.
4. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.

5. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.





USB Receptacle

Pin	Signal	Description
1	VCC	+5V
2	D-	Data -
3	D+	Data +
4	GND	Ground

EXPERIMENT 23: LIGHT DIMMER AND DC MOTOR SPEED CONTROL

AIM:

To construct a transistor circuit for controlling the brightness of an LED and the speed of a DC motor.

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Diode (1)
- LED: Red (1), Yellow (1), Green (1), White (1) , blue (1)
- Resistors: 10kΩ (1), 330kΩ (1)
- Potentiometer: 100kΩ (1)
- Transistor: D882 (1)
- DC motor (1)

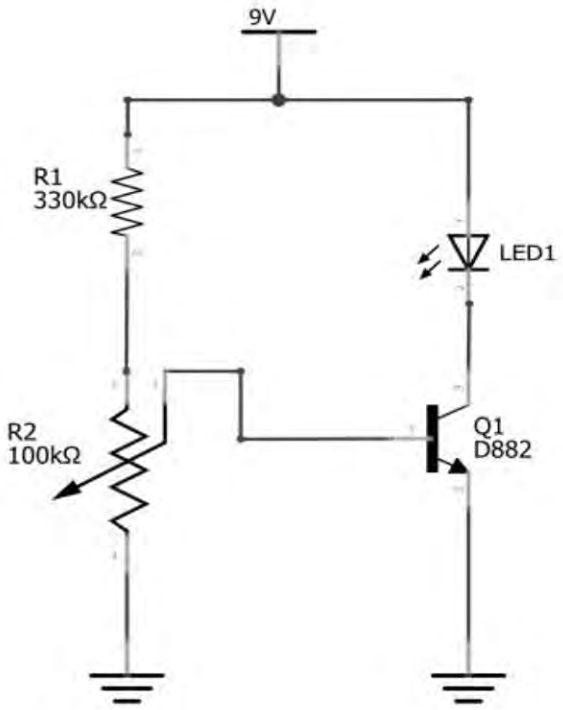
BACKGROUND:

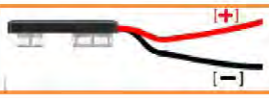
A transistor circuit can be design to behave like a variable resistor so that the current flowing through the load can be smoothly controlled. The transistor variable current circuit has more efficiency than the circuit consisting of only a variable resistor. This efficiency is achieved by using a very small change in the base voltage to cause a large voltage and current variation in the collector. A potentiometer is used at the base of the transistor to bias it and enable the voltage at the base to be changed easily. As the base voltage changes, the transistor is being changed from the cut-off mode, to the active mode and then saturation mode.

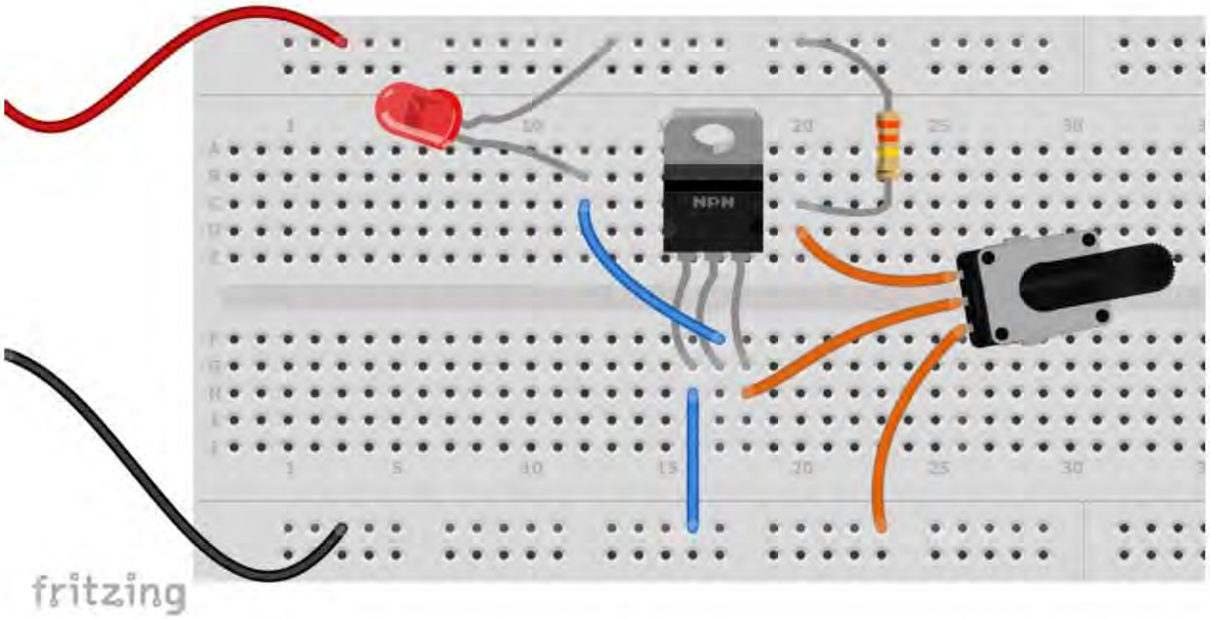
PROCEDURE:

(A) Light Dimmer

1. Set up the transistor circuit for controlling the brightness of an LED using the connection table.
2. Gently rotate the shaft of the potentiometer and observe how the LED light varies from a very bright glow to a dim one.



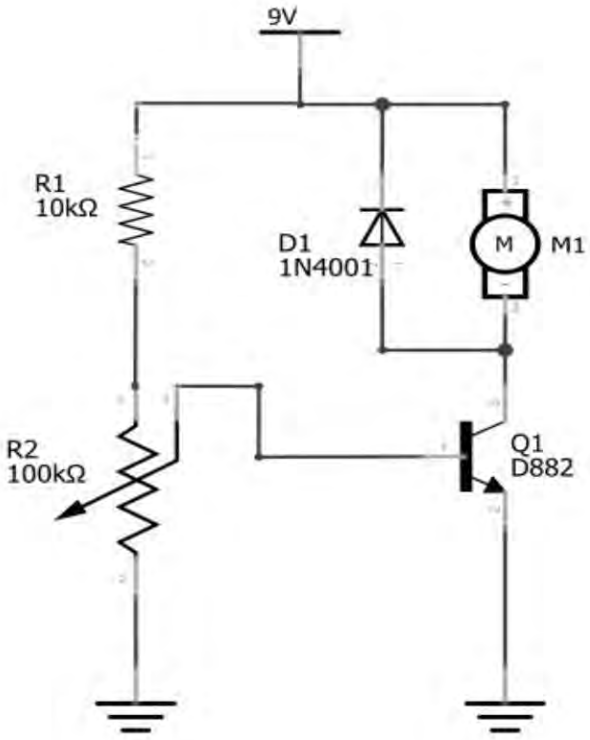
Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: D882		Make connections as indicated in the breadboard connection column.	Q1(E) => G16 Q1(C) =>G17 Q1(B) =>G18	
Jumper wire1			J1(A) => C12 J1(B) => F17	
Jumper wire2			J2(A) => H16 J2(B) => Y14	
LED1			LED1(A)=>W11 LED1(K) =>B12	
Resistor1: 330k Ω **Orange, Orange, Yellow**			R1(A) => C20 R1(B) => W17	
Resistor2:100k Ω **Potentiometer**			R2(A) => D20 R2(B) => H18 R2(C) => Y20	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



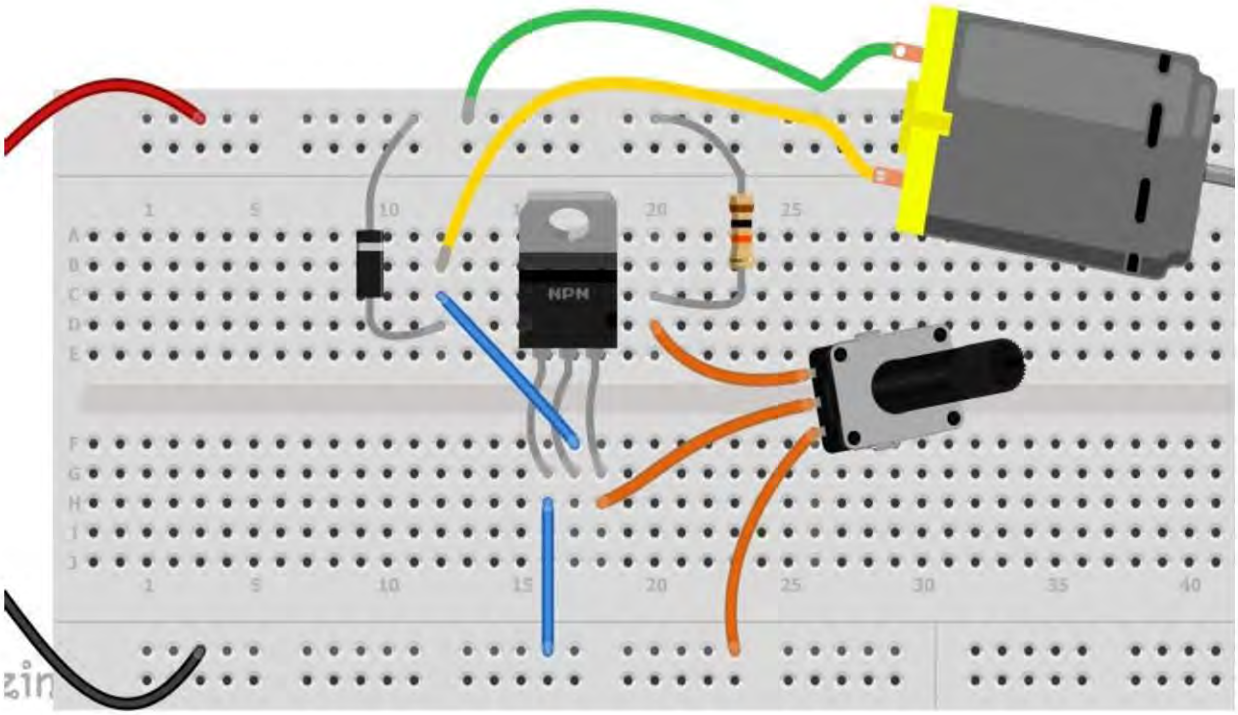
3. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the dial of the selector to the voltage section (DCV or V⎓) and place it on the 20V range.
4. Measure the base-emitter voltage (V_{BE}) when the light is very dim and when it is very bright.

(B) DC motor Speed Control

1. Set up the transistor circuit for controlling the speed of a DC motor using the connection table below.
2. Gently rotate the shaft of the potentiometer and observe how the DC motor speed changes. At one point it rotates slowly and at another it becomes very fast.
3. Repeat steps step 3 and 4 in section A above.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor1:10kΩ Brown, Black, Orange		The LED1 and resistor 1 should be removed from previous before making this adjustment.	R1(A) => D20 R1(B) => W17	This table is an adjustment to the previous table in section A.
Diode 1 (Rectifier)			D1(A) => D12 D1(K) => W10	
DC motor 1			M1(+) => W11 M1(-) => B12	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 24: TRANSISTOR TOUCH SWITCH

AIM:

To demonstrate how transistors' switch require very small current to turn it ON.

MATERIALS:

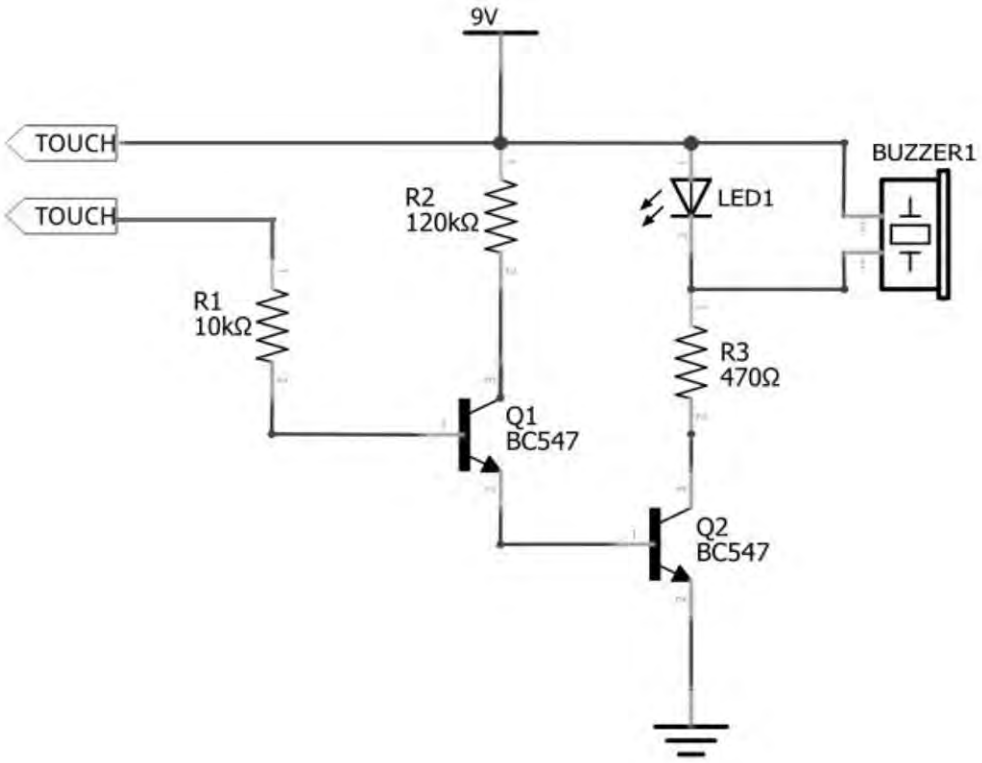
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- LED: Red (1), Yellow (1), Green (1), White (1) , blue (1)
- Resistors: 470Ω (1), 10kΩ (1), 120kΩ (1)
- Transistor: BC547 (2)
- Buzzer (1)

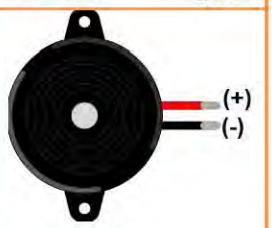
BACKGROUND:

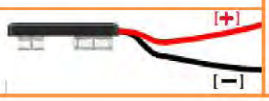
The touch switch is made possible by taking advantage of the very small amount of current required to operate the transistor. The human skin has a resistance value in the range of hundred thousand of ohms which means it can conduct especially when a little damp. In order to get the current allowed through the skin power the connected device, it was amplified using an arrangement of transistors called Darlington pair. When the touch sensitive switch (made by two jumper wires connected at only one end) is touched by a finger, it turns ON the transistor which then powers the connected loads (LED and buzzer).

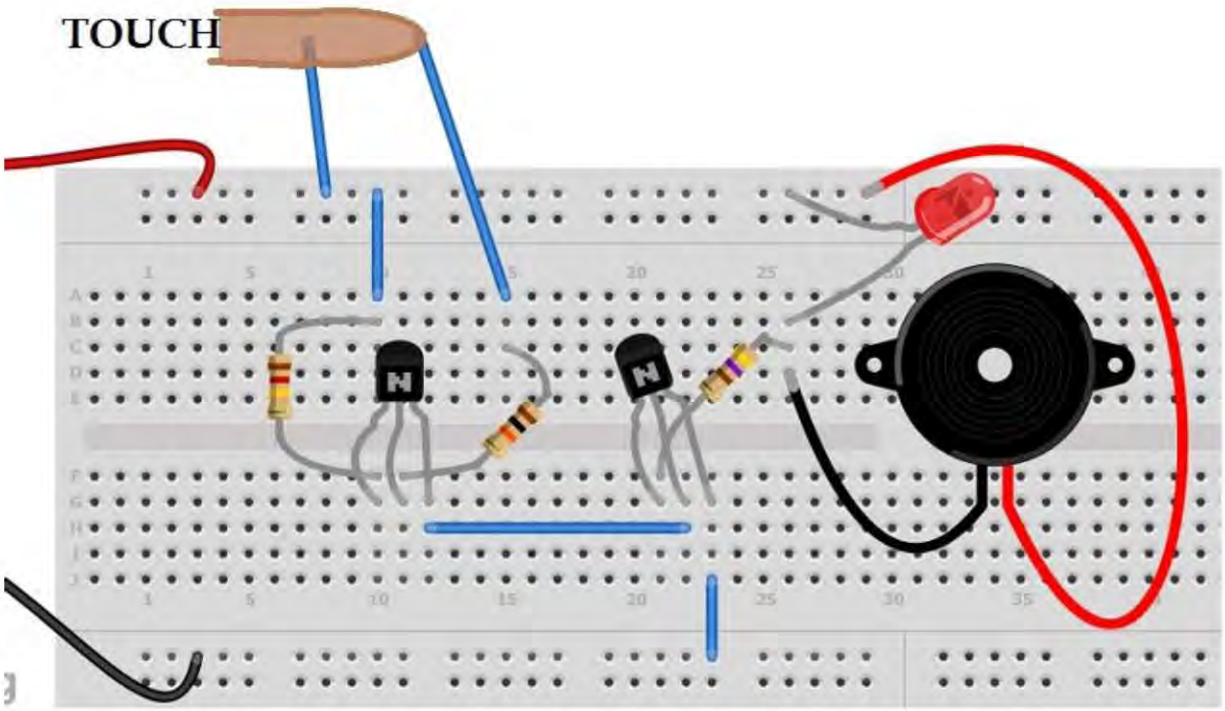
PROCEDURE:

1. Set up the circuit shown for touch switch using the connection table below.
2. With your bare finger, gently bridge the two vertically placed jumper wires on the breadboard. Observe that the LED and buzzer should give out light and sound respectively.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: BC547		Make connections as indicated in the breadboard connection column.	Q1(C) => G10 Q1(B) => G11 Q1(E) => G12	
Transistor 2: BC547			Q2(C) => G21 Q2(B) => G22 Q2(E) => G23	
Resistor1: 10kΩ Brown, Black, Orange			R1(A) => F11 R1(B) => C15	
Resistor2:120k Ω Brown, Red, Yellow			R2(A) => B10 R2(B) => F10	
Resistor3: 470 Ω Yellow, Purple, Brown			R3(A) => F21 R3(B) =>C26	
LED1			LED1(A)=>W22 LED1(K) =>B26	
BUZZER 1			B1 (+) => W25 B1(-) => D26	

Jumper wire1			J1(A) => A10 J1(B) => W9	
Jumper wire2			J2(A) => H12 J2(B) => H22	
Jumper wire3			J3(A) => J23 J3(B) => Y20	
Jumper wire4			J4(A) => W7 J(B) => NOT CONNECTED	
Jumper wire5			J5(A) => A15 J5(B) => NOT CONNECTED	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.

4. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 25: LIGHT CONTROLLED SWITCH

AIM:

To construct a transistor switch that is controlled by a light sensitive device.

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- 9V battery pack (1)
- Alligator clip
- Jumper wires
- LED: Red (1), Yellow (1), Green (1), White (1) , blue (1)
- Resistors: 560Ω (1), 1kΩ, 56kΩ (1)
- Transistor: BC547 (1)
- LDR (1)

BACKGROUND:

This light controlled switch responds to light intensity to operate the transistor base bias. The main device which is responsible for detecting surrounding light is the Light Dependent Resistor (LDR). The LDR is a kind of resistor whose resistance decreases as the intensity of light falling of it increases. In a dark area, its resistance is very high while in a bright area it resistance becomes very low. The LDR was used at the base of the transistor to control the base-emitter voltage as the light intensity changes. The LDR could be connected in two ways at the base, such that when light falls on it, it either turns ON the transistor or turns it OFF.

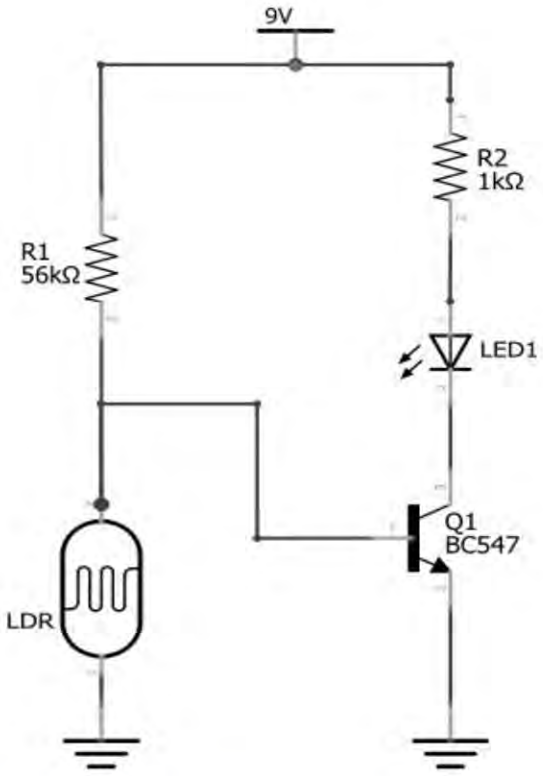
PROCEDURE:

(A) Testing the LDR

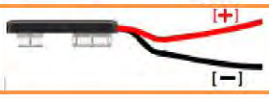
1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the selector to the Ohms section (Ω) and place it on the 200kΩ range.
2. Attach one end of the alligator clips to the probes of your multimeter and the other end to the LDR. Observe the reading on your multimeter.
3. Gently place your hand over the LDR without touching it and observe how the resistance increases as the light intensity goes down.
4. Turn the selector on your multimeter to a higher or lower range to be able to see measurement as the light intensity changes.

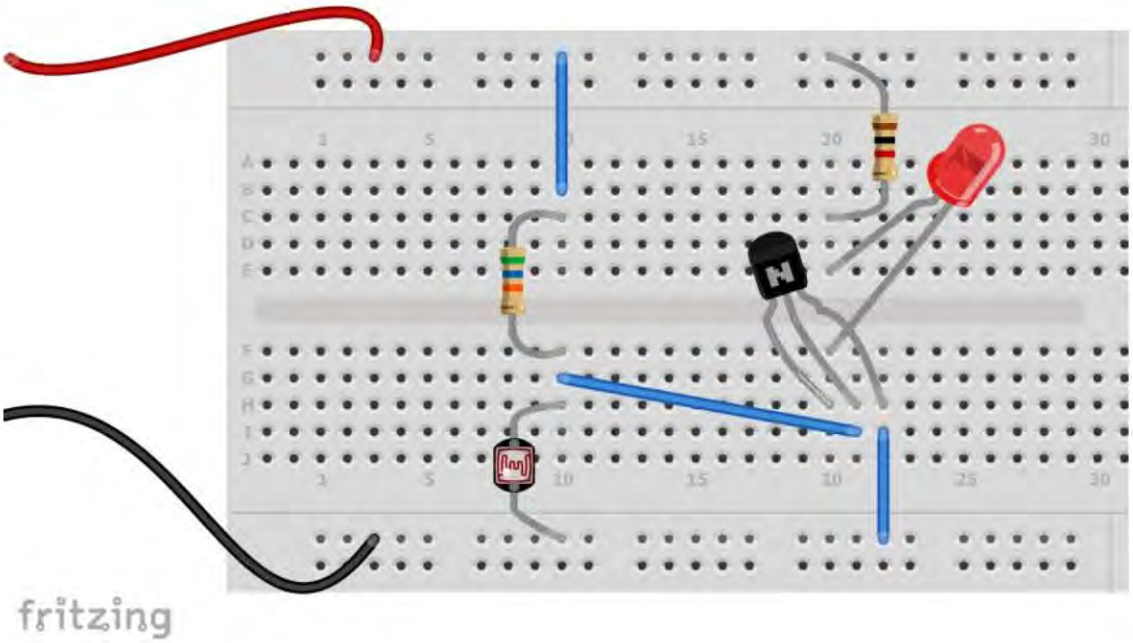
(B) Darkness Activated Switch

1. Set up the transistor circuit with the LDR base bias using the connection table below.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: BC547		Make connections as indicated in the breadboard connection column.	Q1(C) => H20 Q1(B) => H21 Q1(E) => H22	
Jumper wire1			J1(A) => W9 J1(B) => B10	
Jumper wire2			J2(A) => G10 J2(B) => I 21	
Jumper wire3			J3(A) => I 22 J3(B) => Y19	
Resistor1: 56kΩ Green, Blue, Orange			R1(A) => C10 R1(B) => F10	
Resistor2: 1k Ω Brown, Black, Red			R2(A) => W17 R2(B) => C20	

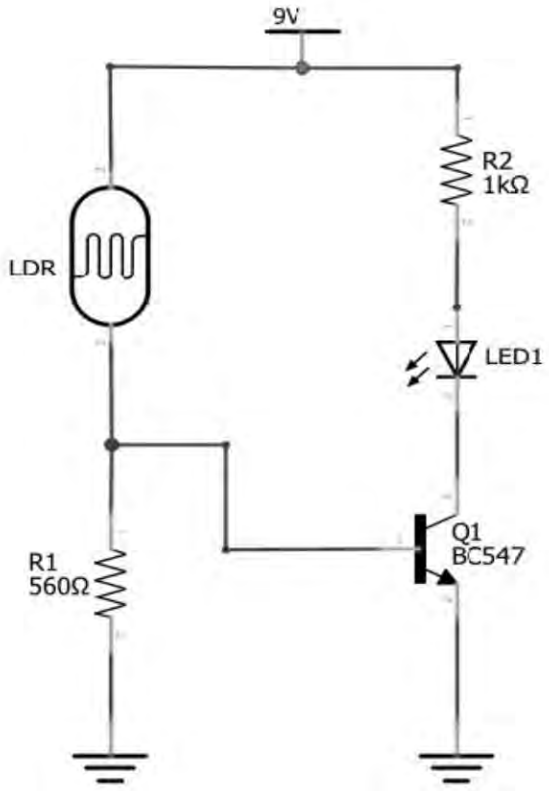
LDR 1			LDR1(A) =>H10 LDR1(B) => Y9	
LED1			LED1(A) =>E20 LED1(K) =>G20	
Battery Connector			Red(+) => W3 Black (-)=> Y3	

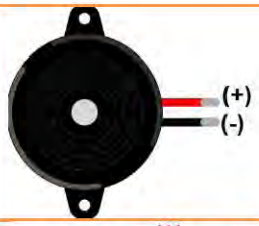


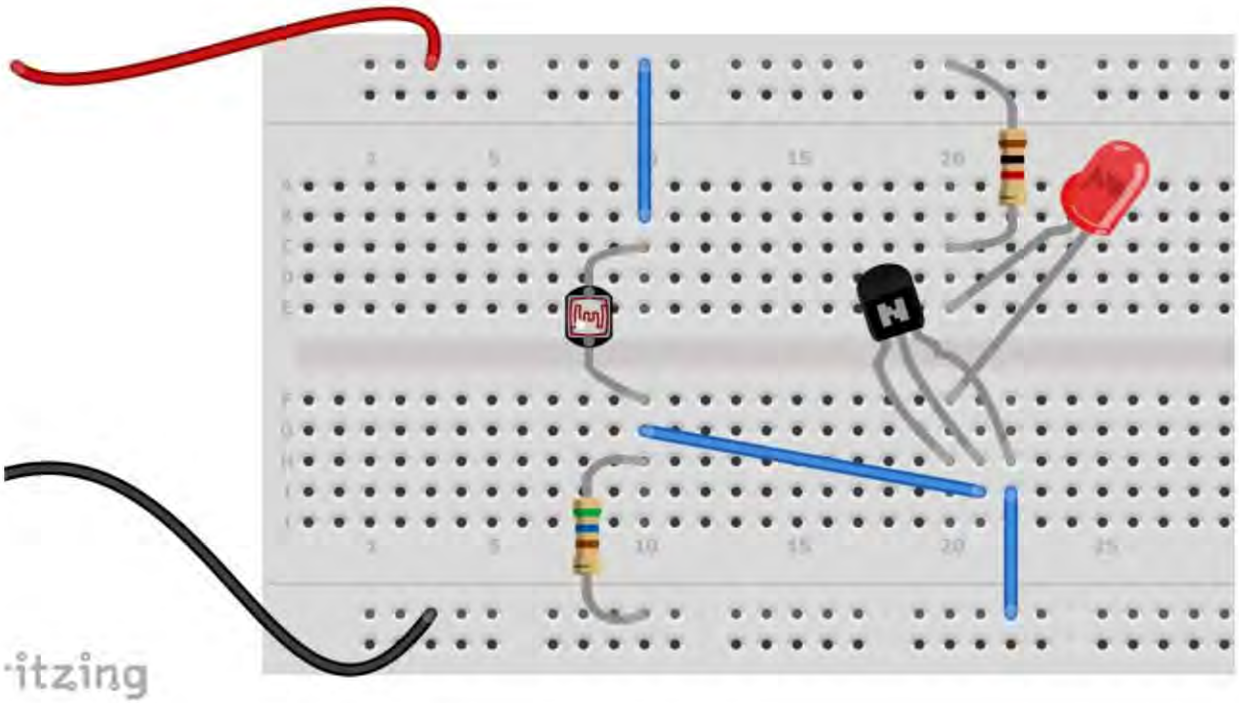
2. Place the setup on the breadboard in a bright area and the LED should go off.
3. Now hover your hand across the LDR and observe that the LED gets brighter as the LDR is covered.

(C) Light Activated Switch

1. Set up the transistor circuit with the LDR base bias using the connection table below.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor1: 560Ω Green, Blue, Brown		The resistor 1 and the LDR1 should be removed from previous setup before making this adjustment.	R1(A) => H10 R1(B) => Y9	This table is an adjustment to the previous table in section A.
LDR 1			LDR1(A) =>C10 LDR1(B) => F10	
BUZZER 1			B1 (+) =>W20 B1(-) => F20	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



2. Place the set up in a less bright area so that the LED does not glow.
3. Now, move the setup close to the window or a light source where the light intensity is higher and then the LED should start to glow bright.

FUTHER ACTIVITIES:

1. Connect a buzzer across the LED and observe how it responds to the light variations.
2. Learn how to draw the circuit diagram(s) in this experiment.
3. Practice the circuit set up on your own without using the connection table guide.
4. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
5. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 26: TEMPERATURE CONTROLLED SWITCH

AIM:

To construct a transistor switch that is controlled by a heat sensitive device.

MATERIALS:

- Digital Multimeter (1)
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Thermistor: 10kΩ NTC
- LED: Red (1), Yellow (1), Green (1), White (1) , blue (1)
- Resistors: 470Ω (1), 1kΩ (3), 100kΩ (1)
- Potentiometer: 100kΩ (1)
- Transistor: BC547 (2)
- Buzzer (1)
- Heat source: match stick, soldering iron, pressing iron, hot air blower e.t.c

BACKGROUND:

Transistor switch can be designed to be temperature controlled by using a temperature sensitive device to turn it ON or OFF. The heat sensitive device used in this experiment is a Negative Temperature Coefficient (NTC) Thermistor. The NTC resistance is the property that changes as it senses heat increase or decrease. For the NTC, as the temperature increases, its resistance value starts decreasing. It can be used to bias the transistor base in such a way that it either turns ON the transistor as the temperature increases or turns it OFF. A variable resistor is also used alongside the Thermistor so that it can help to determine a preset temperature to turn the transistor ON or OFF.

WARNING: Ensure to observe the following safety measures:

- This experiment requires adult support and supervision.
- Handle any heat source with care and observe personal safety at all times.
- Keep all wires and component away from the Thermistor before heating.
- Allow the Thermistor cools off before touching it to avoid blisters or burn.

PROCEDURE:

(A) Testing the Thermistor

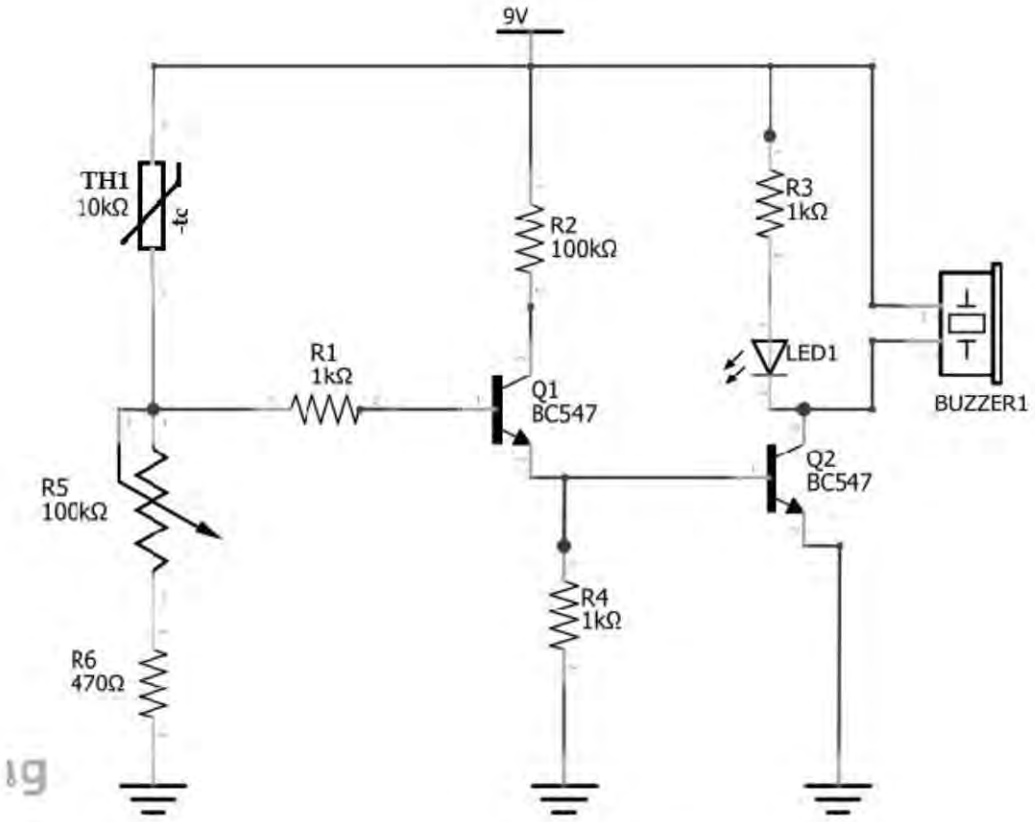
1. Plug the black lead of the multimeter into the COM port and the red lead to VΩmA port. Move the selector to the Ohms section (Ω) and place it on the 20kΩ range.
2. Attach one end of the alligator clips to the probes of your multimeter and the other end to the Thermistor. Observe the reading on your multimeter.

NOTE: The resistance reading on the multimeter when the Thermistor is not heated should be close to the value given by the manufacture.

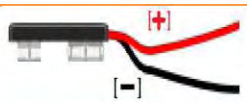
3. Now place the Thermistor in a place where it can be heated and then gently heat it up with one of the listed heat sources at the material section of this experiment. Observe safety at all times.
4. Observe the resistance reading decreasing on the multimeter as the temperature increases. You may need to turn the selector to a lower range to get the reading as it decreases.

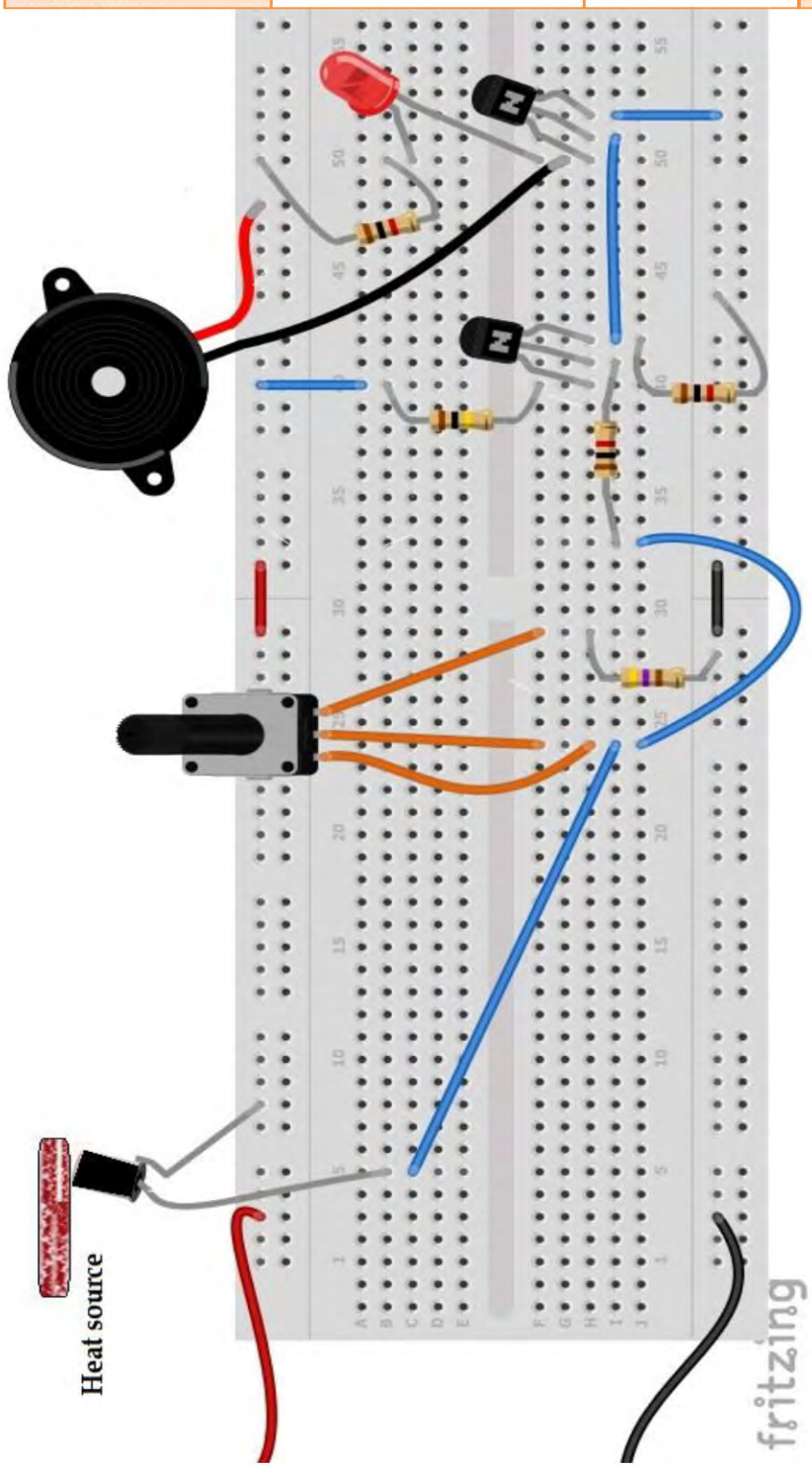
(B) Temperature Increase Turned ON Switch

1. Set up the transistor switch that is turned ON when the temperature increases. Use the connection table for setting up the circuit.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: BC547		Make connections as indicated in the breadboard connection column.	Q1(C) => H40 Q1(B) => H41 Q1(E) => H42	
Transistor 2: BC547			Q2(C) => H50 Q2(B) => H51 Q2(E) => H52	
Resistor1: 1k Ω Brown, Black, Red			R1(A) => I 33 R1(B) => I 41	
Resistor2:100k Ω Brown, Black, Yellow			R2(A) => B40 R2(B) => G40	
Resistor3: 1k Ω Brown, Black, Red			R3(A) => B50 R3(B) => W41	
Resistor4: 1k Ω Brown, Black, Red			R4(A) => J42 R4(B) => Y36	
Resistor5:100k Ω Potentiometer			R5(A) => H24 R5(B) => F24 R5(C) => F29	
Resistor6: 470 Ω Yellow, Purple, Brown			R6(A) => H29 R6(B) => Y24	
Thermistor1: 10k NTC			TH1(A) =>B5 TH1(B) => W7	
LED1			LED1(A)=>C50 LED1(K) => F50	
BUZZER 1			B1(+) => W40 B1(-) => G50	
Jumper wire1			J1(A) => C5 J1(B) => I 24	
Jumper wire2			J2(A) => J24 J2(B) => J33	
Jumper wire3			J3(A) => A40 J3(B) => W33	
Jumper wire4			J4(A) => I 42 J4(B) => I 51	
Jumper wire5			J5(A) => I 52 J5(B) => Y43	
Jumper wire6			J6(A) => W25 J6(B) => W26	
Jumper wire7			J7(A) => Y25 J7(B) => Y26	

Battery Connector			Red(+) => W3 Black (-)=> Y3	



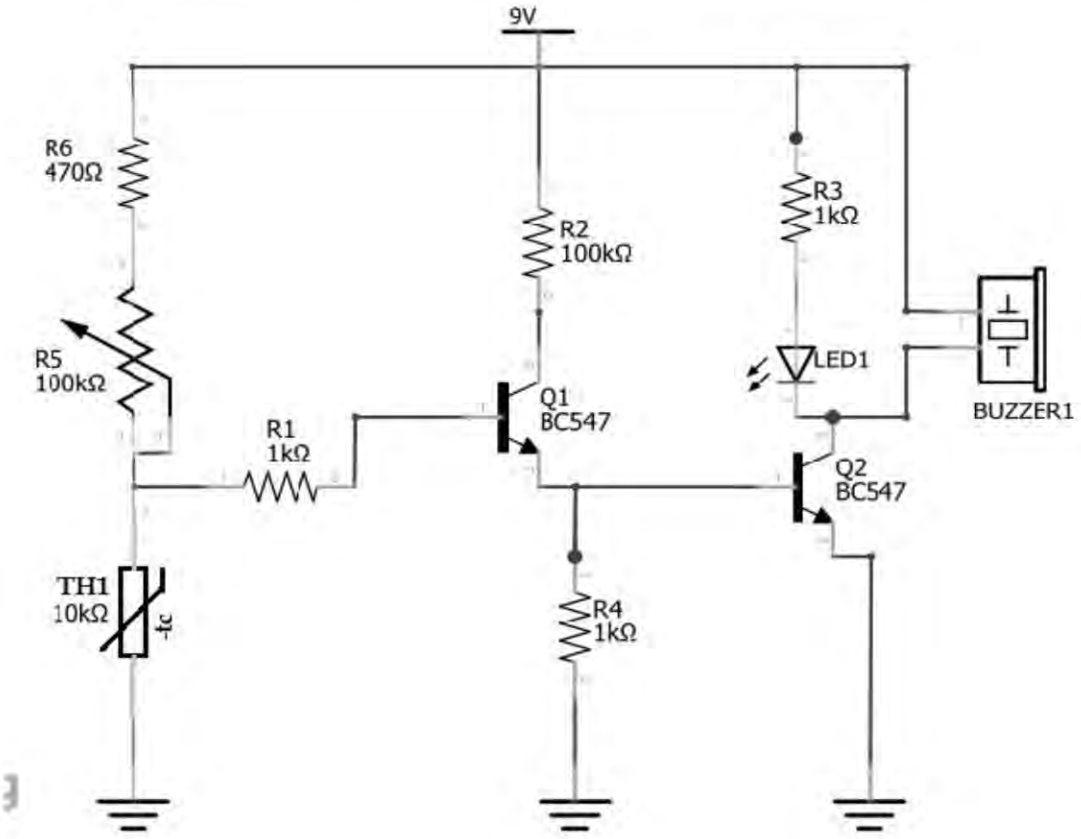
2. Using your potentiometer, gently adjust the LED and buzzer to a point where it is just about to start giving light or sound respectively. (The LED and the buzzer should start glowing and giving off sound when the Thermistor is heated).
3. Now with your heat source place on the Thermistor, heat it up for about 30 sec (depending on the kind of heating source used) so that the temperature would increase. Observe how the LED and buzzer gradually start giving light and sound as the temperature increases.
4. Remove the heat source from the Thermistor once the LED and the buzzer have been turned ON

NOTE: Observe that as the Thermistor temperature drops the LED and buzzer starts becoming dim and sounding lower.
To fast track the cool process for the Thermistor, touch it with a heat sink or damp piece of cloth.

5. Repeat the process on procedure 3 all over again and observe the NOTE.

(C) Temperature Increase Turned OFF Switch

1. Set up the transistor switch that is turned OFF when the temperature increases. Use the connection table for setting up the circuit.

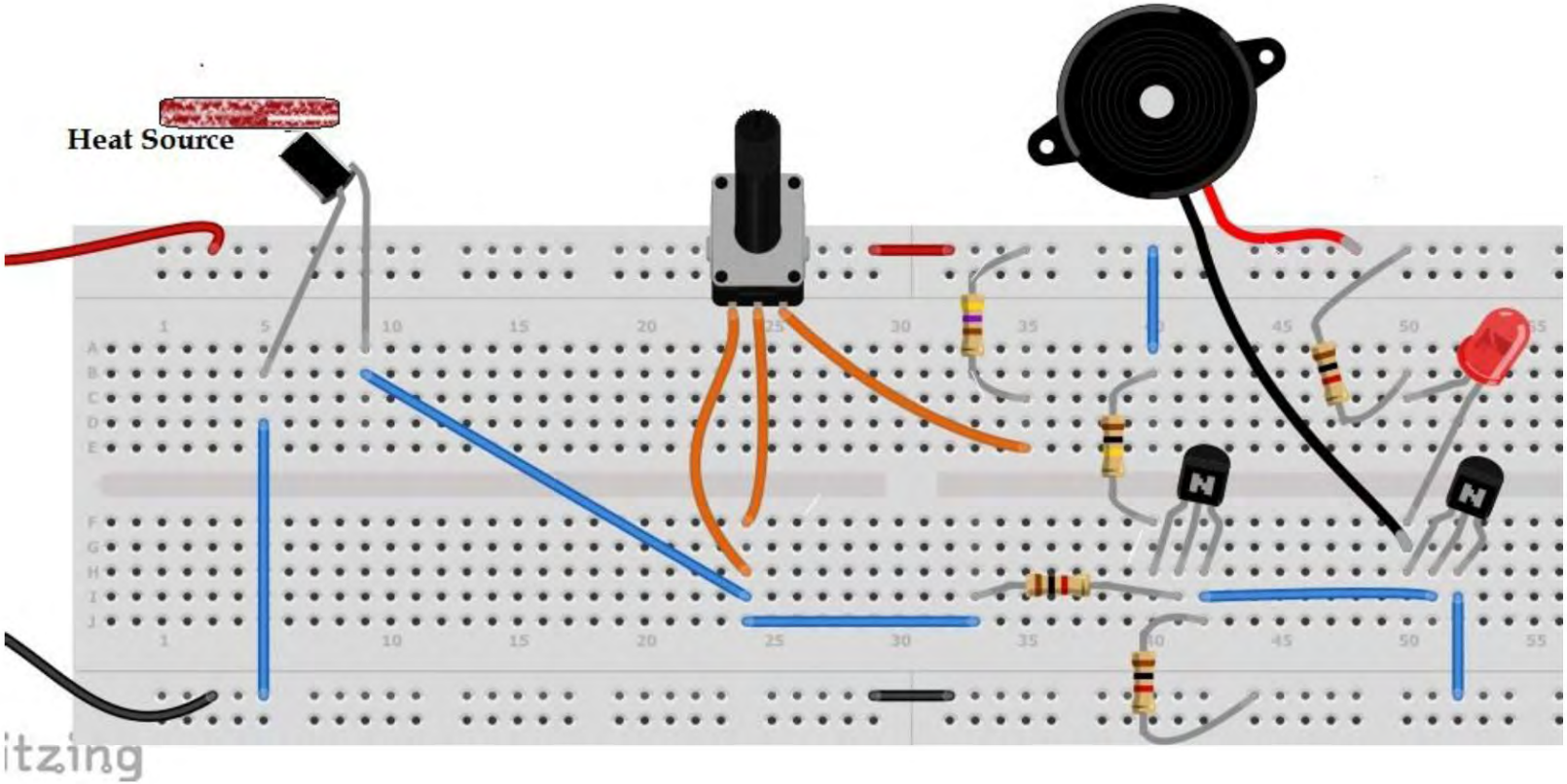


Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Thermistor1: 10k NTC		The Thermistor 1, resistor 5, resistor 6 and jumper wire 1 should be removed before making this adjustment.	TH1(A) =>B5 TH1(B) =>A9	This table is an adjustment to the previous table in section B.
Resistor5:100k Ω Potentiometer			R5(A) => H24 R5(B) => F24 R5(C) => E35	
Resistor6: 470 Ω Yellow, Purple, Brown			R6(A) =>C35 R6(B) => W29	
Jumper wire1			J1(A) => B9 J1(B) => I 24	
Jumper wire6			J6(A) => D5 J6(B) => Y5	
Battery Connector			Red(+) => W3 Black (-)=> Y3	

2. Using your potentiometer, gently adjust the LED and buzzer to a point where it is just about to be turned OFF but still giving light or sound respectively. (The LED and the buzzer should stop glowing and giving off sound when the Thermistor is heated).
3. Now with your heat source place on the Thermistor, heat it up for about 30 sec (depending on the kind of heating source used) so that the temperature would increase. Observe how the LED and buzzer gradually stop giving light and sound as the temperature increases.
4. Remove the heat source from the Thermistor once the LED and the buzzer have been turned OFF.

NOTE: Observe that as the Thermistor temperature drops the LED and buzzer starts becoming bright and sounding louder.
To fast track the cool process for the Thermistor, touch it with a heat sink or damp piece of cloth.

5. Repeat the process on procedure 3 all over again and observe the NOTE.


Heat Source
itzing

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 27: TRANSISTOR MOTION DETECTOR

AIM:

To construct a transistor circuit that detects motion in a location using an infrared source and receiver.

MATERIALS:

- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Infrared LED (1)
- Photodiode (1)
- LED: Red (1), Yellow (1), Green (1), White (1) , blue (1)
- Resistors: 220kΩ (1), 470Ω (1), 1kΩ (1), 3.3kΩ (1), 100kΩ (1)
- Potentiometer: 100kΩ (1)
- Transistor: BC547 (2)
- Buzzer (1)

BACKGROUND:

Infrared light is not visible to the unaided human eye but can be visually detected by infrared capable instruments. For the domestic detection, one could use the cameras found on mobile phones to see such radiation. It is used for wireless applications for sensing and line of sight remote control when used together with the infrared receiver. This experiment operates in a way that if any object passes between the source and the receiver, it break the radiation connection between them and thus detects an object is passing through a point. The resistance of the infrared receiver changes with the intensity of the infrared radiation falling on it, thereby could be use to bias the transistor to turn it ON or OFF as a switch.

PROCEDURE:

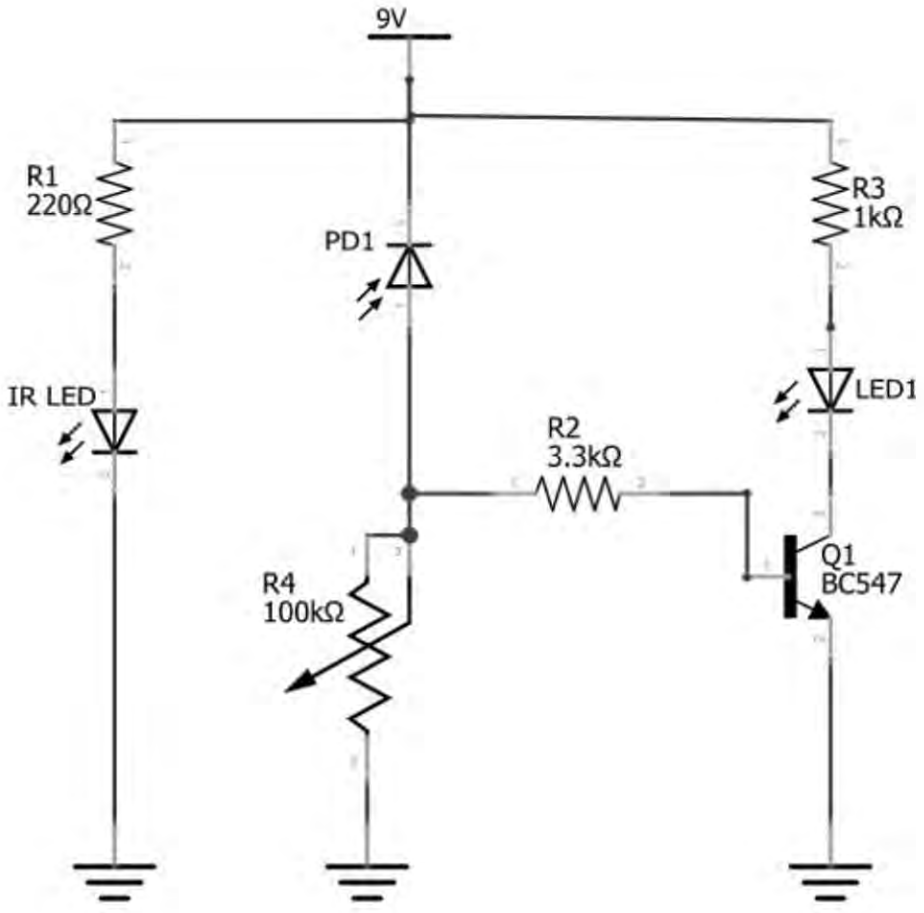
(A) Motion Detector 1

1. Set up the circuit below for detecting motion using the connection table below.

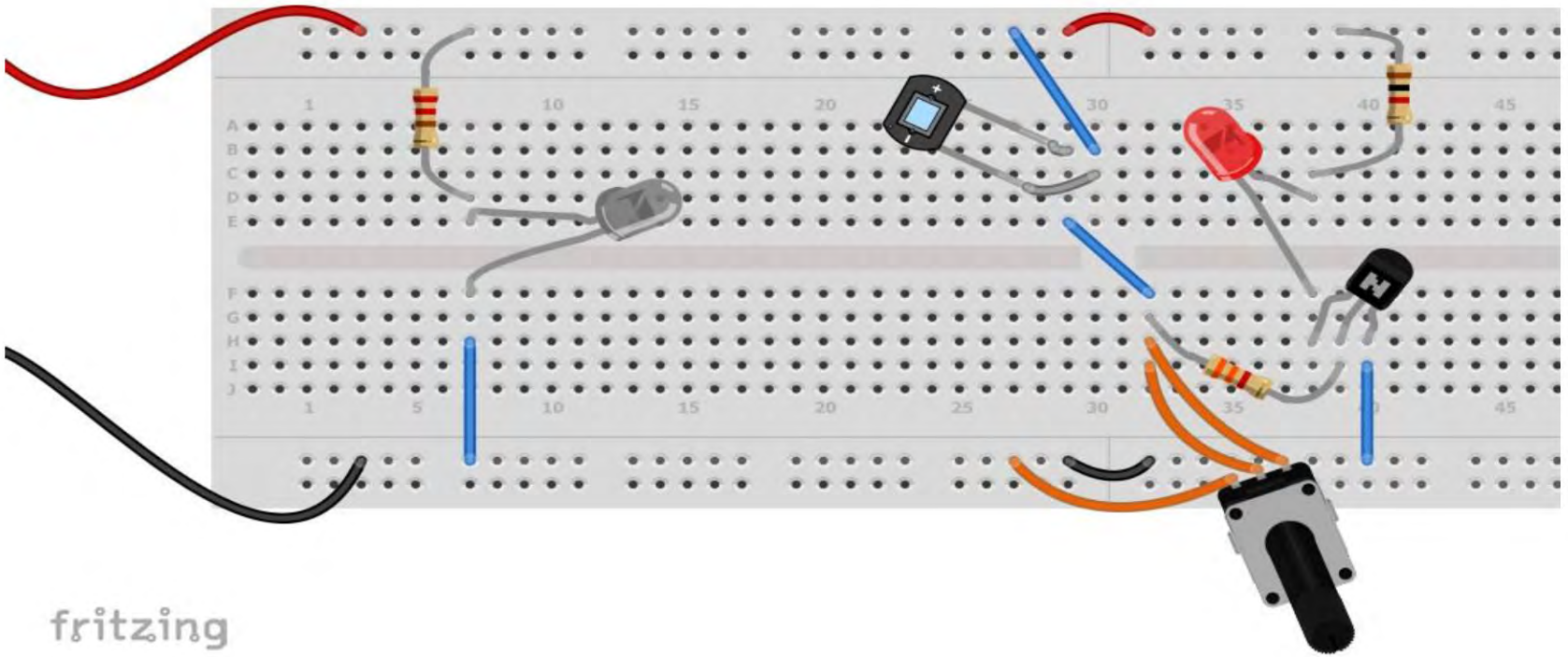
NOTE: Perform this experiment in a room with less illumination in order to get the best result.

2. Now gently rotate the shaft of the potentiometer so that the LED starts glowing.
3. Slowly move your hand or an object between the infrared LED and the photodiode and observe that the LED will stop glowing as your hand or the object passes through.

NOTE: If the LED is still glowing a little while an object is between the infrared LED and the photodiode, then turn the potentiometer so that the LED goes OFF while the object is still between them.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor1: 220Ω **Red, Red, Brown**		The radiation from the infrared LED can be detected using a mobile phone camera when tested with the multimeter diode tester. Bend the infrared source so that it is directly facing the receiver on your breadboard.	R1(A) => D7 R1(B) => W6	Ensure that the photosensitive part of the receiver is directly facing the infrared source.
Infrared LED 1			IR1(A)=>E7 IR1(K)=>F7	
Jumper wire1			J1(A) => H7 J1(B) => Y6	
Transistor 1: **BC547**			Q1(C) => H38 Q1(B) => H39 Q1(E) =>H40	
Jumper wire2			J2(A) => B30 J2(B) => W23	
Jumper wire3			J3(A) => E29 J3(B) => F32	
Jumper wire4			J4(A) => I 40 J4(B) => Y33	
Jumper wire5			J5(A) => W25 J5(B) => W26	
Jumper wire6			J6(A) => Y25 J6(B) => Y26	
Resistor2: 3.3kΩ **Orange, Orange, Red**			R2(A) => G32 R2(B) => I 39	
Resistor3: 1k Ω **Brown, Black, Red**			R3(A) =>C38 R3(B) =>W32	
Resistor4:100k Ω **Potentiometer**			R4(A) => H32 R4(B) => I 32 R4(C) => Y23	
LED1			LED1(A)=>D38 LED1(K) =>F38	
Photodiode			PD1(A) => B29 PD1(K) => C30	
Battery Connector			Red(+) => W3 Black (-)=> Y3	


fritzing

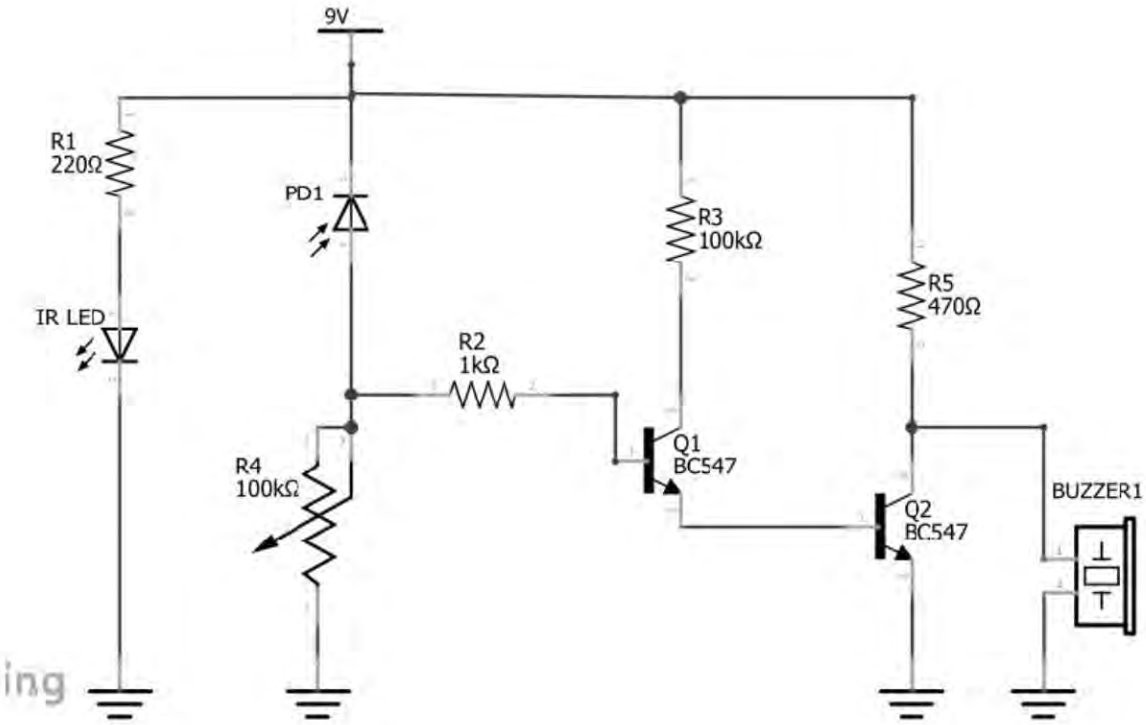
(B) Motion Detector 2

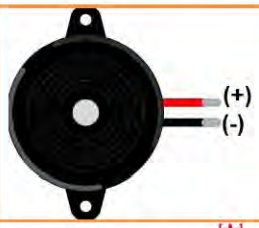
1. Set up the circuit below for detecting motion using the connection table below.

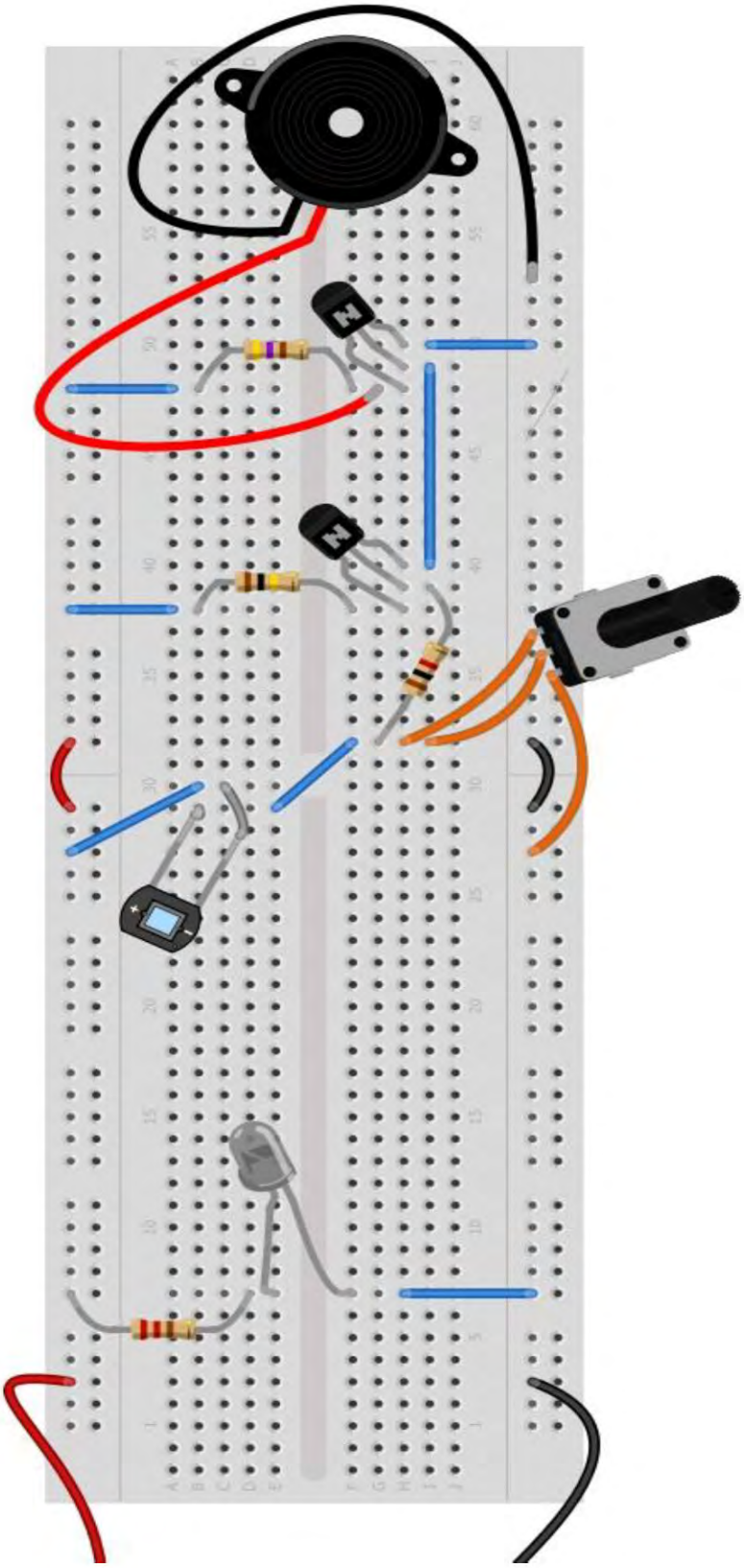
NOTE: Perform this experiment in a room with less illumination in order to get the best result.

2. Now gently rotate the shaft of the potentiometer so that the buzzer is not giving any sound.
3. Slowly move your hand or an object between the infrared LED and the photodiode and observe that the buzzer will start sounding as your hand or the object passes through.

NOTE: If the buzzer does not give a sound while an object is between the infrared LED and the photodiode, then turn the potentiometer so that the buzzer starts giving out sound while the object is still between them.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Resistor2: 1k Ω **Brown, Black, Red**		The LED, resistor 2, resistor 3 and the jumper wire 4 should be removed before making this adjustment.	R2(A) =>G32 R2(B) =>I 39	This table is an adjustment to the previous table in section A.
Resistor3:100k Ω **Brown, Black, Yellow**			R3(A) => B38 R3(B) => F38	
Transistor 2: **BC547**			Q2(C) => H48 Q2(B) =>H49 Q2(E) =>H50	
Jumper wire4			J4(A) => I 40 J4(B) => I 49	
Jumper wire5			J5(A) => I 50 J5(B) => Y41	
Jumper wire6			J6(A) => A48 J6(B) => W40	
Jumper wire7			J7(A) => A38 J7(B) => W31	
Jumper wire8			J8(A) => W25 J8(B) => W26	
Jumper wire9			J9(A) => Y25 J9(B) => Y26	
Resistor5: 470 Ω **Yellow, Purple, Brown**			R5(A) => B48 R5(B) => F48	
BUZZER 1			B1 (+) =>G48 B1(-) => Y44	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 28: LIGHT FLASHER

AIM:

To construct a transistor circuit that flashes two LEDs without any external input

MATERIALS:

- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Transistor: BC547 (2)
- LED: Red (2), Yellow (2), Green (2), White (2) , blue (2)
- Resistors: 470Ω (2), 47kΩ (2)
- Capacitor: 1µF (2), 4.7µF (2), 10µF (2)

BACKGROUND:

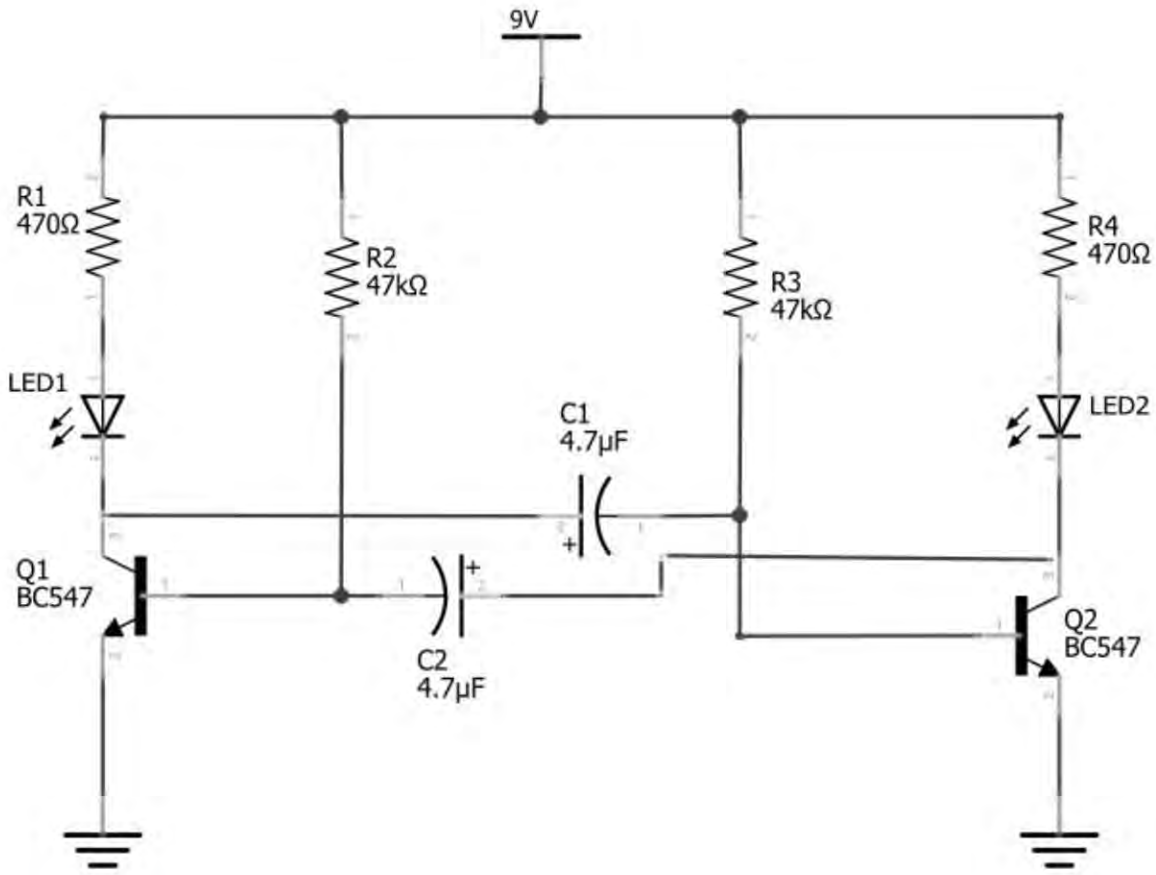
This light flasher is a circuit called Astable multivibrator or a free running multivibrator. It is one the three types of multivibrators, others include: Monostabe and Bistable multivibrators. The astable multivibrator continuously switch the transistors between the cut-off and the saturation mode so that the output is almost zero at one time and at a later time it turns the output high. It uses two transistors whose output alternates between the cut-off and saturation in opposite fashion. When transistor 1 is ON, transistor 2 is OFF likewise when transistor 1 is OFF, the transistor 2 is ON. The transistor switching is controlled by two capacitors connected to their bases so that the charging and discharging of the capacitors bias the transistor to different modes. The period or rate at which the transistors change state is determined by the time constant (τ) of the base resistance and capacitance for each transistor.

PROCEDURE:

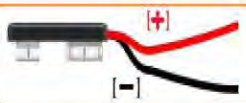
1. Set up the light flasher circuit using the connection table.

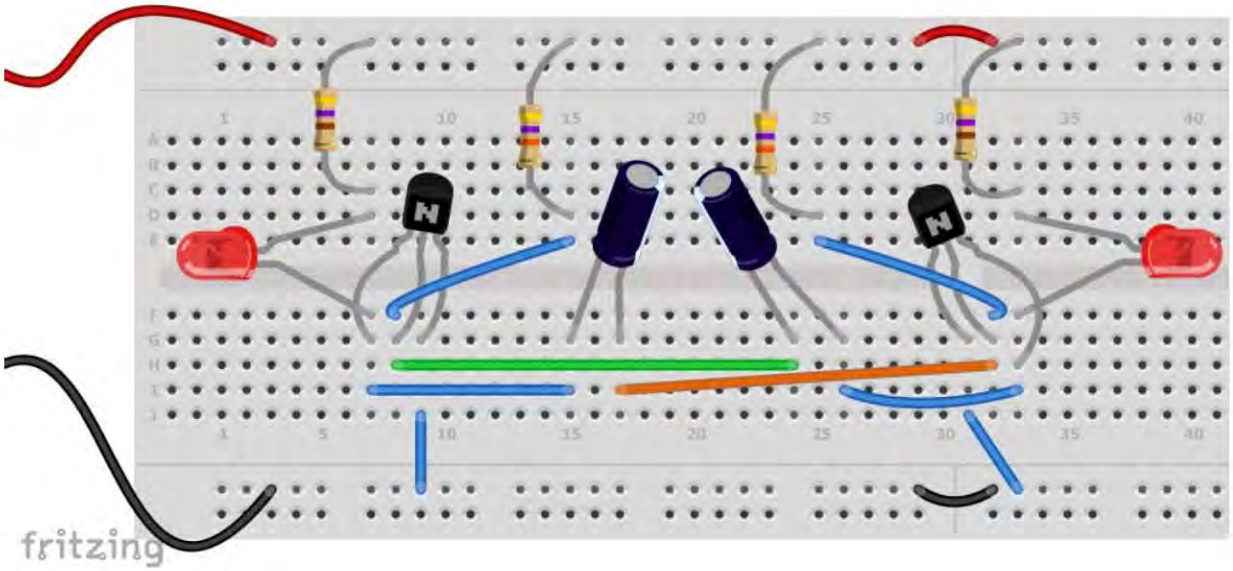
NOTE: Once the power supply is connected to the completed circuit, the led should start flashing immediately.

2. Replace the 4.7µF with the 1µF and the 10µF capacitors and observe how the flashing time changes.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: BC547		Make connections as indicated in the breadboard connection column.	Q1(C) => G7 Q1(B) => G8 Q1(E) => G9	The transistor 2 pins has been reversed when placing it on the breadboard, that is, the curved part is now facing you and the pins from left to right are now, emitter (E), base (B) and collector (c).
Transistor 2: BC547			Q2(E) => G31 Q2(B) =>G32 Q2(C) =>G33	
Resistor1: 470 Ω Yellow,Purple, Brown			R1(A) => C7 R1(B) => W6	
Resistor2: 47k Ω Yellow,Purple,Orange			R2(A) => D15 R2(B) => W13	
Resistor3: 47k Ω Yellow, Purple, Orange			R3(A) => D25 R3(B) => W21	
Resistor4: 470 Ω Yellow, Purple, Brown			R4(A) => C33 R4(B) => W27	
LED1			LED1(A) =>D7 LED1(K) => F7	

LED2			LED2(A) =>D33 LED2(K) =>F33	
Capacitor1:4.7*μF* 25V			C1(+) => G15 C1(-) => G17	
Capacitor2: 4.7*μF* 25V			C2(+) =>G26 C2(-) =>G24	
Jumper wire1			J1(A) => F8 J1(B) => E15	
Jumper wire2			J2(A) => I 7 J2(B) => I15	
Jumper wire3			J3(A) => H9 J3(B) => Y8	
Jumper wire4			J4(A) => E25 J4(B) => F32	
Jumper wire5			J5(A) => I 26 J5(B) => I 33	
Jumper wire6			J6(A) => H31 J6(B) => Y27	
Jumper wire7			J7(A) => H8 J7(B) => I 24	
Jumper wire8			J8(A) => I 17 J8(B) => H32	
Jumper wire9			J9(A) => W25 J9(B) => W26	
Jumper wire10			J10(A) => Y25 J10(B) => Y26	
Battery Connector			Red(+) => W3 Black (-)=> Y3	



FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 29: SIMPLE AUDIO AMPLIFIER

AIM:

To construct a transistor circuit that can amplify audio signals

MATERIALS:

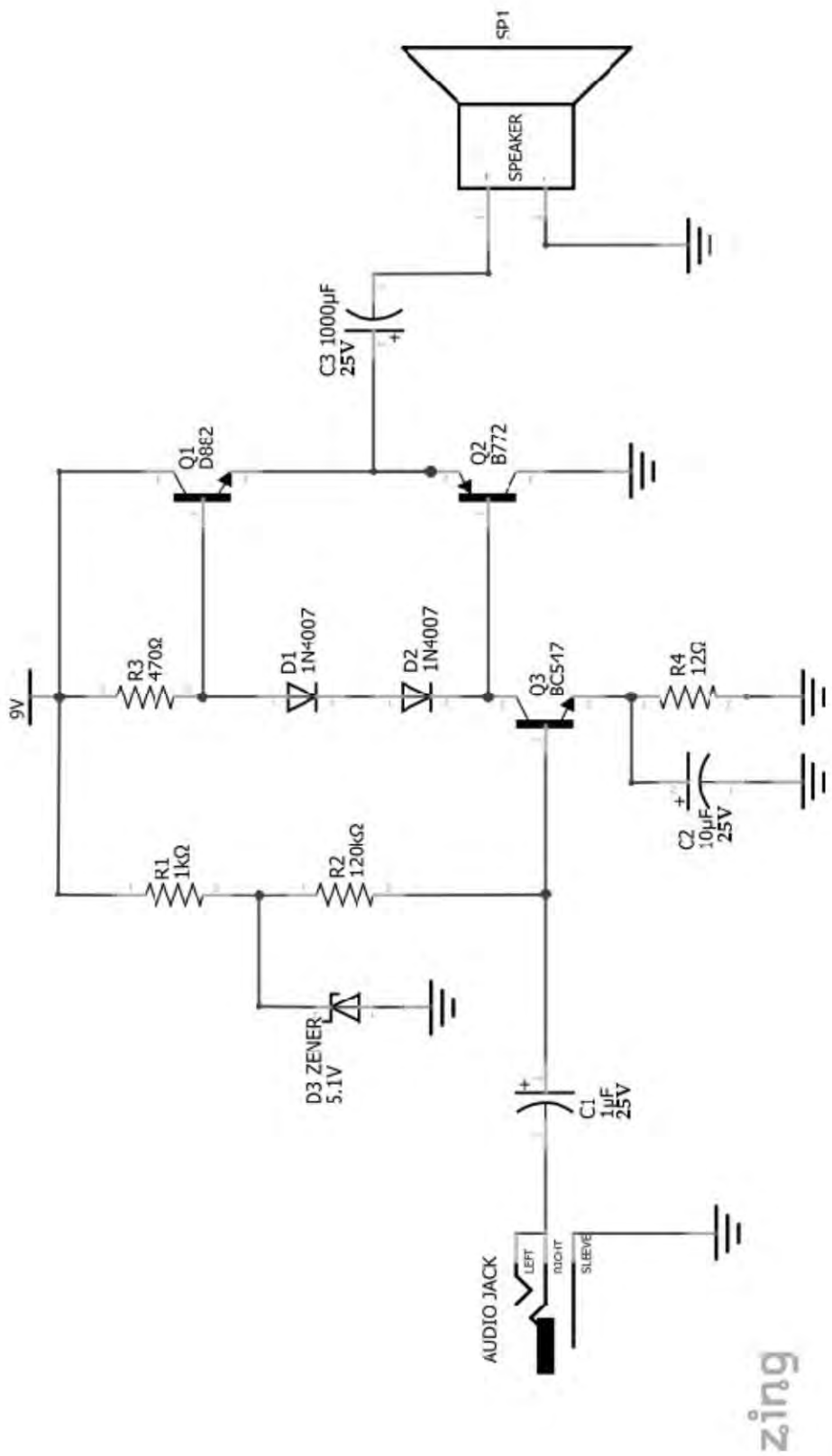
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Zener diode: 5.1V (1)
- Diode (2)
- Transistor: BC547 (1), D882 (1), B772 (1)
- Resistors: 470Ω (2), 47kΩ (2)
- Capacitor: 1µF (1), 10µF (1), 100µF (1), 1000µF (1)
- Audio jack socket (1)
- Audio jack cable (1)
- Speaker: 8Ω, 0.5W (1)

BACKGROUND:

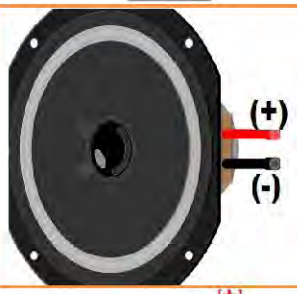
The amplifier is used to increase the amplitude of a signal input sent to it. An audio amplifier is used to amplify signals with the speech frequency of human, that is, $20H_Z \ to \ 20KH_Z$. The human voice alone can only reach some few meters at most, but with an amplifier system, it can be projected to several hundreds of meters. This experiment consists of three transistors; one drive (transistor 3) and two output (transistor 1 and 2) stage. The drive stage is for maximum voltage amplification while the output stage is to ensure maximum power amplification. The output is a combination of an NPN and PNP transistors joined at their emitters and used as a common-collector configuration usually referred to as Push-Pull. When transistor 1 conducts the positive signal the transistor 2 conducts the negative signals. The two diodes at the output transistor base are used to bias them to conduct a little before the signal is applied. The capacitors 1 and 3 are used for coupling purposes to allow only AC to pass through while the capacitor 2 is used for bypassing the emitter resistor of transistor 3.

PROCEDURE:

1. Set up the transistor amplifier circuit shown using the connection table below.

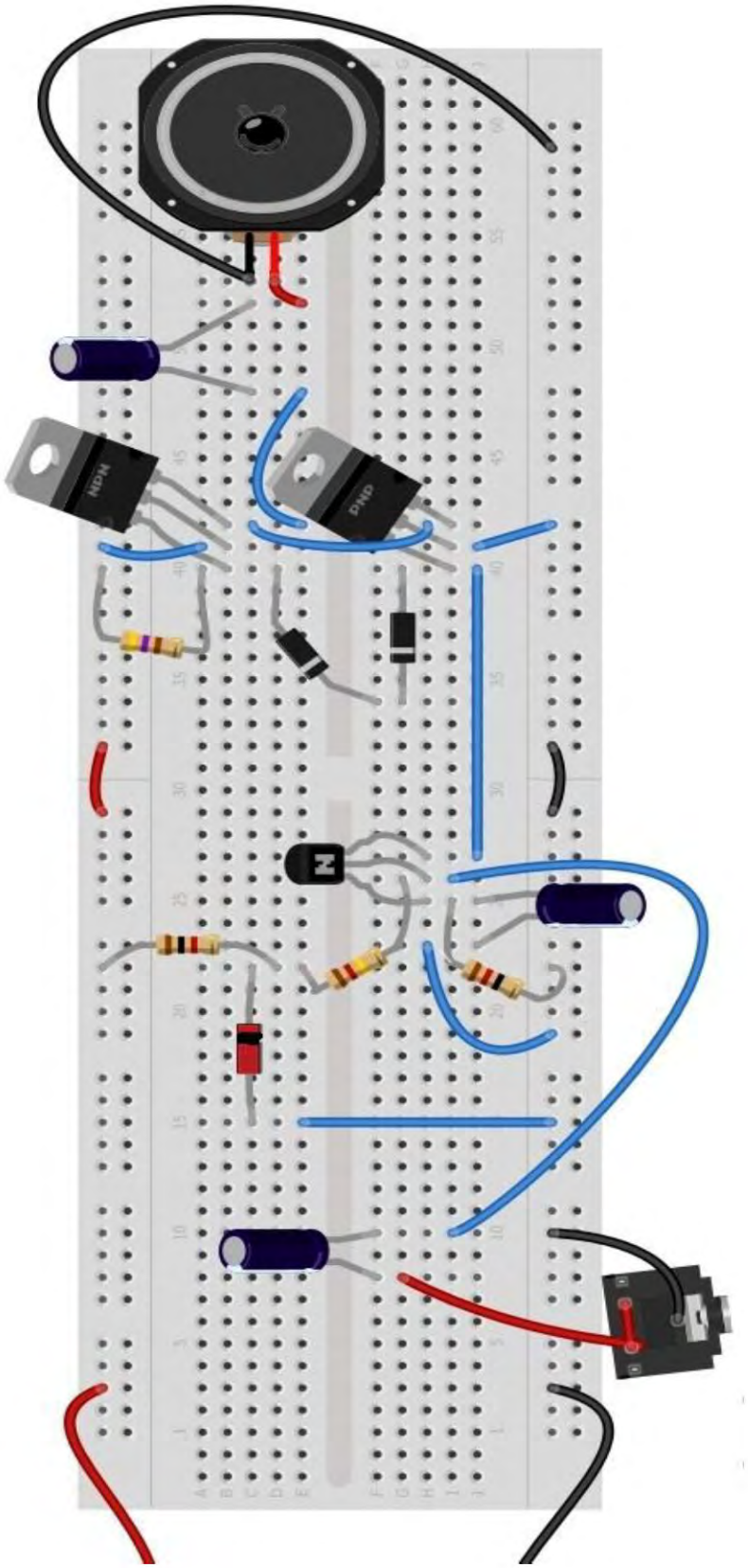

SP1
SPEAKER
C3 1000µF
25V
Q1
D882
Q2
B772
9V
R3
470Ω
D1
1N4007
D2
1N4007
Q3
BC547
R4
12Ω
C2
10µF
25V
R1
1kΩ
R2
120kΩ
D3 ZENER
5.1V
C1
1µF
25V
AUDIO JACK
LEFT
SLEEVE

Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: D882			Q1(B) => B40 Q1(C) =>B41 Q1(E) =>B42	The transistors pins has been reversed when placing it on the breadboard, that is, the metallic part is now facing you and the pins from left to right are now; base (B), collector (c) and emitter (E).
Transistor 2: B772			Q2(B) => I 40 Q2(C) =>I 41 Q2(E) =>I 42	
Transistor 3: BC547			Q3(E) => H25 Q3(B) => H26 Q3(C) => H27	
Resistor1: 1k Ω Brown, Black, Red			R1(A) => D22 R1(B) => W19	
Resistor2:120k Ω Brown, Red, Yellow			R2(A) => E22 R2(B) => G26	
Resistor3: 470 Ω Yellow, Purple, Brown			R3(A) => A40 R3(B) => W33	
Resistor4: 12 Ω Brown, Red, black			R4(A) => I 25 R4(B) => Y19	
Diode 1 (Rectifier)			D1(A) => D40 D1(K) => F34	
Diode 2 (Rectifier)			D2(A) => G34 D2(K) => G40	
Diode3: Zener (5.1V)			D3(A) => C15 D3(K) => C22	
Jumper wire1			J1(A) => A41 J1(B) => W34	
Jumper wire2			J2(A) => C42 J2(B) => H42	
Jumper wire3			J3(A) => E42 J3(B) => E48	
Jumper wire4			J4(A) => J41 J4(B) => Y35	
Jumper wire5			J5(A) => J27 J5(B) => J40	
Jumper wire6			J6(A) => H23 J6(B) => Y16	
Jumper wire7			J7(A) => E15 J7(B) => Y13	
Jumper wire8			J8(A) => I 10 J8(B) => I 26	
Jumper wire9			J9(A) => W25	

			J9(B) => W26	
Jumper wire10			J10(A) => Y25 J10(B) => Y26	
Capacitor1: 1μF 25V			C1(+) => F10 C1(-) => F8	
Capacitor2: 10μF 25V			C2(+) => J25 C2(-) => J23	
Capacitor3: 1000μF 25V			C3(+) => C48 C3(-) => C52	
Audio Jack Connector1			JC1(+) => H8 JC1(-) => Y9	
Loudspeaker1: 8 Ω, 0.5W			LS1(+) =>E52 LS1(-) =>Y49	
Battery Connector			Red(+) => W3 Black (-)=> Y3	

2. Connect the audio cable to jack socket on your breadboard and then connect it to a mobile phone jack socket or any other device that can be used as input.
3. Replace the 1000µF with the 100µF and observe the changes in the frequency of the output.

NOTE: Keep the input signal low enough so that it does not give cracking sound as the battery gets drained.
Check your battery voltage to ensure it is not less than 9V in order to get the best results from the circuit.


NPN
PNP

FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

EXPERIMENT 30: TRANSISTOR H-BRIDGE

AIM:

To construct a transistor circuit that can control the direction of rotation of a DC motor.

MATERIALS:

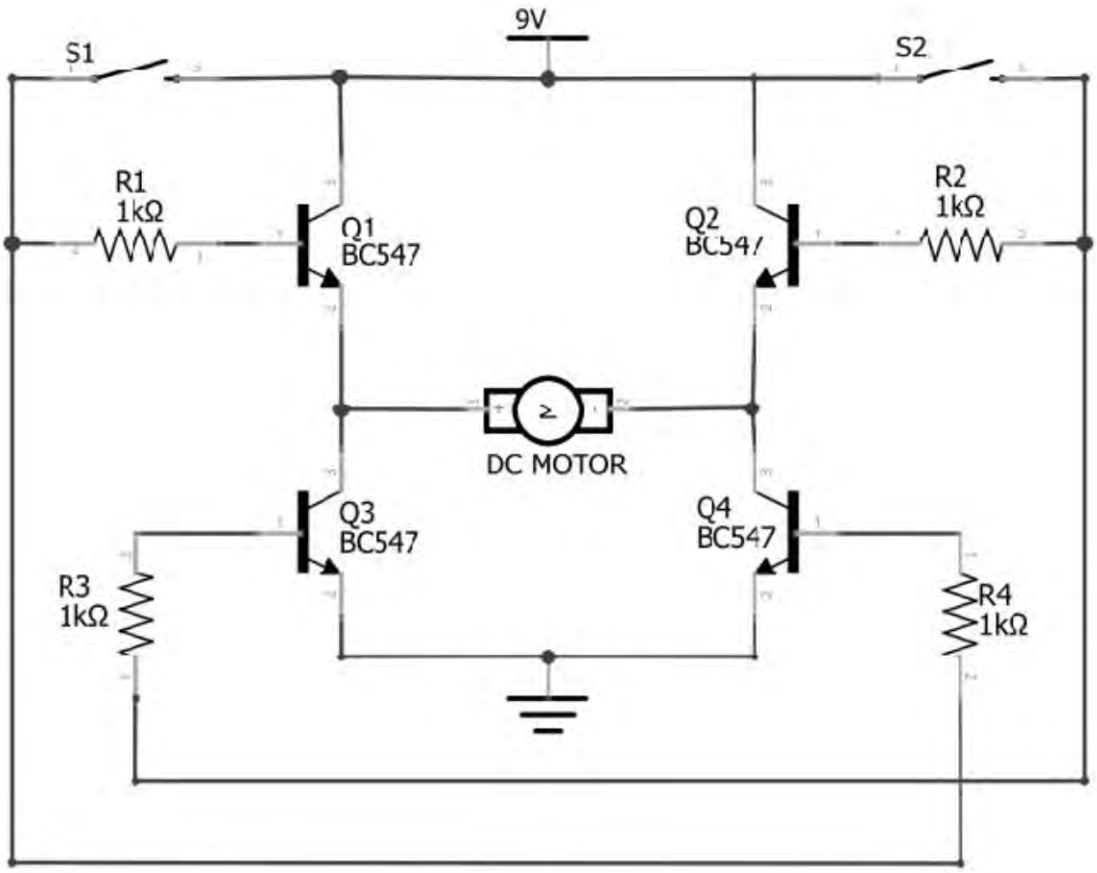
- Breadboard (1)
- 9V battery pack (1)
- Jumper wires
- Transistor: BC547 (4)
- Resistors: 1kΩ (4)
- DC motor (1)
- Press button switch (2)

BACKGROUND:

A transistor H-bridge is a circuit arrangement of four transistors that can fully control the rotation direction and speed of a DC motor. It derives its name from the arrangement of transistors which looks like the letter "H". It achieves the direction control by providing a path through which current can flow in one direction through the DC motor and then in the opposite direction. It also enables speed control by interrupting the current through the DC motor at a specific frequency so that the resultant current flow leads to a reduced speed. Two transistors are turned ON at a time to achieve the forward or reverse motion. When only switch 1 is closed, then transistors 1 and 4 start to conduct. When only switch 2 is closed, then transistors 2 and 3 start to conduct. The four resistors are used to set a limit the maximum current that will flow into the transistor bases.

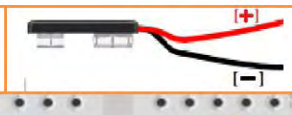
PROCEDURE:

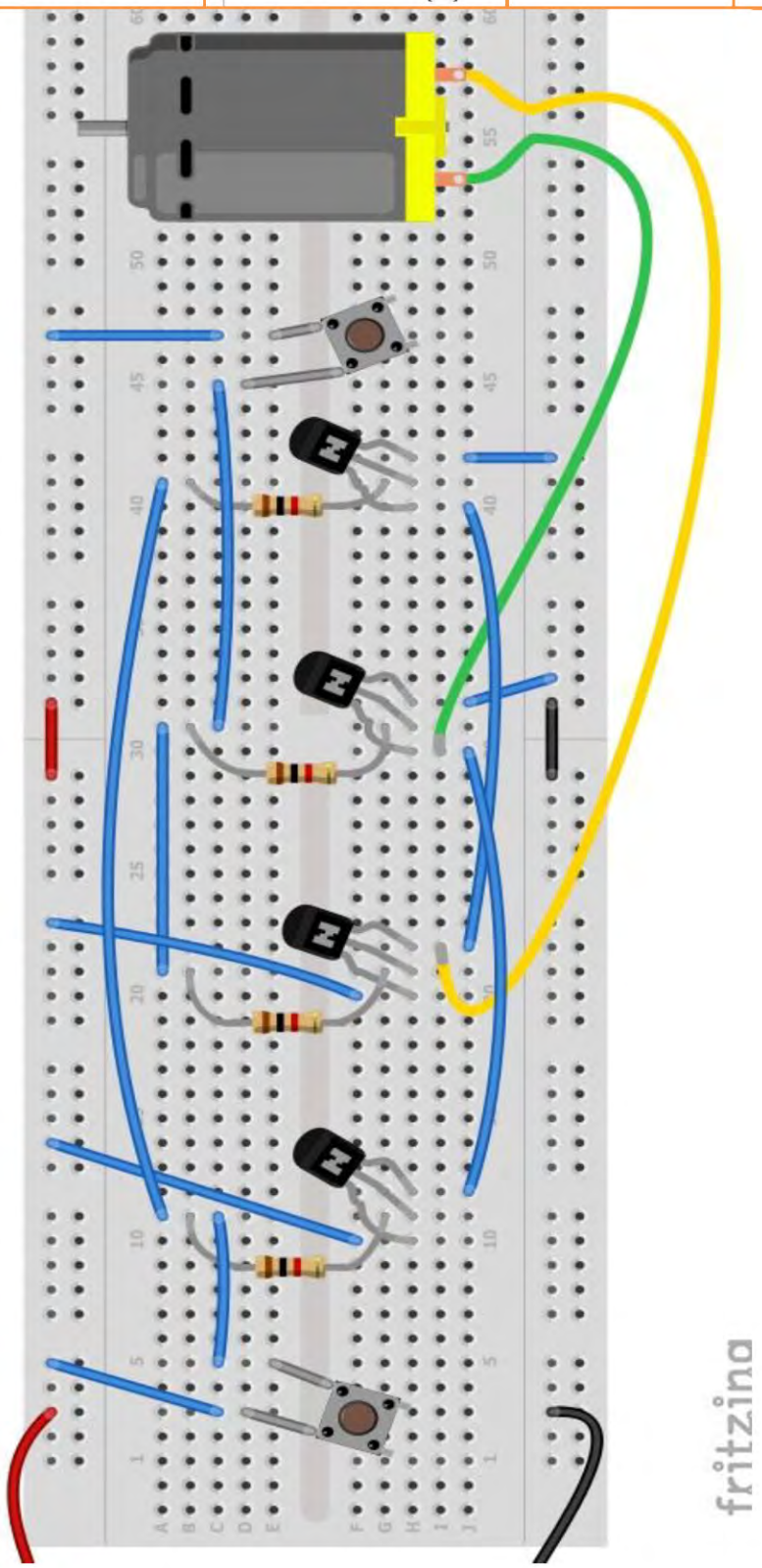
1. Set up the transistor H-bridge circuit shown using the connection table below.
2. Press the button on switch 1 only and then switch 2 only and observe the rotation of the DC motor.
3. Now press down switch 1 and then press switch 2 at intervals of 0.5 sec or less to gradually slow down the speed.



Component Name and Value	Component Image and Label	Connection Description	Breadboard Connection	Note
Transistor 1: BC547		Make connections as indicated in the breadboard connection column.	Q1(C) =>H10 Q1(B) =>H11 Q1(E) =>H12	
Transistor 2: BC547			Q2(C) => H20 Q2(B) =>H21 Q2(E) =>H22	
Transistor 3: BC547			Q3(C) => H30 Q3(B) =>H31 Q3(E) =>H32	
Transistor 4: BC547			Q4(C) => H40 Q4(B) => H41 Q4(E) => H42	
Resistor1: 1k Ω Brown, Black, Red			R1(A) => B11 R1(B) => G11	

Resistor2: 1k Ω **Brown, Black, Red**			R2(A) => B21 R2(B) => G21	
Resistor3: 1k Ω **Brown, Black, Red**			R3(A) => B31 R3(B) => G31	
Resistor4: 1k Ω **Brown, Black, Red**			R4(A) => B41 R4(B) => G41	
Switch1 **(Press Button)**			S1(A) => D3 S1(B) =>E5	
Switch2 **(Press Button)**			S2(A) => D45 S2(B) => E47	
Jumper wire1			J1(A) => C3 J1(B) => W5	
Jumper wire2			J2(A) => C5 J2(B) => C11	
Jumper wire3			J3(A) => F10 J3(B) => W12	
Jumper wire4			J4(A) => A11 J4(B) => A41	
Jumper wire5			J5(A) => F20 J5(B) => W20	
Jumper wire6			J6(A) => J12 J6(B) => J30	
Jumper wire7			J7(A) => A21 J7(B) => A31	
Jumper wire8			J8(A) => J22 J8(B) => J40	
Jumper wire9			J9(A) => J32 J9(B) => Y27	
Jumper wire10			J10(A) => J42 J10(B) => Y35	
Jumper wire11			J11(A) =>C31 J11(B) =>C45	
Jumper wire12			J12(A) => C47 J12(B) => W39	
Jumper wire13			J13(A) => W25 J13(B) => W26	
Jumper wire14			J14(A) => Y25 J14(B) => Y26	
Motor 1			M1(+) =>I 22 M1(-) =>I 30	

Battery Connector			Red(+) => W3 Black (-)=> Y3	



FUTHER ACTIVITIES:

1. Learn how to draw the circuit diagram(s) in this experiment.
2. Practice the circuit set up on your own without using the connection table guide.
3. Read more about the circuit(s) and devices and the different ways of achieving the result using other devices.
4. Think of ways you could apply this knowledge to solve your immediate problem and for innovations.

NOTES:

APPENDIX

Prefix	In words	Multiply by	Factor
nano (n)	Billionth	1/1000000000	$1*10^{-9}$
micro (μ)	Millionth	1/1000000	$1*10^{-6}$
milli (m)	Thousandth	1/1000	$1*10^{-3}$
centi (c)	Hundredth	1/100	$1*10^{-2}$
deci (d)	Tenth	1/10	$1*10^{-1}$
		1	
deca (da)	Ten	10	$1*10^{1}$
hecto (h)	Hundred	100	$1*10^{2}$
kilo (k)	Thousand	1000	$1*10^{3}$
mega (M)	Million	1000000	$1*10^{6}$
giga (G)	billion	1000000000	$1*10^{9}$

METRIC CONVERSION CHART

LENGTH CONVERSIONS					
1 centimetre	=	10 millimetres	1 cm	=	10 mm
1 decimetre	=	10 centimetres	1 dm	=	10 cm
1 metre	=	100 centimetres	1 m	=	100 cm
1 metre	=	10 decimetres	1 m	=	10 dm
1 kilometre	=	1000 metres	1 km	=	1000 m

AREA CONVERSIONS					
1 sq. centimetre	=	100 sq. millimetres	1 sq. cm	=	100 sq. mm
1 sq. metre	=	10,000 sq. centimetres	1 sq. m	=	10,000 sq. cm
1 hectare	=	10,000 sq. metres	1 ha	=	10,000 sq. m
1 sq. km	=	100 hectares	1 sq. km	=	100 ha
1 sq. km	=	1 million sq. metres	1 sq. km	=	1,000,000 sq. m

VOLUME CONVERSIONS					
1 cubic centimetre	=	1000 cubic millimetres	1 cu cm	=	1000 cu mm
1 cubic decimetre	=	1000 cubic centimetres	1 cu dm	=	1000 cu cm
1 cubic metre	=	1 million cubic centimetres	1 cu m	=	1,000,000 cu cm
1 cubic metre	=	1000 cubic decimetres	1 cu m	=	1000 cu dm

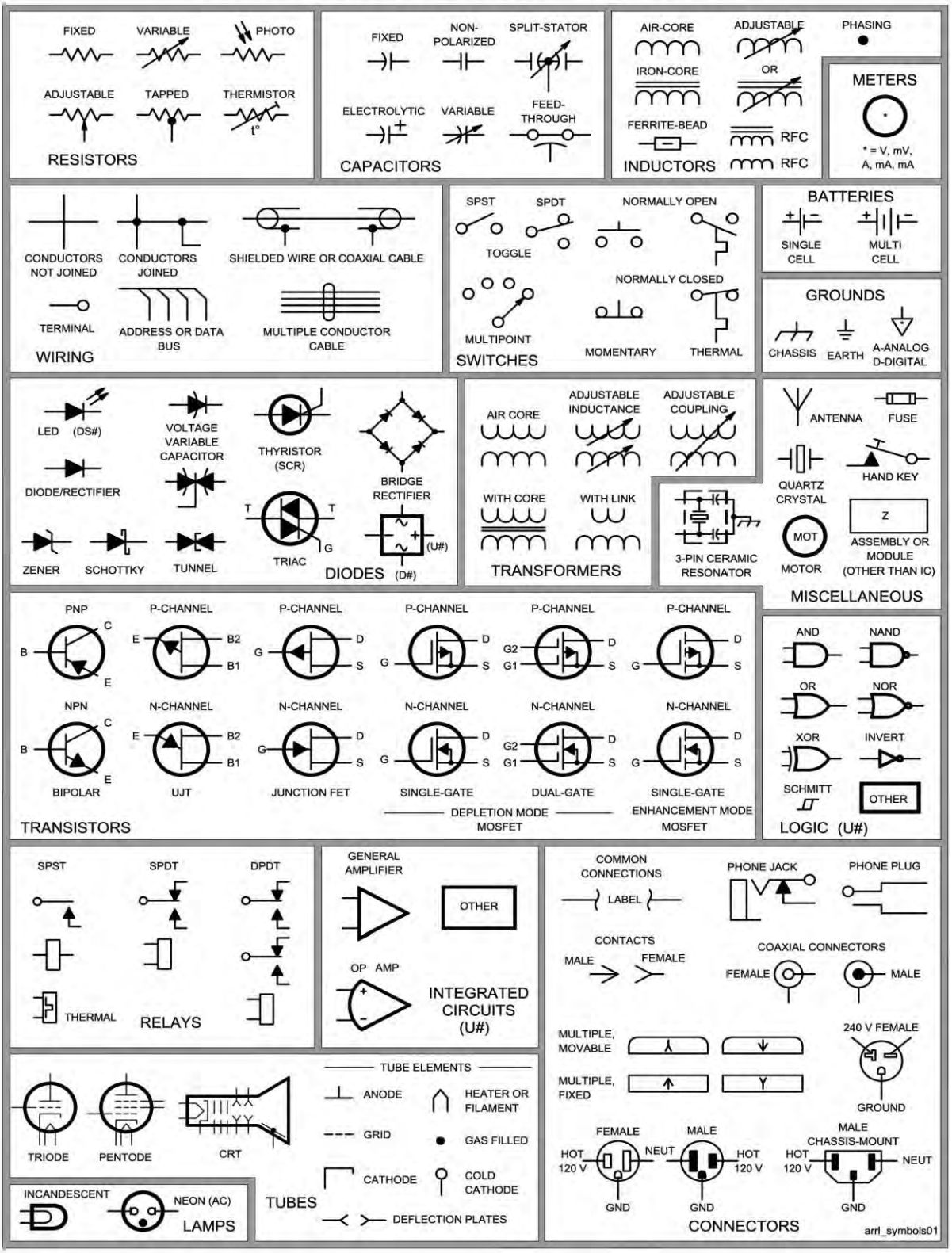
WEIGHT CONVERSIONS					
1 gram	=	1000 milligrams	1g	=	1000 mg
1 decagram	=	10 grams	1dag	=	10g
1 kilogram	=	1000 grams	1 kg	=	1000 g
1 tonne (1 megagram)	=	1000 kilograms	1 t (1 Mg)	=	1000 kg
1 gigagram	=	1000 megagrams	1 Gg	=	1000 Mg or 1000 MT

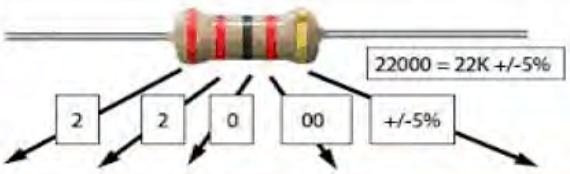
LIQUID VOLUME (CAPACITY) CONVERSIONS					
1 centilitre	=	10 millilitres	1 cl	=	10 ml
1 decilitre	=	10 centilitres	1 dl	=	10cl
1 litre	=	1000 millilitres	1 l	=	1000 ml
1 litre	=	10 decilitres	1 l	=	10dl
1 kilolitre	=	1000 litres	1 kl	=	1000 l

MATHEMATICS SYMBOLS

Symbol	Meaning
+	Plus
−	Minus
±	Plus or Minus
×	Multiplied by
•	Multiplied by
÷	Divided by
/	Divided by
=	Equals
>	Is Greater Than
<	Is Less Than
≤	Is Less Than or Equal to
≥	Is Greater Than or Equal to
%	Percent
√	Root
π	Pi (3.1416)
°	Degree
∞	Infinity
≈	Is Approximately Equal to
∠	Angle
≡	Identical to, Congruent
≠	Does not equal
:	Ratio; Is to
::	As
{	Set (Left Side)
}	Set (Right Side)
'	First Derivative, Feet
''	Second Derivative, Inches
~	Difference
...	Ellipsis

Electrical Schematic Symbols

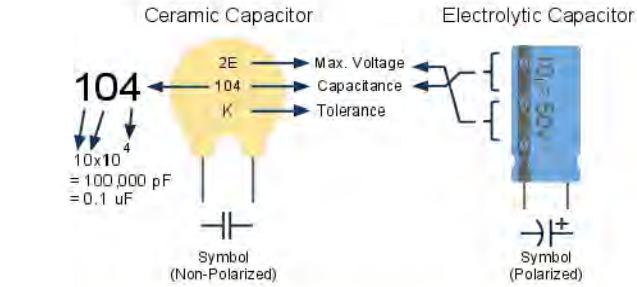




Band	1	2	3	4	5
Meaning	1st Digit	2nd Digit	3rd Digit	(No. of zeros)	Tolerance % (No band +/- 20%)
Silver				.00 (divide by 100)	+/-10%
Gold				.0 (divide by 10)	+/-5%
Black	0	0	0	No Zeros	
Brown	1	1	1	0	+/-1%
Red	2	2	2	00	+/-2%
Orange	3	3	3	,000	
Yellow	4	4	4	0,000	
Green	5	5	5	00,000	+/-0.5%
Blue	6	6	6	,000,000	+/-0.25%
Violet	7	7	7	0,000,000	+/-0.1%
Grey	8	8	8		+/-0.05%
White	9	9	9		

Quantity	Unit	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

Capacitors



Capacitance Conversion Values

Microfarads (µF)	Nanofarads (nF)	Picofarads (pF)
0.000001 µF	0.001 nF	1 pF
0.00001 µF	0.01 nF	10 pF
0.0001 µF	0.1 nF	100 pF
0.001 µF	1 nF	1,000 pF
0.01 µF	10 nf	10,000 pF
0.1 µF	100 nF	100,000 pF
1 µF	1,000 nF	1,000,000 pF
10 µF	10,000 nF	10,000,000 pF
100 µF	100,000 nF	100,000,000 pF

Max. Operating Voltage

Code	Max. Voltage
1H	50V
2A	100V
2T	150V
2D	200V
2E	250V
2G	400V
2J	630V

Tolerance

Code	Percentage
B	± 0.1 pF
C	±0.25 pF
D	±0.5 pF
F	±1%
G	±2%
H	±3%
J	±5%
K	±10%
M	±20%
Z	+80%, -20%

My advice to every educated young Nigerian is that he should take each day as a sacred unit which must not be misused or dissipated. He should ensure that out of the 24 hours available to him, he spends 8 hours on hard work, 8 hours concentration should be spent on serious studies, the remaining 8 hours are enough for feeding, relaxation and sleeping.

--CHIEF OBAFEMI AWOLOWO

EDUSOD Logistics Service

...LEARN, APPLY AND DEVELOP