1

Ohm's Law / The Basic Circuit

INTRODUCTION

Unit 1 is designed to assist you, the learner, understand the basic theory of electricity, basic electrical circuits and complete basic circuit calculations.

Objectives

By the end of this unit you will be able to:

- Understand the basic theory of electricity
- List common conducting materials
- List common insulating materials
- Recognizes and use important circuit symbols
- State the units of Current, Voltage and Resistance
- Calculate circuit values using Ohm's Law
- Understand basic circuit protection
- Understand basic circuit control
- Explain the term "short circuit"
- Explain the term "open circuit"
- Understand the basic effects of an electric current
- Measure circuit currents using an ammeter
- Measure circuit voltages using a voltmeter
- Measure resistor values using an ohmmeter
- Check continuity of circuits using an ohmmeter
- Understand and use the basic resistor colour code
- Perform calculations involving indices

STRUCTURE OF MATTER

Our world is made up of various materials. It contains soil, water, rock, sand etc. It is Surrounded by an invisible layer of gas, which we call air. The scientific name given to each of these materials is **matter.**

"Matter is anything which occupies space and which has mass"

Matter can exist in one of three forms *i.e.* as a solid, a liquid or a gas. Wood is a solid, water is a liquid and air is a gas. These three forms of matter are known as the **States of Matter.**

States of Matter

Many of these materials are found in the earth. Coal is mined, oil is found underground and many metals can be found in the rocks of the earth. Some materials come from plants. Sugar comes from beet and rubber comes from a tree. The main properties of each state can be summarised as follows:

Solids

1. **Solids have a definite shape.** Each solid has its own shape and will retain this shape unless it is subjected to heating or considerable force.
2. **Solids have a definite volume.** It is very difficult to squeeze them into smaller bulks. Solids are said to be almost incompressible.
3. **Solids do not flow.** They do not spread over a surface.

Liquids

1. **Liquids have no definite shape.** They always adopt the shape of the container into which they are placed.
2. **Liquids have a definite volume.** Like solids, they are almost incompressible.
3. **Liquids flow and evaporate.** When spilled they usually spread over the surface. Most liquids evaporate from open containers *i.e.* they change to a gaseous form, (vapour) at the surface.

Gases

1. **Gases have no definite shape.** They always take up the shape of the container into which they are placed.
2. **Gases have no definite volume.** They always spread out in all directions to fill the Container into which they are placed. This spreading out of gas to fill all the available space is called **diffusion.**
3. **Gases can be compressed easily.** A given volume of gas can be squeezed (pressurized) into a smaller volume. Refer to Figure 1.1 (*a*).

In a solid the particles are arranged in a regular pattern. They cannot be moved out of position. Therefore the solid has a definite shape. Refer to Figure 1.1 (*b*).

In a liquid the particles can slide over one another. Since there are no regular arrangements of Particles, the liquid has no shape of its own. A liquid always takes up the shape of its container. Refer to Figure 1.1 (*c*).

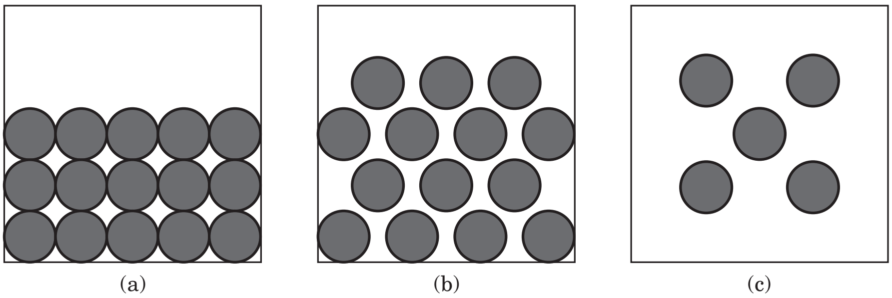


Fig. 1.1

In a gas the particles are much further apart than in a liquid or a solid. Particles in a gas move into all the space available.

THE ATOM

All matter is composed of atoms. An atom is the basic building block of matter. There are different types of atoms, but all atoms are **extremely** small.

Atoms are made up of smaller particles called **Protons, Neutrons and Electrons.**

Definitions

Atom: The smallest portion of a material that still exhibits all the characteristics of that material.

Proton: The **P**roton has a **P**ositive (+) charge of electricity. It is situated in the **nucleus** (or core) of the atom.

Neutron: The **N**eutron is electrically **N**eutral. It is also situated in the **nucleus** of the atom.

Electron: The **E**lectron has a **Negative** (–) charge of electricity. Electrons **orbit** the nucleus of the atom at great speed.

Simplified Representation of Atoms

The models of three different atoms are shown in Figures 1.2 (*a*), 1.2 (*b*) and 1.2 (*c*). They illustrate how the electron(s) are arranged around the nucleus.

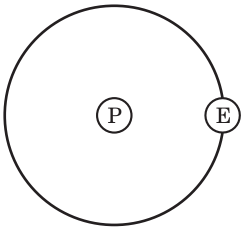
The simplest atom of all - the **Hydrogen** atom, consists of a single electron orbiting a nucleus, which, is composed of a single proton.

The carbon atom consists of, 6 electrons orbiting a nucleus of 6 protons and 6 neutrons.

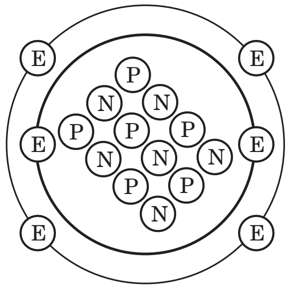
The **copper** atom consists of, 29 electrons orbiting a nucleus of 29 protons and 35 neutrons.

Electrons orbit the nucleus of the atom in shells. The inner shell cannot have any more than two electrons. The copper atom has four shells.

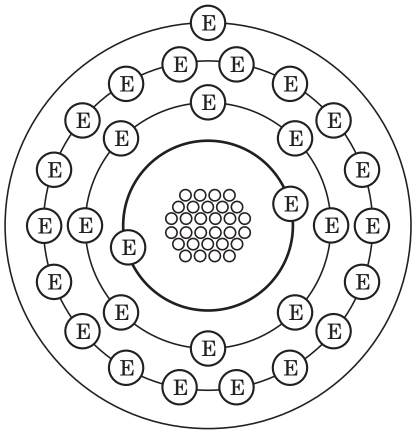
The outer shell is known as the valence shell. The electrons in the outer shell are more easily dislodged from the atom than the electrons in the inner shells. An atom cannot have more than eight electrons in its outer or valence shell.



(a)
Hydrogen atom
1 Electron, 1 Proton



(b)
Carbon atom
6 Electron, 6 Protons, 6 Neutrons



(c)
Copper atom
29 Electrons, 29 Protons, 35 Neutrons

Fig. 1.2

Laws of Electric Charge

There are basic laws of nature, which describes the action of electric charges. These laws state:

1. Like charges repel each other
2. Unlike charges attract each other.

Two Negative charges

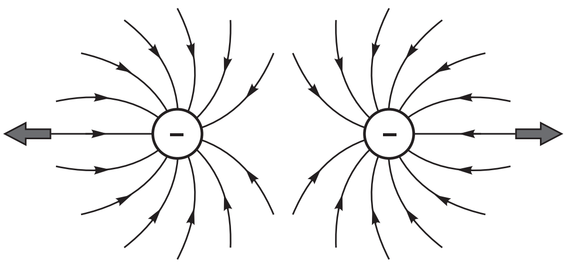


Fig. 1.3 (a) Electrons repel.

Two Positive charges

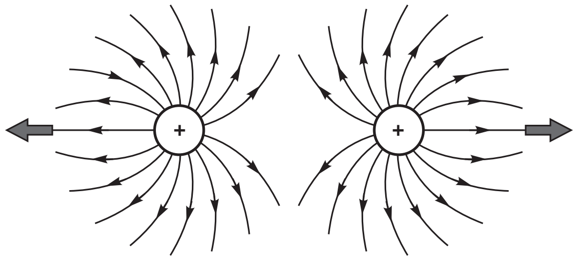


Fig. 1.3 (b) Protons repel.

A Negative charge and a Positive charge

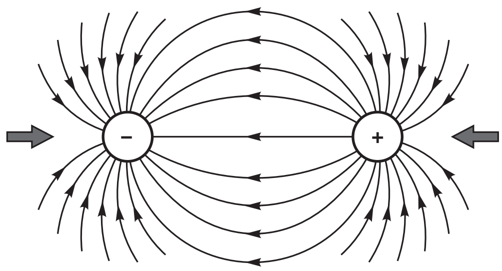


Fig. 1.3 (c) Electrons and protons attract.

The Balanced Atom

In the previously mentioned examples (hydrogen, carbon and copper) you may have noticed that the number of electrons was always equal to the number of protons.

This is normally true of any atom. When this is the case, the atom is said to be neutral, balanced or normal. However, external forces can upset this state.

The Unbalanced Atom

An atom that has gained or lost one or more electrons is no longer balanced. An unbalanced atom is called an **ion.**

The atom that has **lost** an electron has an overall **Positive** charge.

The atom that has **gained** an electron has an overall **Negative** charge.

Conductors

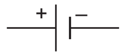
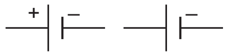
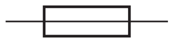
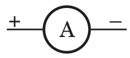
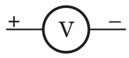
In some materials the electrons in the outer shells are easily dislodged. They can move from atom to atom inside the material. This movement of electrons is **electric current flow**.

Materials, through which electric current can flow freely, are called **conductors.** Some typical **conductors are copper, aluminium, brass, steel, silver and gold.**

Insulators

In other materials the electrons are tightly bound to their own particular atoms. Electric current cannot flow freely through them. These materials are known as **insulators**. Some typical insulators are (Poly-vinyl chloride), **PVC, rubber, plastic, glass, porcelain and magnesium oxide.**

GRAPHICAL SYMBOLS

Cell	
Battery	
Resistor	
Incandescent Lamp	
Fuse	
One Way Switch	
Ammeter	
Voltmeter	
Ohmmeter	

ELECTRIC CURRENT FLOW

Electric current is the movement of free electrons. These electrons have a negative charge and are attracted to a positive charge. When the terminals of a cell are connected via a conductor as shown in Figure 1.4, free electrons drift purposefully in one direction only. This flow of current, is known as **Direct Current** (DC).

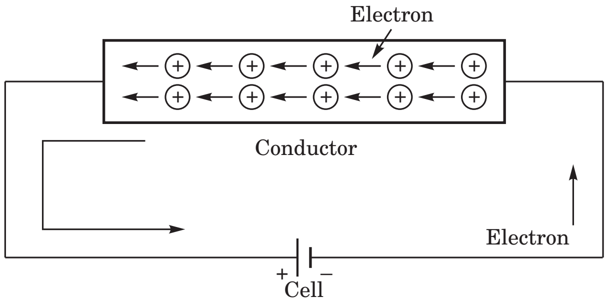


Fig. 1.4

The electrons close to the positive plate of the cell are attracted to it. Each electron that enters the positive plate causes an electron to leave the negative plate and move through the conductor. The number of electrons in the conductor remains constant.

The movement of electrons through a conductor is from negative to positive. Long before this theory was discovered, it was thought that current flowed from **positive to negative.** This direction of current flow is called **conventional current flow.** See Figure 1.5.

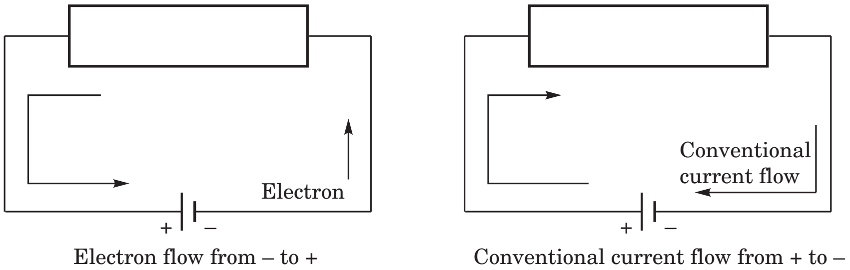


Fig. 1.5

This movement of electrons through a conductor is known as an **electric current** and is measured in **Amperes.**

The Ampere

The symbol for current flow is ***I.***

The **Ampere** (Amp), is the unit of measurement for current flow.

When 6.28×10^{18} electrons pass a given point in one Second, a current of one Ampere is said to flow. See Figure 1.6.

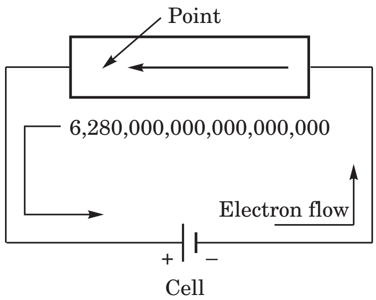


Fig. 1.6

The Coulomb

This number of electrons is exceptionally large. A unit called the **Coulomb** is used to represent this figure.

A coulomb is the quantity (charge) of electricity, which passes a point when a steady current of 1 Ampere flows for one Second.

The symbol for Quantity of electricity is **Q.**

Formula $\mathbf{Q = I \times t}$

where Q = Quantity of electricity (Coulombs)

I = Current flow in Amperes (Amps)

t = the time for which current flows, measured in **Seconds.**

WORKED EXAMPLES

Example 1. *A current of 8.5 Amps passes through a point in a circuit for 3 Minutes. What quantity of electricity is transferred?*

Solution.

$$Q = I \times t$$

$$I = 8.5 \text{ Amps}$$

$$t = 3 \text{ Minutes} = 3 \times 60 \text{ Seconds}$$

$$Q = 8.5 \times 3 \times 60$$

$$Q = \mathbf{1530\ Coulombs}$$

Example 2. *A current of 1.5 Amps transfers a charge of 1800 Coulombs. For what period of time did the current flow?*

Solution.

$$Q = I \times t$$

$$I = 1.5 \text{ Amps}$$

$$Q = 1800 \text{ Coulombs}$$

To find t, the formula must be transformed. Divide both sides by I.

$$\frac{Q}{I} = \frac{I \times t}{I}$$

$$\frac{Q}{I} = t$$

$$t = \frac{Q}{I}$$

$$t = \frac{1800}{1.5}$$

$$t = 1200 \text{ Seconds}$$

$$t = \frac{1200}{60} \text{ Minutes}$$

$$t = \mathbf{20\ Minutes}$$

Example 3. *What current will flow in a circuit if 540 Coulombs is transferred in 2 Minutes?*

Solution.

$$Q = I \times t$$

$$Q = 540 \text{ Coulombs}$$

$$t = 2 \text{ Minutes} = 2 \times 60 \text{ Seconds}$$

To find I, the formula must be transformed. Divide both sides by t.

$$\frac{Q}{t} = \frac{I \times t}{t}$$

$$\frac{Q}{t} = I$$

$$I = \frac{Q}{t}$$

$$I = \frac{540}{2 \times 60}$$

$$I = \mathbf{4.5\ Amps}$$

SAMPLE QUESTIONS

1. A current of 15 Amps flows for 3 Minutes. What charge is transferred?
2. For how long must a current of 3 Amps flow so as to transfer a charge of 240 Coulombs?
3. What current must flow if 100 Coulombs is to be transferred in 5 Seconds?

THE ELECTRICAL CIRCUIT

For continuous current flow, we must be a **complete** circuit. If the circuit is broken, by opening a switch for example, electron movement and therefore the current will stop immediately. To cause a current to flow through a circuit, a driving force is required, just as a circulating pump is required to drive water around a central heating system. See Figure 1.7.

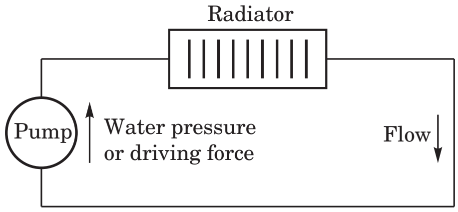


Fig. 1.7

This driving force is the **e**lectro**m**otive **f**orce (abbreviated to EMF). It is the energy, which causes current to flow through a circuit. Each time an electron passes through the source of EMF, more energy is provided to keep it moving. See Figure 1.8.

A circuit must have:

1. A source of supply (EMF).
2. A load (Lamp).
3. Connecting cables (Conductors).

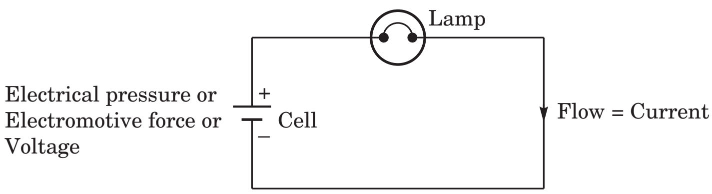


Fig. 1.8

1. The **source of supply** is always associated with energy conversion.

(*a*) Generator (converts mechanical energy to electrical energy)

(*b*) Cell or Battery (converts chemical energy to electrical energy)

The source of supply will provide pressure called **Electromotive Force** or **Voltage.** The symbol for voltage is **V.**

2. **The load** is any device that is placed in the electrical circuit that produces an **effect** when an electric current flows through it. When an electric current flows through an incandescent lamp, the lamp gives off light from heat.

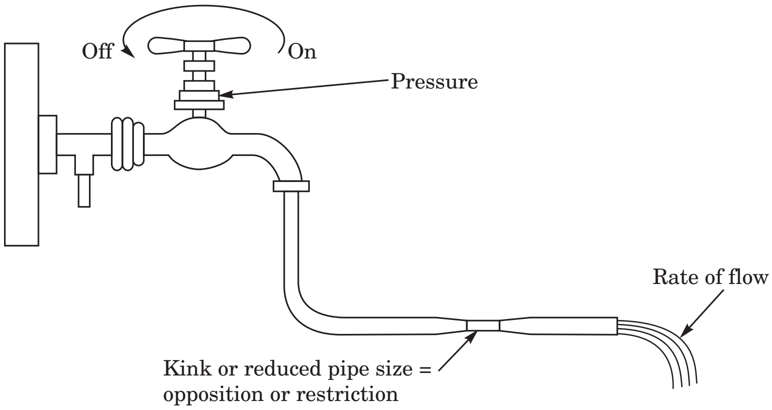
3. **The connecting leads** or cables complete the circuit. The cable consists of the conductor to carry the current and insulation to prevent leakage. A water pipe must have a bore to carry the water and the pipe material (*e.g.* copper) to prevent leakage.

Circuit Analogy

The simplest analogy of an electric circuit is to consider a hosepipe connected to a tap. The rate of flow of water from the end of the hosepipe will depend upon:

1. The water pressure at the tap.
2. The diameter of the hosepipe
3. The restriction / resistance of the inner walls of the hosepipe.
4. The degree of any bends or kinks in the hosepipe.

If there are many restrictions, the water will flow out of the hosepipe at a reduced rate. See Figure 1.9.



Kink or Reduced pipe sise = Opposition or Restriction

Fig. 1.9

In much the same way, current flows through conductors by means of electric pressure provided by a battery or generating source. This source of electric pressure, **electromotive force** (EMF), provides the energy required to push current through the circuit. It can be referred to as the **supply voltage.**

Every circuit offers some opposition or restriction to current flow, which is called circuit **resistance**. The unit of resistance is the **Ohm,** symbol Ω, pronounced **Omega.** At this stage, conductor resistance is ignored and the **load resistance** is treated as the total opposition to current flow.

For a stable supply voltage, the **current** (I) which flows, is determined by **resistance** (R) of the circuit. There will be a **voltage drop** across different parts of the circuit and this is called **Potential Difference** (PD). See Figure 1.10.

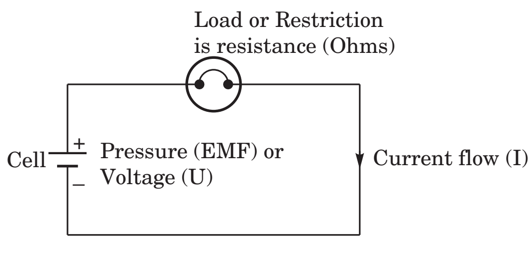


Fig. 1.10

Unlike the hosepipe analogy, the electric circuit requires a "go" and "return" conductor to form a closed loop or complete circuit. These conductors must offer a low resistance path to the flow of current. Most metallic conductors satisfy this requirement.

OHM'S LAW

George Ohm discovered the relationship between, current flowing in a circuit and the pressure applied across that circuit. This became known as **Ohm's Law.**

Ohm's Law states that the current (I) flowing through a circuit is directly proportional to the potential difference (V), across that circuit, and inversely proportional to the resistance (R), of that circuit, provided the temperature remains constant.

$$I = \frac{V}{R}$$

To find **U,** transpose the formula by multiplying both sides of the equation by R.

$$I = \frac{V}{R}$$

$$I \times R = \frac{V \times R}{R}$$

$$I \times R = \frac{V \times \cancel{R}}{\cancel{R}}$$

$$I \times R = V$$

or $$V = I \times R$$

To find **R**, divide both sides by I as follows:

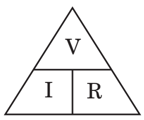
$$V = I \times R$$

$$\frac{V}{I} = \frac{I \times R}{I}$$

$$\frac{\mathbf{V}}{\mathbf{I}} = \boldsymbol{R}$$

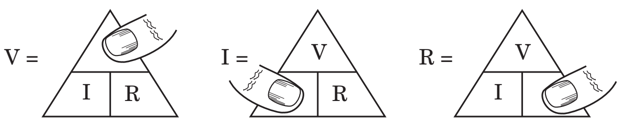
or $$\boldsymbol{R} = \frac{\mathbf{V}}{\mathbf{I}}$$

The Magic Triangle



Now consider any circuit in which you know the values of any two of the three factors - voltage, current and resistance - and you want to find the third. The rule for working the "Magic Triangle" to give the correct formula is as follows:

Place your thumb over the letter in the triangle whose value you want to know - and the formula for calculating that value is given by the two remaining letters.



To Confirm Ohm's Law

Experiment

Refer to Figure 1.11. In this arrangement the resistor value is kept constant whilst the voltage is increased in steps of two volts and current readings are taken.

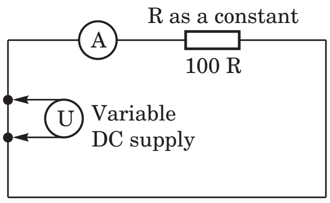


Fig. 1.11. In this circuit the resistance is constant.

The following results were obtained from the experiment and plotted in graph form as shown below.

Voltage	=	*I*	×	*R*
2	=	0.02	×	100
4	=	0.04	×	100
6	=	0.06	×	100
8	=	0.08	×	100
10	=	0.10	×	100

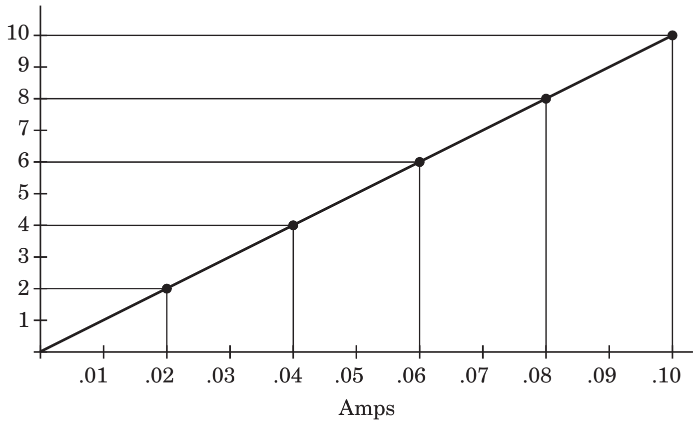


Fig. 1.12

The above graph and experiment illustrates, that current flow increases proportionally as the applied voltage is increased.

WORKED EXAMPLES

Example 1. *An electrical lamp used on a 230 Volt supply takes a current of 0.42 Amps. What is the resistance of the lamp?*

Solution. $R = \dfrac{V}{I}$

$V = 230$ Volts

$$I = 0.42 \text{ Amps}$$

$$I = \frac{230}{0.42}$$

R = **547 Ohms** (Hot resistance)

Example 2. *An immersion heater connected to a 230 Volts supply takes a current of 13.5 Amps. Calculate the resistance of the element.*

Solution.

$$R = \frac{V}{I}$$

$$V = 230 \text{ Volts}$$

$$I = 13.5 \text{ Amps}$$

$$R = \frac{230}{13.5}$$

R = **17 Ohms**

Example 3. *An electric heater has a resistance of 23 Ω and is connected to a 230 Volts supply. Calculate the current the heater will take.*

Solution.

$$I = \frac{V}{R}$$

$$V = 230 \text{ Volts}$$

$$R = 23 \text{ Ohms}$$

$$I = \frac{230}{23}$$

I = **10 Amps**

Example 4. *An electrical circuit has a resistance of 23 Ω and takes a current of 5 Amps. Calculate the voltage applied to the circuit.*

Solution.

$$V = I \times R$$

$$I = 5 \text{ Amps}$$

$$R = 23 \text{ Ohms}$$

$$V = 5 \times 23$$

V = **115 Volts**

From the previous exercises it will be noticed that the amount of current that flows in a circuit is directly proportional to the voltage and inversely proportional to the resistance.

With a fairly constant supply of 230 Volts, the load or resistance of the circuit will determine the amount of current that will flow.

ELECTRICAL CIRCUIT REQUIREMENTS

Circuit Protection

One of the basic requirements that a circuit must have is over current protection. This is essential for protection of the cables and accessories in the circuit. A **fuse** or **circuit breaker** is used to provide this protection. It is fitted as close to the origin of the circuit as possible to cut off the supply if too much current flows in the circuit. This is called circuit protection. See Figure 1.13.

Circuit Control

Another basic requirement is that the circuit can be controlled. A **switch** must be fitted to turn the supply **on** or **off.** This is called circuit control.

The principles of circuit protection and circuit control are illustrated in Figure 1.13.

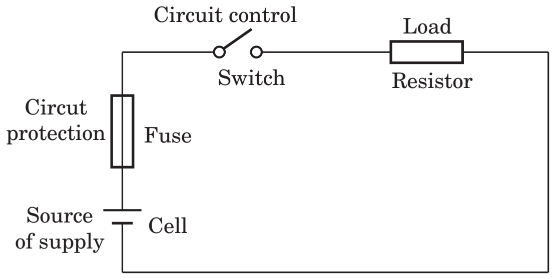


Fig. 1.13

BASIC CIRCUITS CONCEPTS

Open Circuit

An open circuit exists, when there is a break in a circuit. This break results in an extremely high resistance in the circuit. This will stop current flow. This value of extremely high resistance is referred to as infinity. It is denoted by the symbol ∞.

Examples: See Figure 1.14.

1. A switch is open.
2. A fuse is blown or a circuit breaker is tripped.
3. A physical break in the resistor or element.
4. A connecting cable is broken.

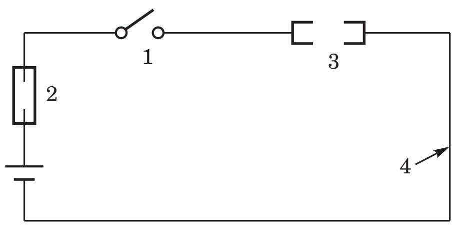


Fig. 1.14

Assume a supply of 230 Volts and the circuit resistance of 1,000 Ohms.

From Ohm's Law $I = \frac{V}{R}$

$$I = \frac{230}{1,000}$$

$$I = \mathbf{0.23\ Amps}$$

Assume a supply of 230 Volts and the circuit resistance of 1,000.000 Ohms.

From Ohm's Law $I = \frac{V}{R}$

$$I = \frac{230}{1,000,000}$$

$$I = \mathbf{0.00023\ Amps}$$

Short Circuit

Current will flow through the path of least resistance or opposition in a circuit. A short circuit occurs when the resistance or opposition in a circuit is very low. Examples: See Figures 1.15, 1.15A and 1.15B.

1. The "load" is shorted out and the current takes the path of least resistance.

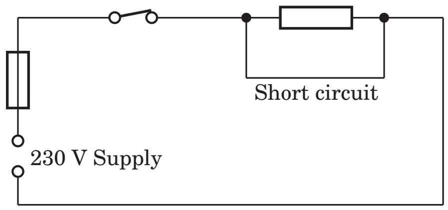


Fig. 1.15

2. The connecting cables are damaged prior to or after the wiring process.

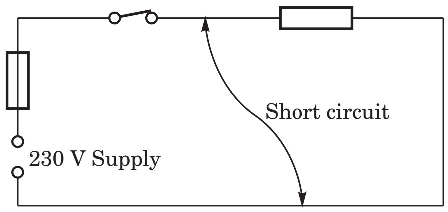


Fig. 1.15A

3. The connecting cables in the circuit are connected together during the wiring process.

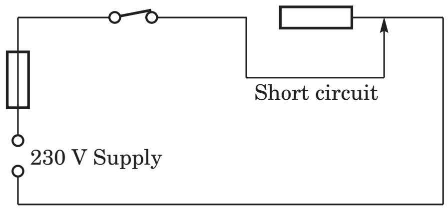


Fig. 1.15B

A short circuit usually results in a dangerously high current flowing. A fuse or circuit breaker is the deliberate "weak link" in a circuit. Either will open the circuit when too much current flows.

Assume a supply of 230 Volts and the circuit resistance of 1 Ohm.

From Ohm's Law $I = \frac{V}{R}$

$I = \frac{230}{1}$

$I =$ **230 Amps**

Assume a supply of 230 Volts and the circuit resistance of 0.1 Ohm.

From Ohm's Law $I = \frac{V}{R}$

$I = \frac{230}{0.1}$

$I =$ **2300 Amps**

Assume a supply of 230 Volts and the circuit resistance of 0.01 Ohm.

From Ohm's Law $I = \frac{V}{R}$

$I = \frac{230}{0.01}$

$I =$ **23,000 Amps**

THE EFFECTS OF AN ELECTRIC CURRENT

When an electric current flows in a circuit it can have one or more of the following effects:

1. Heating Effect
2. Magnetic Effect
3. Chemical Effect

The Heating Effect

The movement of electrons in a circuit, which is the flow of an electric current, causes an increase in the temperature of the load resistance. The huge number of electrons being pushed through the load resistance, results in high friction and collision of these electrons. This generates heat. The amount of heat generated depends upon the type and dimensions of the load resistance wire and the value of current flowing. By changing these variables, a length of resistance wire may be operated at different temperatures to give different effects, *e.g.* an ordinary light bulb or an electric heater. See Figure 1.16.

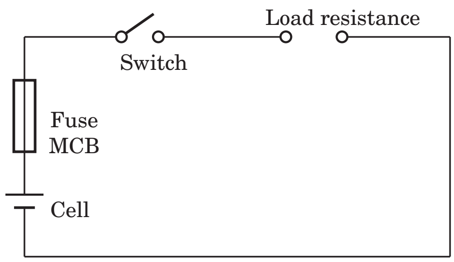


Fig. 1.16

The Magnetic Effect

Whenever a current flows in a conductor a magnetic field is set up around that conductor. See Figure 1.17 below.

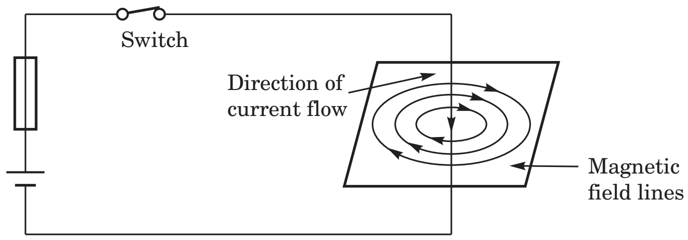


Fig. 1.17

This magnetic field increases in strength if the current is increased and collapses if the current is switched off. A "current carrying conductor", wound in the form of a solenoid (coil), produces a magnetic field very similar to that of a permanent magnet, but has the advantage in that it can be switched on or off by any switch controlling the circuit current.

The magnetic effect of an electric current is the principle upon which electric bells, relays, moving coil instruments, motors and generators work.

The strength of the magnetic field is directly proportional to the current in the circuit. The "clamp on" type ammeter measures the strength of the magnetic field and produces a reading in Amps.

The Chemical Effect

When an electric current flows through an electrolyte (conducting liquid / paste), this electrolyte is separated into chemical parts. The two conductors, which make contact with the electrolyte, are called the anode (positive plate) and the cathode (negative plate).

An anode or cathode of dissimilar metals placed in an electrolyte can react chemically and produce an EMF. When a load is connected across the anode and cathode, a current will flow in the circuit.

The chemical effect of an electric current is the principle upon which electric cells operate. See Figure 1.18.

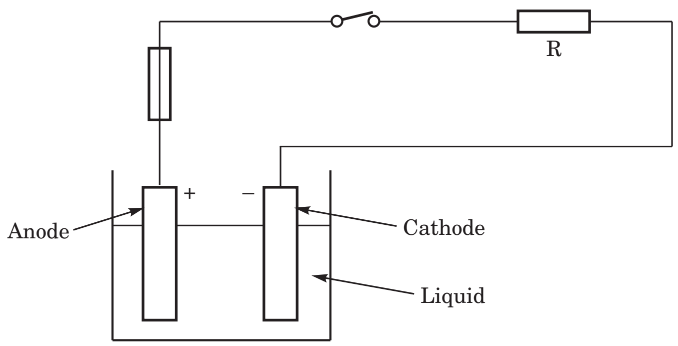


Fig. 1.18

SI UNITS

A unit is what we use to indicate the measurement of a quantity. For example, the unit of current is the **Ampere.** The unit of length could be the **Inch** or the **Metre.** However, the Metre is the SI unit of length.

In order that we all work to a common standard, an international system is used. It is known as the SI system (System International). This system is used throughout the course. A number of prefixes will be used *e.g.* microamps and milliamps, millivolts and kilovolts, kilohms and megohms.

Metric Prefixes

Prefix	*Symbol*	*Multiplying Factor*	*Power Index*
mega*	**M**	**1 000 000**	**(10^6)**
kilo*	k	**1 000**	**(10^3)**
hecto	h	100	(10^2)
deca	da	10	(10^1)
unity		1	(10^{-0})
deci	d	0.1	(10^{-1})
centi	c	0.01	(10^{-2})
milli*	**m**	**0.001**	**(10^{-3})**
micro*	μ	**0.000 001**	**(10^{-6})**
nano	n	0.000 000 001	(10^{-9})
pico	p	0.000 000 000 001	(10^{-12})

* denotes frequently used prefixes in the Electrical Trade.

Examples

To convert amps to milliamps multiply by 1,000 (10^3)

To convert amps to microamps multiply by 1,000,000 (10^6)

To convert milliamps to amps multiply by 0.001 (10^{-3})

To convert microamps to milliamps multiply by 0.001 (10^{-3})

Examples. *Convert the following:*

1. 13,000,000 Ohms to megohms
2. 500,000 Ohms to megohms
3. 0.5 Volts to millivolts
4. 100 Volts to millivolts
5. 15,000 Volts to kilovolts
6. 0.4 kilovolts to Volts
7. 600 milliamps to Amps
8. 0.03 Amps to milliamps

Solutions.

1. 1,000,000 Ohms	=	1 megohm	=	1 MΩ
13,000,000 Ohms	=	13 megohms	=	13 MΩ
2. 500,000 Ohms	=	0.5 megohms	=	0.5 MΩ
3. 1 Volt	=	1000 millivolts	=	1000 mV
0.5 Volts	=	500 millivolts	=	500 mV

4. 100 Volts	=	100,000 millivolts	=	100,000 mV
5. 1,000 Volts	=	1 kilovolt	=	1 kV
15,000 Volts	=	15 kilovolts	=	15 kV
6. 1 kilovolt	=	1,000 Volts	=	1000 V
0.4 kilovolts	=	400 Volts	=	400 V
7. 1,000 milliamps	=	1 Amp	=	1 A
600 milliamps	=	0.6 Amps	=	0.6 A
8. 1 Amp	=	1,000 milliamps	=	1000 mA
0.1 Amps	=	100 milliamps	=	100 mA
0.01 Amps	=	10 milliamps	=	10 mA
0.03 Amps	=	30 milliamps	=	30 mA

ELECTRICAL MEASURING INSTRUMENTS

The Ammeter

An **ammeter** is a device used to measure current flowing through a circuit or part of a circuit. It indicates, in terms of amperes, the number of coulombs passing a given point in a circuit, in one second. The ammeter shown in Figure 1.19 has a Full Scale Deflection (FSD) of 40 A.

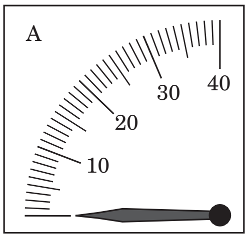


Fig. 1.19

The ammeter must be physically connected into the circuit. It can then measure *all* the electrons passing through it.

The ammeter in Figure 1.20 is said to be **in series** with the resistor or load.

The **positive** and **negative** terminals of a **direct current** (DC) meter must be connected correctly as shown in Figure 2. This is referred to as correct **polarity.** It allows the meter to read **up-scale.** Reversed polarity causes the meter to read **down scale.** This forces the pointer against the stop at the left, which may damage the meter.

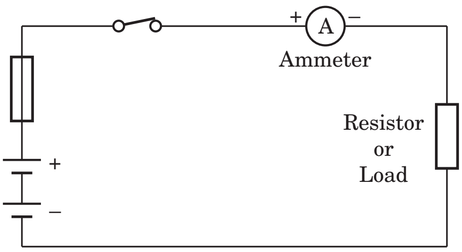


Fig. 1.20

Note: The ammeter may be damaged if incorrectly connected.

Meter Range and Selection

The current required to be measured should be estimated. Select a meter having a FSD a good deal higher than the estimated current. Any current value in excess of the FSD of the meter will not only fail to register properly on the scale, but will probably cause **serious damage** to the meter.

On the other hand, any current value very low in relation to the FSD will not cause the pointer to move. An accurate reading cannot be obtained in this situation. The useful range of any meter never, in fact, extends right down to zero on its scale. It only goes down to the point at which readings can be distinguished from zero with reasonable accuracy.

Activity

Apprentices to install an ammeter into a circuit as shown in Figure 1.21 and measure the current.

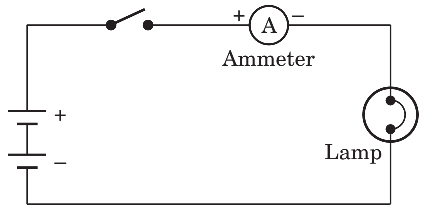


Fig. 1.21

The Voltmeter

A voltmeter measures electromotive force (EMF) or potential difference (PD). It must be connected **across** the supply or load resistance in order to record the voltage. That is, it must be connected in **parallel** with the component as in Figure 1.22.

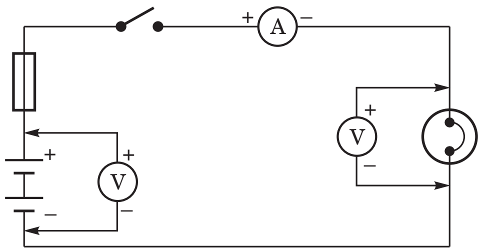


Fig. 1.22

Note: The voltmeter may be damaged if incorrectly connected.

A DC voltmeter (analogue type) must be connected with the correct polarity for the meter to read up scale. When selecting a meter to measure voltage, choose one having a maximum range a good deal higher than the value of any voltage you expect to be measuring. The reason for this is that a voltage in excess of the maximum rated value of the meter will not only fail to register properly on the scale, but will probably cause serious damage to the meter.

Activity

Measure the voltage at the supply terminals and the potential difference across the load of the circuit shown in Figure 1.23.

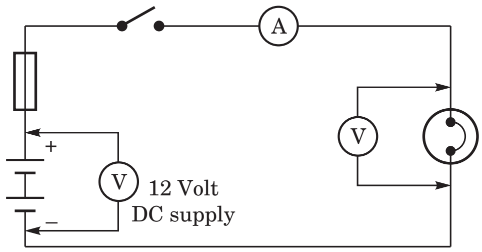


Fig. 1.23

The Ohmmeter

An ohmmeter is used to check the electrical continuity of components and to measure their resistance. It is powered by its own internal battery. A typical ohmmeter is depicted in Figure 1.24. Before connecting an ohmmeter in circuit it is important to ensure that:

1. There is no voltage across the component (supply disconnected).
2. The component to be measured is not connected in parallel with any other component.
3. The instrument has been set to infinity ∞ with the leads separated.
4. The instrument has been set to Zero Ohms with the leads connected together.

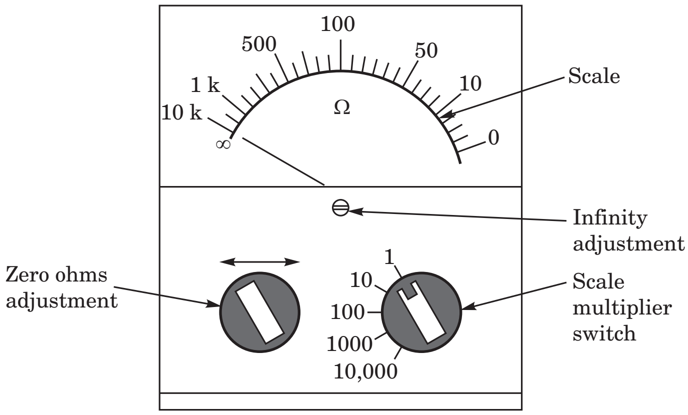


Fig. 1.24

Measurements are taken by connecting the meter across the unknown resistor as shown in Figure 1.25. It is important to select the most suitable scale for the resistance under test. The current flowing through the unknown resistance will cause the pointer to deflect. This deflection, when multiplied by the scale factor (range selection switch setting), **will give the value of the resistance being measured.** The ohmmeter scale is normally **non-linear** with zero on the opposite side of the scale to that used for voltage and current measurement.

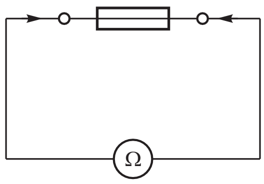


Fig. 1.25

The Multimeter

A multimeter is an instrument that can be **set** or **programmed** to measure voltage, current or resistance. Most modern multimeters have a number of other functions such as diode checking and capacitance measurement. These instruments can measure Direct Current (DC) or Alternating Current (AC) over several ranges.

The main types are:

- **Volt-Ohm-Milli-ammeter (VOM) and**
- **Digital Multimeter (DMM)**

Comparison of Analogue and Digital Multimeters

Analogue Type	**Digital Type**
Features:	Features:
Analogue Display	Digital Display
Manual Range Setting	Range Setting Automatic/Manual

It is important that the instruction manual supplied with a meter is studied prior to operation of the meter. These manuals normally contain warnings and information, which must be followed to ensure safe operation and retain the meter in a safe condition.

Meter Operating Suggestions

1. Ensure that the instrument is **set** to measure the desired unit *e.g.* Volts to measure voltage.

2. Set the range switch to the proper **position** before making any measurement.

3. Ensure the instrument test leads are connected to the appropriate **jack sockets.** When the voltage, current or resistance to be measured is not known, always start with the **highest range first** and work your way down to a lower range that gives an accurate reading.

4. Always observe correct test lead polarity when making DC **voltage and current** measurements.

5. For most accurate readings, look at the scale from a position where the pointer and its reflection on the mirror come together to avoid **parallax error.** Wherever possible, use a range setting, which results in a reading in the centre 1/3rd of the meter scale.

6. Set the range selector switch to the **"Off"** position when the tester is not in use or during transit.

7. Remove the battery before **storing** the meter for a long period of time.

8. Great care must be taken to ensure that the instrument range setting is **not exceeded** when measuring a voltage or current.

RESISTORS

All materials have some resistance to the flow of an electric current. In general, the term **resistor** describes a conductor specially chosen for its resistive properties.

Resistors are the most commonly used electronic components. They are made in a variety of ways to suit particular types of application. They are usually manufactured as either carbon composition or carbon film. In both cases the base resistive material is carbon. The general appearance is of a small cylinder with leads protruding from each end.

Resistor Colour Code

The **value** of the resistor and its **tolerance** may be marked on the body of the component. This may be done either by direct numerical indication or by using a **standard colour code.**

The **coloured bands** are located on the component towards one end. If the resistor is turned so that this end is towards the left, then the bands are read from left to right, See Figure 1.26.

Fig. 1.26

Explanation of Colour Coding Bands (4 Band Resistors)

1st Band Colour	—	1st Digit
2nd Band Colour	—	2nd Digit
3rd Band Colour	—	Multiplier (in effect the number of zeros)
4th Band Colour	—	Tolerance

Resistor Colour Code Values

Black	0	Brown	1
Red	2	Orange	3
Yellow	4	Green	5
Blue	6	Violet	7
Grey	8	White	9

Resistor Tolerance

The fourth resistor colour band indicates the resistor tolerance. This is commonly **gold** or **silver,** indicating a tolerance of 5% or 10% respectively. Sometimes the coloured bands are not clearly oriented towards one end. In this case, first identify the tolerance band and turn the resistor so that this is to the right. Then read the colour code as described below.

The tolerance band indicates the maximum tolerance variation in the declared value of resistance. Thus a 100 Ω resistor with a 5% tolerance will have a value of somewhere between 95 Ω and 105 Ω, since 5% of 100 Ω is 5 Ω.

If no fourth band exists this indicates a tolerance of + / – 20%.

Tolerance indicators	Gold	Silver	No band
	5%	10%	20%

Reading a resistor colour code

Fig. 1.27

If a resistor has colour code bands of blue, grey, red, gold, what is its ohmic value?

Solution:

Blue	=	6 1^{st} Digit
Grey	=	8 2^{nd} Digit
Red	=	2 Number of zeros
Gold	=	5% Tolerance

Resistor value is **6,800 Ω** with a **5% tolerance**

This resistor will have an ohmic value between 6,460 and 7,140 ohms.

Activity

Practice reading the colour code of different values of resistors and calculate the tolerance range.

Resistor Colour Code Mnemonic

Mnemonic to Remember the Resistor Colour Code:
Better Be Right Or Your Great Big Venture Goes Wrong

Resistor Preferred Values

It is difficult to manufacture small electronic resistors to exact values by mass production methods. This is not a disadvantage as in most electronic circuits the values of the resistors is **not critical.** Manufacturers produce a limited range of **PREFERRED** resistance values rather than an overwhelming number of individual resistance values. Therefore, in electronics we use the preferred value **closest to the actual value required.**

A resistor with a preferred value of 100 Ω and a 10% tolerance could actually have any value between 90 Ω and 110 Ω. The next largest preferred value, which would give the maximum possible range of resistance values without too much overlap, would be 120 Ω. This could have any value between 108 Ω and 132 Ω.

Table 1 indicates the preferred values between 10 Ω and 82 Ω, but the **larger values,** which are manufactured, can be obtained by multiplying these preferred values by a **factor of 10.**

Example:

47 Ω,	(47 × 10)	=	470 Ω	=	470R
470 Ω,	(470 × 10)	=	4,700 Ω	=	4.7k
4,700 Ω,	(4,700 × 10)	=	47,000 Ω	=	47k
47,000 Ω	(47,000 × 10)	=	470,000 Ω	=	470k
470,000 Ω	(470,000 × 10)	=	4,700,000 Ω	=	4.7M

For a number of reasons the decimal point is not used. Take the **4.7k** resistor, this may be written **4k7.** The k is positioned so that it indicates where the decimal point should be. The **R** and **M** can be used in the same manner as in the examples below.

Examples:

18 Ω	=	18R	
2.7 kΩ	=	2k7	(2,700R)
39 kΩ	=	39k	(39,000R)
5.6 MΩ	=	5M6	(5,600,000R)
82 MΩ	=	82M	(82,000,000R)

E12 Series of Preferred Values

(10% Tolerance)

Table 1

Rated Value in Ohms	*Possible Range of Values in Ohms*
10	9.0 to 11.0
12	10.8 to 13.2
15	13.5 to 16.5
18	16.2 to 19.8
22	19.8 to 24.2
27	24.3 to 29.7
33	29.7 to 36.3
39	35.1 to 42.9
47	42.3 to 51.7
56	50.4 to 61.6
68	61.2 to 74.8
82	73.8 to 90.2
	and so on in multiples of 10

INDICES

It is very important to understand what *Indices* are and how they are used. Without such knowledge, calculations and manipulation of formulae are difficult and frustrating.

So, what are *Indices*? Well, they are perhaps most easily explained by example. If we multiply two identical numbers, say 2 and 2, the answer is, clearly, 4, and this process is usually expressed thus:

$$2 \times 2 = 4$$

However, another way of expressing the same condition is:

$$2^2 = 4$$

The upper 2 simply means that the lower 2 is multiplied by itself. The upper 2 is known as the index. Sometimes this situation is referred to as 'two *raised to the power of* two'. So 2^3 means 'two multiplied by itself *three* times'.

i.e. $2 \times 2 \times 2 = 2 \times 8$

Do not be misled by thinking that 2^3 is 2×3

$$2^4 = 2 \times 2 \times 2 \times 2 = 16 \ (\textit{not}\ 2 \times 4 = 8)$$

$$24^2 = 24 \times 24 = 576 \ (\textit{not}\ 24 \times 2 = 48)$$

Examples:

$$3^3 = 3 \times 3 \times 3 = 27$$

$$9^2 = 9 \times 9 = 81$$

$$4^3 = 4 \times 4 \times 4 = 64$$

$$10^5 = 10 \times 10 \times 10 \times 10 \times 10 = 100{,}000$$

A number by itself, say 3, has an invisible index, 1, but it is not shown. Now consider this: $2^2 \times 2^2 \times 2$ may be written as $2 \times 2 \times 2 \times 2 \times 2$, or as 2^5, which means, that the indices 2 and 2 or the invisible index 1 have been added together. So the rule is, when multiplying like figures, add the indices.

Examples:

$$4 \times 4^2 = 4^1 \times 4^2 = 4^3 = 4 \times 4 \times 4 = 64$$
$$3^2 \times 3^3 = 3^5 = 3 \times 3 \times 3 \times 3 \times 3 = 243$$
$$10 \times 10^3 = 10^4 = 10 \times 10 \times 10 \times 10 = 10{,}000$$

Multiplication of Indices

$$3^2 \times 3^3 = 3^5$$
$$Y^M \times Y^N = Y^{M+N}$$

Rule 1. When multiplying powers of the same number **add** the indices.

Let us advance to the following situation:

$10^4 \times \dfrac{1}{10^2}$ is the same as $\dfrac{10^4}{10^2} = \dfrac{10 \times 10 \times 10 \times 10}{10 \times 10}$

Cancelling out the 10s $\dfrac{10 \times 10 \times 10 \times 10}{10 \times 10}$

We get $10 \times 10 = 10^2$

which means that the indices have been subtracted *i.e.* $4 - 2$.

$$\frac{Y^M}{Y^N} = Y^{M-N}$$

Rule 2. When dividing powers of the same number, **subtract** the indices.

How about this: $4 - 2$ is either 4 subtract 2, or 4 add -2, and remember, the addition of indices is used with multiplication. So from this we should see that 10^4 divided by 10^2 is the same as 10^4 multiplied by 10^{-2}. So

$\dfrac{1}{10^2}$ is the same as 10^{-2}

Examples:

$$\frac{1}{3^4} = 3^{-4} \quad \frac{1}{2^6} = 2^{-6}$$

and conversely:

$$\frac{1}{10^{-2}} = 10^2$$

Hence we can see that indices may be moved above or below the line providing the sign is changed.

Examples:

1. $$\frac{10^6 \times 10^7 \times 10^{-3}}{10^4 \times 10^2} = \frac{10^{13} \times 10^{-3}}{10^6}$$

$$= \frac{10^{10}}{10^6} = 10^{10} \times 10^{-6} = 10^4 = 10{,}000$$

2. $$\frac{10^4 \times 10^{-6}}{10} = 10^4 \times 10^{-6} \times 10^{-1}$$

$$10^4 \times 10^{-7} = 10^{-3} = \frac{1}{10^3}$$

$$= \frac{1}{1000} = 0.001$$

WORKED EXAMPLES

Example 1. *What is the resistance of a circuit if the voltage across it is 50 kV and a current of 500 mA is flowing?*

Solution. $V = 50 \text{ kV} = 50 \times 10^3$ Volts

$I = 500 \text{ mA} = 500 \times 10^{-3}$ Amps

$$R = \frac{V}{I}$$

$$R = \frac{50 \times 10^3}{500 \times 10^{-3}}$$

$$R = \frac{50 \times 10^6}{500}$$

$$R = \frac{50{,}000}{500}$$

$$R = \frac{000}{5}$$

$R = 000$ Ohms

Example 2. *What current will flow through a circuit if the supply voltage is 50 kV and the circuit resistance is 5 megohms?*

Solution. $V = 50 \text{ kV} = 50 \times 10^3$ Volts

$R = 5 \text{ M}\Omega = 5 \times 10^6$ Ohms

$$I = \frac{V}{R}$$

$$I = \frac{50 \times 10^3}{5 \times 10^6}$$

$$I = \frac{50 \times 10^3 \times 10^{-6}}{5}$$

$$I = \frac{50 \times 10^{-3}}{5}$$

$$I = \frac{10 \times 10^{-3}}{1}$$

$I = 0.01$ Amps
$I = 10$ milliamps

Example 3. *What voltage will cause a current of 50 mA to flow through a resistance of 1 kΩ ?*

Solution. $I = 50 \text{ mA} = 50 \times 10^{-3}$ Amps
$R = 1 \text{ k}\Omega = 1 \times 10^{3}$ Ohms
$V = I \times R$
$V = 50 \times 10^{-3} \times 1 \times 10^{3}$
$V = 50$ Volts

CHOOSE THE CORRECT ANSWER

1. Solid have a ....
(*a*) Definite shape and volume
(*b*) Definite shape and not definite volume
(*c*) No definite shape and definite volume
(*d*) No definite shape and volume

2. Liquids have a ....
(*a*) Definite shape and volume
(*b*) Definite shape and not definite volume
(*c*) No definite shape and definite volume
(*d*) No definite shape and volume

3. Gases have a ....
(*a*) Definite shape and volume
(*b*) Definite shape and not definite volume
(*c*) No definite shape and definite volume
(*d*) No definite shape and volume

4. The carbon atom consists of .... electrons orbiting a nucleus of 6 protons and 6 neutrons.
(*a*) 5 (*b*) 7
(*c*) 4 (*d*) 6

5. Like charges always ....
(*a*) Repel each other (*b*) Attract each other
(*c*) (*a*) and (*b*) correct (*d*) none of the above

6. Electric current cannot flow freely through them
(*a*) Conductor (*b*) insulator
(*c*) (*a*) and (*b*) correct (*d*) none of the above

7. Electric current measured in ....
(*a*) Amps (*b*) volts
(*c*) ohms (*d*) mhos

8. Resistance is measured in ....
(*a*) Amps (*b*) volts
(*c*) ohms (*d*) mhos

9. .... electrons pass a given point in one second, a current of one ampere is said to flow.

(*a*) 6.24×10^{16} (*b*) 6.24×10^{18}

(*c*) 6.28×10^{18} (*d*) 6.28×10^{16} mhos

10. Voltmeter is used for measuring ....

(*a*) Current (*b*) voltage

(*c*) frequency (*d*) resistance

11. Ammeter is used for measuring ....

(*a*) Current (*b*) voltage

(*c*) frequency (*d*) resistance

12. Define Ohm's law ?

(*a*) $V = IR$ (*b*) $I = VR$

(*c*) $R = I/V$ (*d*) none of the above

13. An electric current has a resistance of 23 ohms and takes a current of 5 amps. Calculate the voltage applied to the circuit ?

(*a*) 115 V (*b*) 110 V

(*c*) 120 V (*d*) 125 V

14. In chemical effect, the two conductors which make contact with the electrolyte are called

(*a*) Anode (negative plate) and cathode (positive plate)

(*b*) Anode (positive plate) and cathode (negative plate)

(*c*) None of the above

15. Metric prefixes Mega stands for

(*a*) 10^3 (*b*) 10^2

(*c*) 10^6 (*d*) 10

Answers

1. (*a*)	**2.** (*c*)	**3.** (*d*)	**4.** (*d*)	**5.** (*a*)	**6.** (*b*)
7. (*a*)	**8.** (*c*)	**9.** (*c*)	**10.** (*b*)	**11.** (*a*)	**12.** (*a*)
13. (*a*)	**14.** (*b*)	**15.** (*c*)			