CHAPTER 5

BASIC ELECTRICITY

CHAPTER's Objectives

- Describe electrical phenomena associated with the existence of electrical charges and its origin
- Discuss and distinguish between conductors and insulators
- Describe Coulomb's law of the force between two charges
- Describe the flow of charges that constitute electrical current
- Describe and apply Ohm's law in simple and complex electrical circuits
- Describe electrical instruments
- Describe power sources of energy such as batteries
- Describe and analyze basic electrical circuit properties such as current, voltage, and resistance

Electricity is a force of nature and it exists everywhere, in the air, water, in this paper that you read now, and even in our bodies.

When we control it by confining it inside wires and cables it provides a useful and safe energy for use in machines, devices, and household appliances. Useful electricity has changed our life and our views of nature.

Lightning, however, is uncontrolled electricity, fatal and dangerous electricity, which threaten life and economy as well.

How humans have developed their understanding, experience, and encounter with electricity? History tells that the ancient Greeks, during the 5th century B.C, had the first encounter with electricity. They observed that if a rod of amber, a fossilized tree resin, is rubbed with a wool cloth it attracts small pieces of leaves and straws. Because they did not understand this unusual observation, the Greeks looked at it as magic, one of the nature tricks, but for scientists of the 15th century this observation marked the beginning of new science, the electricity of matter. They give it a name, electricity, a Greek word for electron, which means amber.

In this chapter, you will learn more about electricity, its origin, the laws that describe it, the devices that measure it, and its application in electrical circuits.

5.1 Electrical phenomena

Consider these electrical phenomena that you are familiar with

- When you comb your dry hair with a plastic comb you hear a crackling sound or, if the room is totally dark, even seeing a spark. Interestingly, the comb could picks up tiny bits of paper, but a metal comb does not.
- When you walk across a wool rug on a dry day, you feel a shock when you touch a metal doorknob, or if the room is totally dark you observe a blue spark when bringing your finger close to the doorknob.
- When you slide your back a cross a car seat, you feel a shock when you touch the metal doorknob

What do all of these observations have in common? All involve different materials rubbing against each other. The comb is rubbed against the hair, the shoe is rubbed against the rug, and the person back is rubbed against the car's seat. This rubbing or the friction between two objects is responsible for all these electrical phenomena.

To understand these electrical phenomena we will do an experiment, which is illustrated in Figure 5.1. Tools needed are two plastic rulers and a piece of wool and two glass rods with a piece of silk. Figure 5.1 (a) and (b) demonstrate the outcome of rubbing both the plastic and glass by the fur and glass respectively.

Based on the observations from Figure 5.1, we conclude the following:

- The rubbing process is a charging process where charge is transferred from one object to another
- There are only two kinds of charges
- Like charges repel each other and unlike or opposite charges attract each other.
- The repulsion and/or attraction force is a non-contact force and it is inversely proportional with distance.
- Non-rubbed objects display no effect on each other, therefore, they are neutral and have both kinds charges

Benjamin Franklin proposed the terms positive and negative charge. He suggested that the glass rod that has been rubbed with silk is a positively charged object. Any other object repelled by the glass rod should carry the same positive charge. Any object attracted to the glass rod should carry a negative charge. After the discovery of the electron and proton, it was found that electron is attracted to the glass rod while the proton is repelled. From that discovery, electrons were associated with a negative charge and the protons with the positive charge.

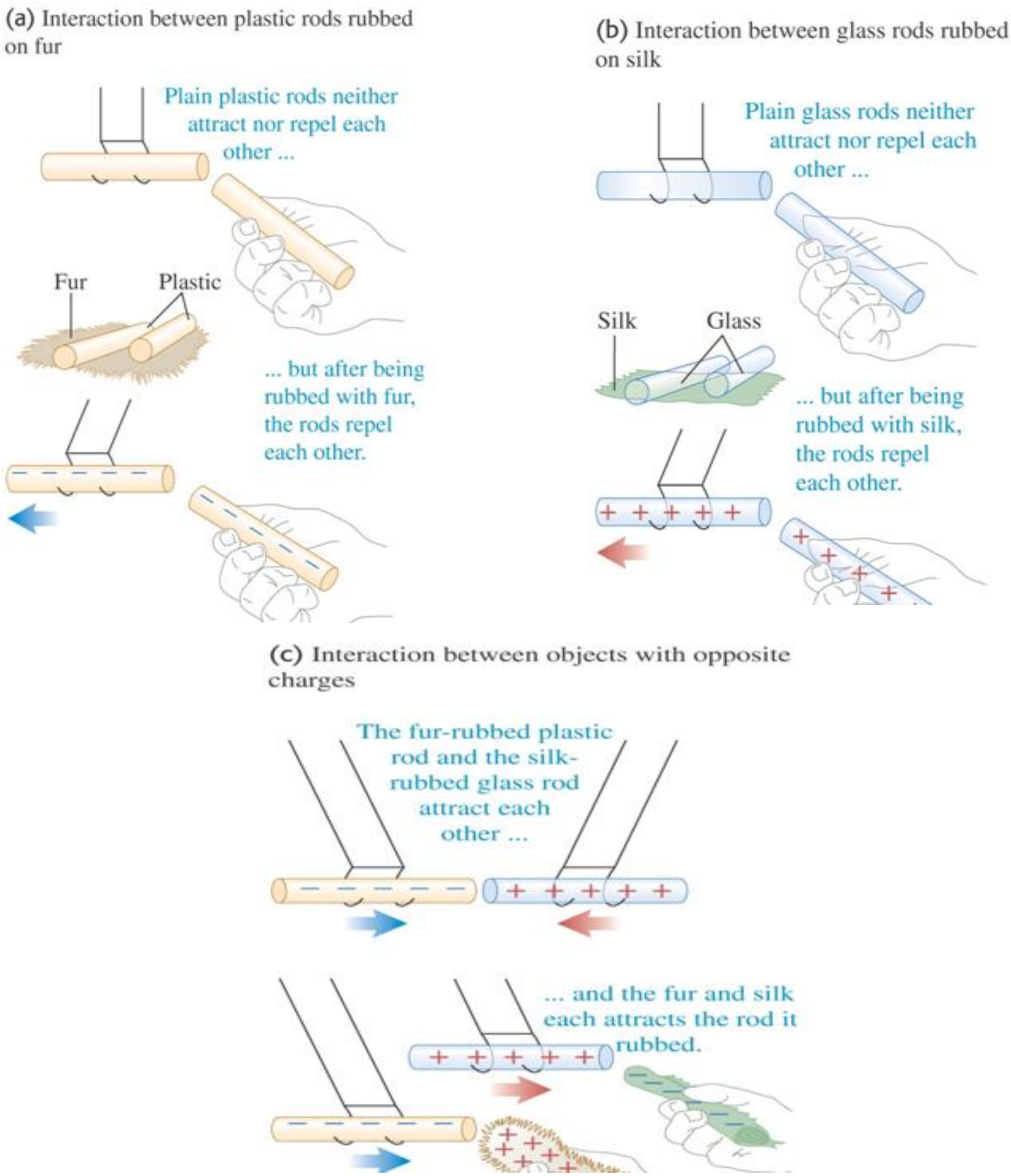


Figure 5.1: (a) When two plastic rulers are rubbed with wool they repel each other. (b) When two glass rods rubbed with silk they repel each other. (c) The rubbed plastic ruler attracted to the wool after separation of the two. The plastic ruler is repelled by the silk piece use to charge the glass rod (why?)

5.2 The origin of electricity: The atomic structure

Matter is the origin of electricity. Our knowledge of matter and atomic structure can be summarized as follows

- matter is made up of atoms
- Atoms are made up of electrons, protons, and neutrons as shown in Figure 5.2
- Each electron carries a negative charge, a proton carries a positive charge, and the neutron carries none
- Protons and neutrons are located inside the nucleus and the electrons are orbiting the positive nucleus
- At normal conditions, the atom is neutral or uncharged, meaning that the number of positive charges (protons) equal to the number of negative charges (electrons)
- If an electron is removed from an atom, then the atom becomes a positively charged atom. This is because the number of protons is now bigger than that of electrons. This is illustrated by Figure 5.2
- If an external electron is added to an atom, then the atom becomes a negatively charged atom (why?)

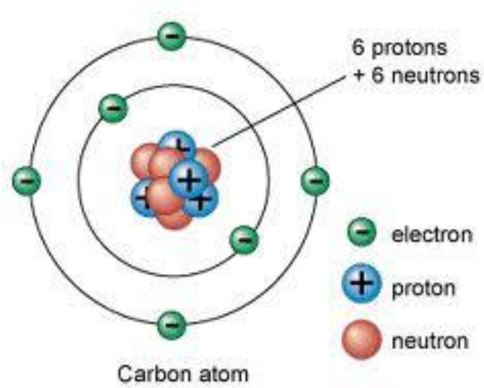


Figure 5.2: The neutral atom of carbon**.** The atom consists of 6 protons, 6electrons, and 6 neutrons. Protons and neutrons are inside the nucleus and electrons circling around the nucleus.

The atom that carries a net charge is called an ***ion***. A positive ion is an atom that losses an electron so that the number of protons is greater than the number of electrons as shown in Figure 5.2 (B). Figure 5.2 (C), however, shows that if an atom acquires an electron it becomes a negative ion (Why?).

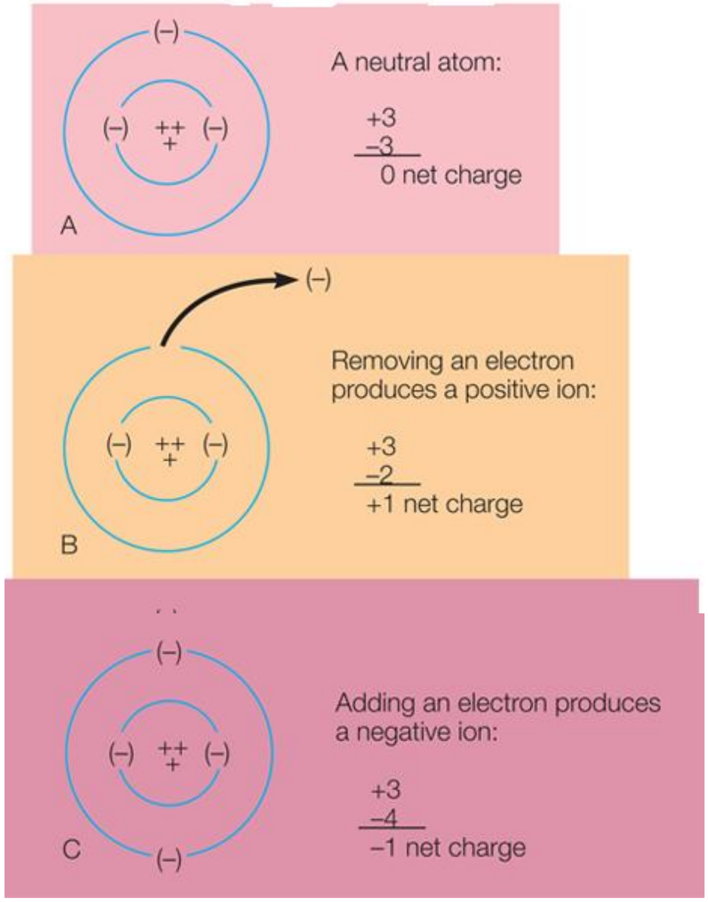


Figure 5.2: (A) a neutral atom. (B) a positive in,and (C) a negative ion. Credit**:** *B.W. Tillery, E. D. Enger, and F. C. Ross, "Integrated science", 3rd Ed., McGraw Hill 2004.*

5.2 Insulators and Conductors

Materials can be classified as either insulators or conductors. An ***insulator*** like plastic, wood, and glass is a material that does not have free electrons and do not allow electrons to move through it. ***Free electrons*** are the outer atomic electrons commonly as valence electrons.

A ***conductor,*** on the other hand, has free electrons and allows the free movement of electrons. All metals are good examples of conductors. Under certain conditions, liquids and gases can be made as good conductors too. The positive and negative ions in liquids and gases are the charge carriers and are able to conduct electricity.

To distinguish between a conductor and an insulator we will do the following observation shown in Figure 5.3. Assume we have two identical metal spheres, one is charged and the other is neutral. If we connect both balls by a metal as Figure 5.3 (B shows), we found that the neutral sphere becomes a charged one. If, instead, we connect the balls by wood as in Figure 5.3(C), the neutral ball does not become a charged one. Metals are good conductors, they conducts electricity by providing a path for the charge to flow through. Insulators, on the other hand, like wood do not allow the flow of charge to pass through.

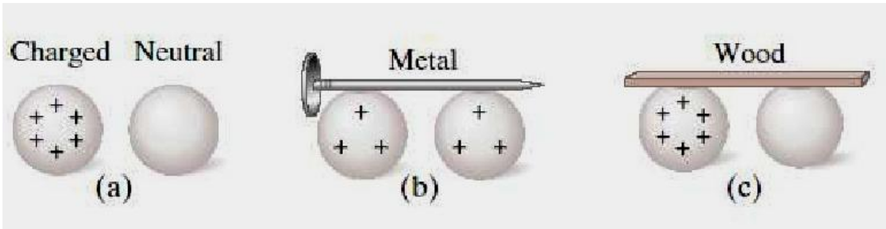
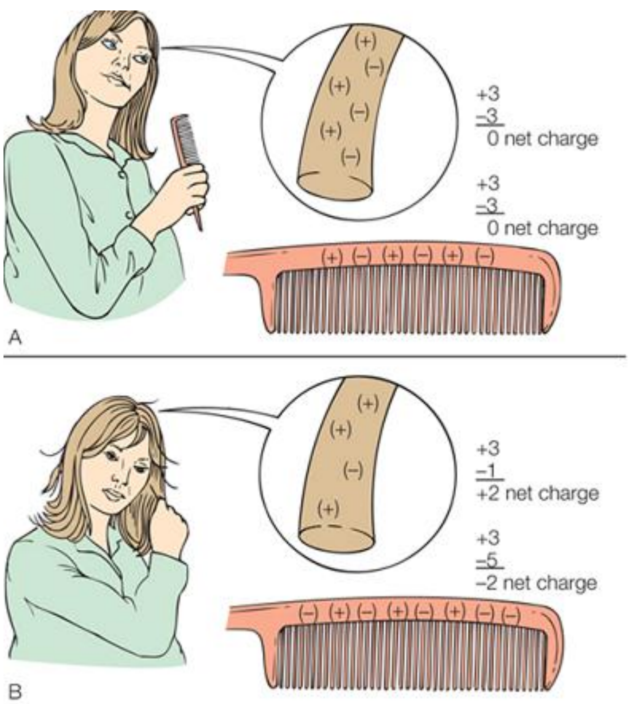
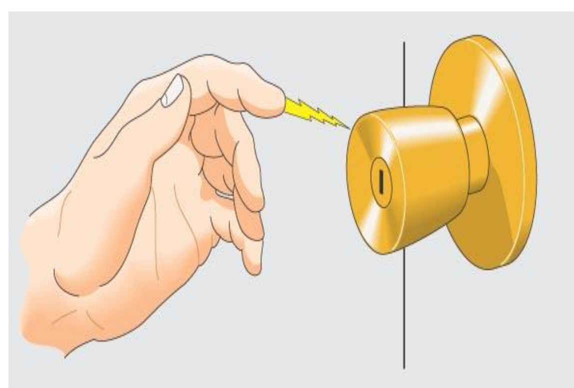


Figure 5.3 (a) A charged metal sphere and a neutral metal sphere. (b) The two spheres are connected by a metal, which allows the flow of charge between the spheres. (c) The two spheres are connected by a wood, which does not allow the flow of charge between the spheres.

5.3 Static Charge

Static charge is a build-up charge that does not move (immobile). It is a direct result of the rubbing process between two objects like a comb and hair as Figure 5.4(A &B) shows. Another example is the charge builds up on a person the walking in a carpeted room or. When this person touch a door metal knob he feels an inconvenient shock as illustrated in Figure 5.4 (C).





C

Figure5.4: The buildup of static charge during a rubbing process of two objects. Figure 5.4 (A &B) are before and after rubbing the comb against hair. Credit (A &B): *B.W. Tillery, E. D. Enger, and F. C. Ross, "Integrated science", 3rd Ed., McGraw Hill 2004.*

5.4 Charging of Matter

5.4.1 Charging an Insulator

Insulators like plastic and glass can be charged by rubbing them with a cloth. Figure 5.5 illustrates what happens when a plastic rod is rubbed with wool. Detailed explnation of this process implies the following

- Rubbing is friction and produces frictional force
- Frictional force breaks the large molecular bonds on the surface of the wool and produce a positive and negative ions
- The positive ions stay on the wool and the negative ions transfer to the plastic. A positive charge appears on the wool and a negative charge on the plastic
- These charges are immobile (why?) and stay at rest. This explains why the charge appears on points of contact with wool only.
- Charge is conserved; there is no creation or destruction of charge

Similar observation is noticed when the glass rod is rubbed by silk

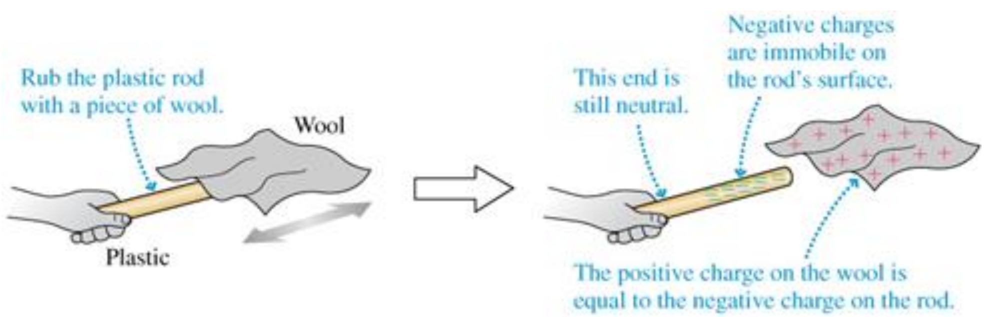


Figure 5.5 Charging an insulator (plastic rode) by rubbing it with a cloth (wool). Courtesy of *Randall D. Knight* "*Physics for scientists and engineers a strategic approach*" by Pearson-Addison Wesley 2004.

5.4.2 Charging a Metal

Neutral metals can be charged by ***conduction*** and ***induction*** processes. Charging by conduction process consists of touching a neutral metal by another charged meta, charged with positive or negative chargel. Figure 5.6 illustrates what happens when a charged object touches an intially neutral metal. Conduction process implies the following

- The neutral metal must be touched by a charged object
- Touching implies electron transfer between the two touched objects
- After removing the charged object, the metal keeps the charge on it
- Charge is conserved; there is no creation or desruction of charge

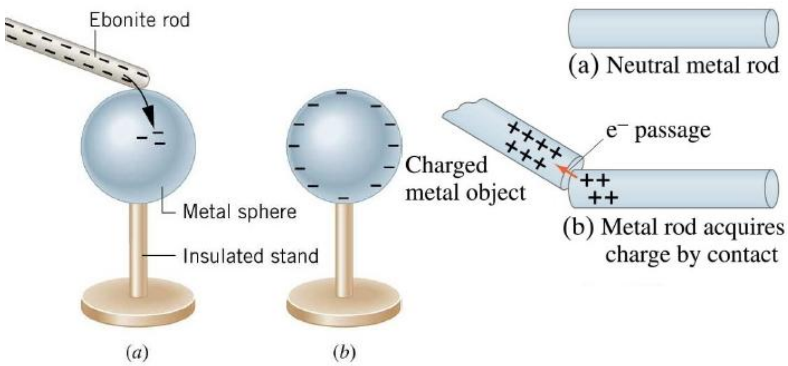


Figure 5.6: charging a metal by conduction. (a) And (b) implies before and after touching respectively.

Figure 5.7 illustrates what happens when a metal is charged by induction. The process of induction implies the following

- No contact between objects. Instead, the charged object of positive or negative scharge is brought close to the neutral metal
- The neutral metal is polarized. Polarization separate the negative and positive charges
- Connect the bpolarized metal to the ground while the charged object is still close
- Removeing the charged object will leave the metal with a net charge on it. Charge is distributed uniformally on symmetic metals

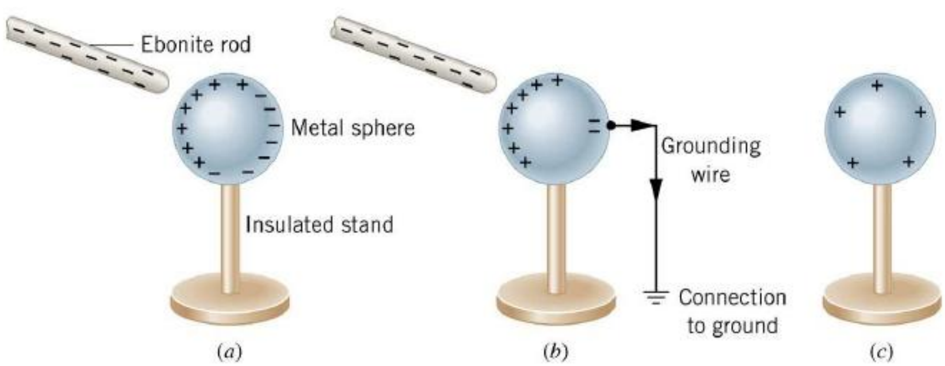


Figure 5.7: charging a metal by induction. (a) Charge is separated (why), (b) grounding allows electrons travel to ground, and (c) positive charge distributed uniformly on sphere.

5.5 Charge Detector: The Electroscope

The ***electroscope*** as shown in Figure 5.8 is a device that is used for detecting charges. It consists of two lmovablel leavs of thin metalic foil made of gold or aluminum. The two leavs are connected by a metal to metal ball. The two leaves are protected from outside disturbances such as air currens by a glass walled container. The device works as follows

- If a negatively charged object is brought close to the metal sphere it separates charge on the electrscope. negative charge are pushed a way by repulsion and setteled at the leaves leaving the ball with a postive scharge

- If the metal ball is touched by negatively charged object, the electroscope then acquired a net charge (by conduction) as shownin Figure 5.8 (a). The separation of the leaves depends on the amount of charge on the charged object; the greater amount of the charge, the greater the separation of leaves as shown in Figure 5.8 (b)

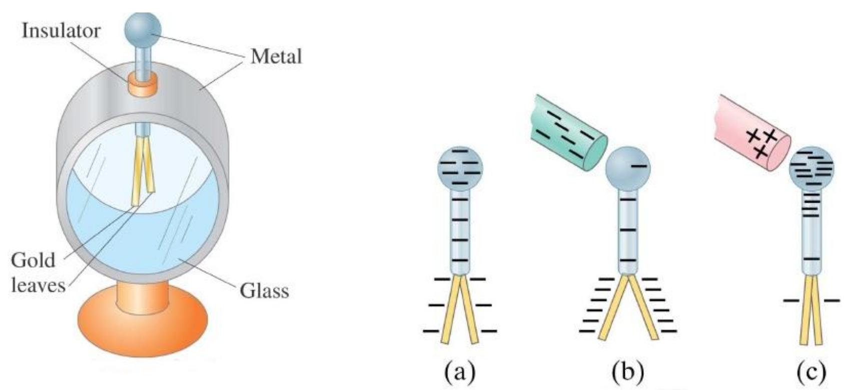


Figure 5.8: The electroscope. (a) A negatively charged electroscope by conduction. (b, &c) Negatively charged electroscope used to determine the charge sign on unidentified charged objects.

To use the elcetroscope to identify the sign of the charge on a charged object, the following must be done

- Charge the electrscopewith a negative charge by conduction as shown in Figure 5.8 (a)

- Bring the charged object close and observe the effect on the leaves. A negatively charged objects increases the separation of leaves as shown in Figure 5.8 (b). A positively charged object reduces the separation between the leaves as shown in Figure 5.8 (c)

Example 5.1

Is pure liquid water a good or bad conductor? If the answer is no, can you develop a procedure to make a pure water reasonbly good conductor? Is the human body good or bad conductor?

Solutio

Pure water is not good conducror. Adding, however, salt to it will make it a reasonbly good conductor.

This is how. The water attacks the salt molecules and break them down into Na^{+} and Cl^{-1} ions. These ions are the charge carriers, which allow water to conduct electricity. 75% of human body consists of salt water, and therfore human body is reasonably a good conductor. If we touch a positively charged metal, for example a non grounded microwave, the Cl^{-1} ions on the skin surface give off their extra electrons to the metal in contact , neutralizing the metal and the chlorine atoms as well. This decrease of Cl^{-1} ions from the skin leaves the human body with net Na^{+} positive charge that will be distributed uniformally around the human body’s surface.

Example 5.2

Is air a good or bad conductor? How about earth?

Solution

Moist air (saturated with water vapor) is poor conductor. If a charged object (such as a rubbed plastic ruler or rubber balloon) is left in air, the air, slowley, neutralizes the plastic or the balloon and leave it neutral.

Earth, on the other hand, is a big conductor because of its huge amount of water, its wet soil, and different ions. A charged object (with positive or negative charge) that is connected to earth through a conductor such a wire made of copper as in Figure 5.7 (b) is a grounded object and it will lose its cahrge completely.

5.6 Grounding

Grounding *or* ***earting*** is connecting an electrical device such as TV, refregrator, a microwave, or a hand drill as shown in Figure 5.9 to the ground to provide a discharge path of all charge build up on the surface of these dvices or the case they enclose in . Charge build up is the result of a circuit break or fault in theelectrical circuit.

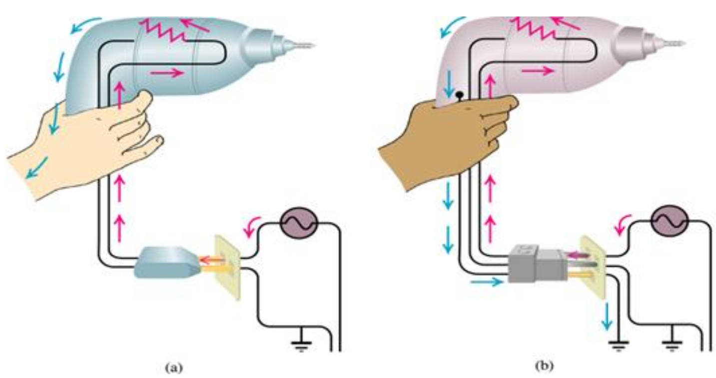


Figure 5.9: (a) ungrounded circuit (b), and grounded circuit. Grounding ensures safety by providing path for buildup charge to ground to ensure safety.

Therfore, grounding ensures that these objects are at ground voltage or zero voltag. For safety purposes, most apliances and elecronics use a three-prong plug wiring. The third circular prong is a connection to the ground; itcon nects the device to the ground. Through wiring of a building (house for example), the third circular prong is connected deep in the ground outside the building to a metal water pipe for example.

5.7 The Unit of Charge: Charge Quantization

The metric (SI) unit of charge is the ***Coulomb*** (C). The electron and proton have charges of opposite sign but exactly of the same magnitude. This charge is represented by the letter e. In terms of Coulomb C, e can be written as

$$e = 1.6\times10^{-19}C$$

Charge quantization means that the charge on any object q can be written as

$$q = ne \tag{5.1}$$

Where n refer to the number of electrons.

Example 5.3

Find the number of electrons in 1C of charge?

Solution

Given Data: q = 1C,

Wanted: n

$$\because\ q = ne \Rightarrow \therefore\ \ n = \frac{q}{e} = \frac{1C}{1.6\times10^{-19}C} = 6.25\times10^{18}\text{Electrons or protons}$$

5.8 Coulombs Law

Coulomb's law is a descrecption of the of the electrical force between two charges and on the factors that affect the magnitude of this force. As Figure 5.10 shows to charged objects having charges q_1 and q_2 be separated by a distance d .

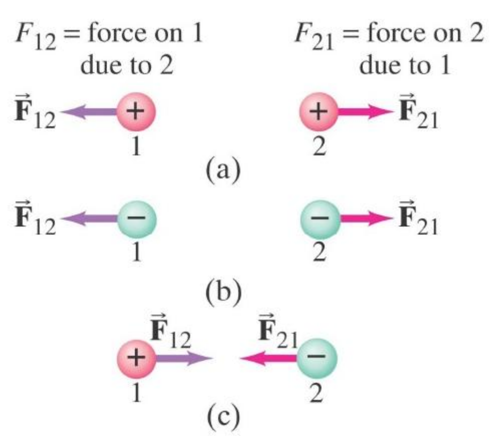


Figure 5.10: Coulomb's force between two charges. (a &b) a repulsive Coulomb force for charges of same sign. (c) attractive Coulomb's force for opposite sign charges

Coulomb's forces on each other have magnitude given by

$$F_{1on2} = F_{2on1} = \frac{kq_1q_2}{d^2} \quad (5.2)$$

Where $k = 9\times10^9\, N.m^2 / C^2$ is a constant called Coulomb's constant.

Coulomb' slaw implies the following

- Coulomb's forces are action/reaction force (non contact forces). It applies for charges at rest only
- Coulomb's forces are directed along the line connecting the two charged objects
- Coulomb's forces are attractive for opposite charges and repulsive for like charges
- Coulomb's force is proportional to the product of the charges and inversely proportional to the square of the distance between the two charges

Example 5.4

Two positive charges, each of magnitude $2\times10^{-6}\,C$, are located a distance of 10 cm from each other. (a) What is the magnitude of the force exerted on each charge? (b) On a drawing, indicate the directions of the forces acting on each charge

Solution

Given Data

$$q_1 = q_2 = 2\times10^{-6} C,\ \ d = 10cm = 0.01m,\ \ k = 9\times10^9\, N.m^2 / C^2$$

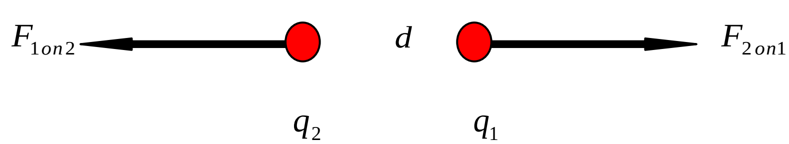
Wanted: (a) magnitude and (b) direction of Coulomb's force

(a)

$$\because F = \frac{kq_1q_2}{d^2} = F_{1on2} = F_{2on1}$$

$$\therefore F = \frac{(9\times10^9\, N.m^2 / C^2)(2\times10^{-6})(2\times10^{-6)}}{(0.1)^2\, m^2} = 3.6N$$

(b)



5.9 Electric Field $\vec{E}$

According to the British scientist Michael Faraday who introduced the concept called the field, a charge modifies the space, or field, around it, and when a second charge is placed near it the second charge feels a force of the field at its location. The second object sets up its own field around it and acts on the first object the same way the first object acts on it. The space around the charge that exerts a force on other charges is called the ***electric field*** $\vec{E}$ **.**

The electric field is a vector and at each point it has a magnitude and direction. Its magnitude depends on the charge that produces it and inversely on the distance between the two charges. It is represented by lines. For a positive charge the lines point outward and inward for a negative charge. Figure 5.11shows electric field lines of positive and negative charges. When two opposite charges brought close to each other, the field lines look much like that shown in Figure 5.11(c), the lines start at the positive and end at the negative charge.

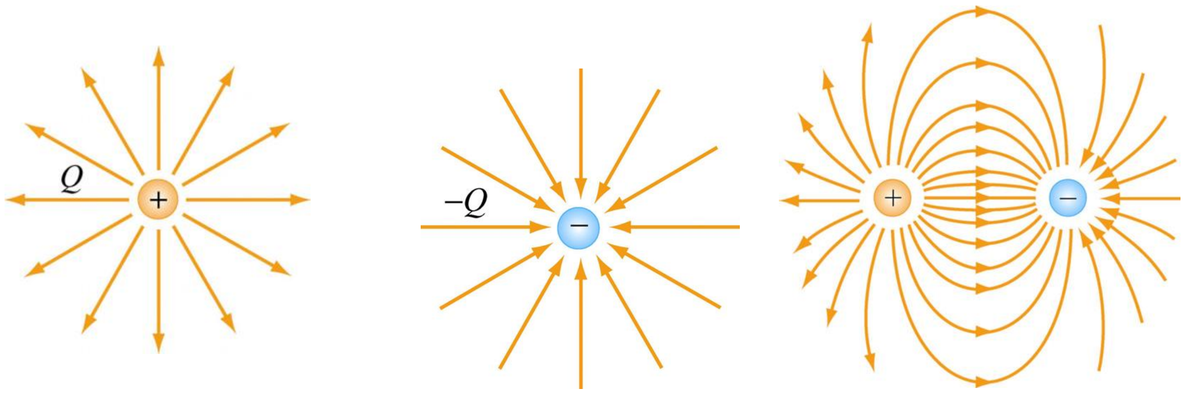


Figure 5.11: electric field lines of (a) a positive, (b) negative, and (c) when both charges are broufgt close to each other.

5.10 Electrons Motion Inside a Wire: The Electron Current i

A metal wire like a copper, for example, has too many of free electrons. On the average, each copper atom donates one free electron. In copper, there are about 5.8×10^{28} free electrons / m^3. A 20 cm wire made of copper contains about 5×10^{22} free electrons (how?). The rate flow of these free electrons in the wire is called can easily move ***electron current*** i, which can written as

$$i = \frac{n}{t} \tag{5.3}$$

Where n is the number of electrons per unit of volume, and t is time.

Typically, in 2 mm diameter copper wire at room temperature the number would be $i \approx 10^{19}$ electrons / sec. This means that 10^{19} electrons pass through a circle of 2 mm diameter each second.

Because of heat, these free electrons are moving in an arbitrary way. Meaning that they move in all directions and at different speeds and, therefore, there is no net motion as shown in Figure 5.12 (a).

To overcome this arbitrary motion, an external source is needed to push on the electrons continuously and force them to move in one direction at constant speed i.e., have a net motion like a gas or liquid flowing inside a pipe. The flow of the fluid (gas or liquid) inside the pipe is maintained by the pressure difference at both ends of the pipe. Similarly, the metal wire must be connected to a device, which maintains a potential difference or an electric field at both of its ends. The electric battery is such a good choice.

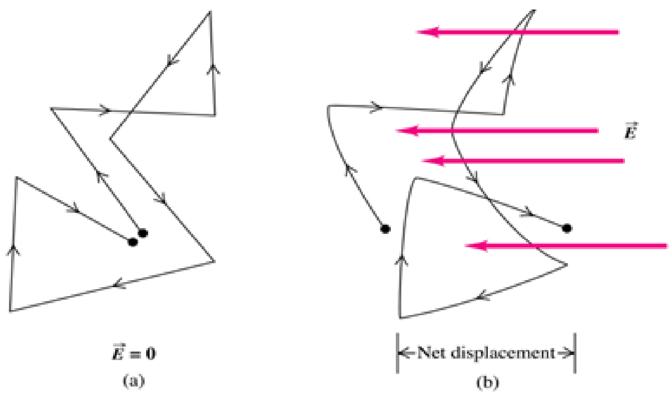


Figure 5.12: Electron motion inside a wire. (a) electron motion without an external source of electric field E. (b) a net motion caused by an external source of electric field.

5.11 Electric Battery

Electric battery is a device that produces electricity by changing chemical energy into electrical energy. Basically, the battery consists of two dissimilar metallic plates such as zinc and carbon called electrodes immersed inside a solution of a dilute acid or a paste called electrolyte.

To see how it works, we need to look inside the battery. As a consequence of chemical reaction between the electrolyte and the electrodes, the battery removes electrons from one electrode and positive charge from the other. The electrode that loses electrons becomes positively charged and the other one that looses a positive charge become a negatively charged electrode. The battery then pushes the released electrons towards the negatively charged electrode. This push (work done) against the repulsive force increases the electrical potential energy of these electrons i.e. these electrons become energetic. This is similar to the situation of lifting an object upward against the force of gravity and resulted of increasing gravitational potential energy of the object.

Figure 5.13 shows that the battery works as a charge escalator between the two electrodes, doing work by lifting electrons from bottom to top. The energy spends to run the escalator comes from the chemical energy released due to the chemical reaction of removing electrons and positive charges inside the battery.

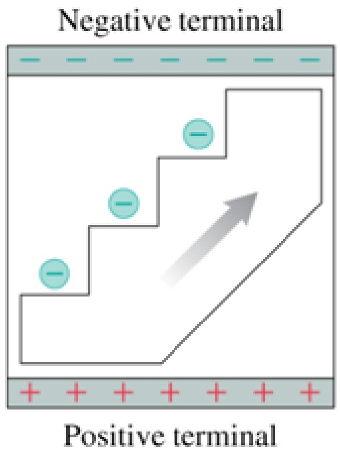


Figure 5.13: A battery works as a charge escalator, lifting electrons from positive terminal to the negative terminal**.** *Credit***:** *Randall D. Knight* "*Physics for scientists and engineers a strategic approach*" *by Pearson-Addison Wesley 2004*.

This separation of charges creates a potential difference or voltage between the two electrodes.

When the two ends of the copper wire are attached to the battery as Figure 5.14 shows, the energetic electrons of the battery produce an electric field $\vec{E}$ inside the wire. This field forces the free electrons inside the wire to line up and move with constant speed.

To see how the battery pushes on the electrons inside the wire, let us make an analogy with a hose filled with water and attached to a faucet. For each drop of water that enters the end of the hose attached to the faucet a one drop of water leaves from the other end of the hose. Similarly, for each electron that enters the wire from the negative electrode one electron must leave the wire and enters the positive electrode.

This flow of electrons inside the wire is called electron current and the flow continues as long as the chemical reaction is capable of removing charges from the electrodes and lifting electrons up the escalator

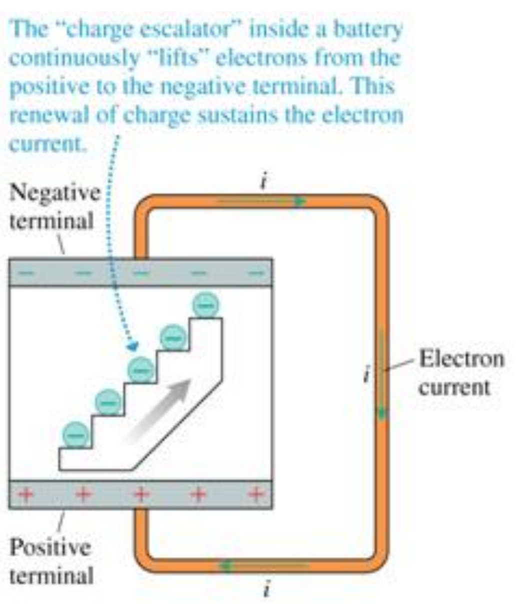


Figure 5.14 The electron current through a wire connected to a source of energy (battery). This current is shown as i . Credit: *Randall D. Knight* "*Physics for scientists and engineers a strategic approach*" by Pearson-Addison Wesley 2004.

5.12 Voltage and Electric Potential energy

Lifting a charge up through the escalator against the electric force of repulsion requires work. This work will be stored in the charge as an electrical potential energy U , which can be written as

$$U = q \times V,\ or$$
$$V = \frac{U}{q} \qquad (5.3)$$

Where, q is the charge, and V is the electric potential difference between the two positive and negative electrodes or the voltage. The metric (SI) unit of voltage is Joule/Coulomb or simply ***volt***. One volt is the potential difference between two points if one Joule of energy is used to move one Coulomb of charge between the two points

Example 5.5

How much work does the charge escalator do to move $1.0 \times 10^{-6} C$ of charge from the negative electrode to the positive electrode of 1.5 V battery?

Solution

Given Data

$$q = 1.0 \times 10^{-6} C$$
$$V = 1.5 volt$$

Wanted: work (stored potential energy)

$$\because U = q \times V$$
$$\therefore U = (1.0 \times 10^{-6} C)(1.5 volt) = 1.5 \times 10^{-6} J$$

The work done by the escalator on the charge is stored as electric potential energy of the charge

5.7 Conventional Electric Current I

The electron current given in equation 5.3 is not practical one because it involves a huge number of electrons that hard to count. To resolve this problem a ***conventional current I*** was introduced. It is the rate flow of charge of electrons rather than just electrons, which can be expressed as

$$I = \frac{q}{t} \qquad (5.4)$$

Where, $q = ne$ is the charge in Coulomb and t is time in seconds. The metric (SI) unit of this current is ***Ampere*** (or Amp). One Ampere is the rate of flow of 1 Coulomb of charge (or 6.25×10^{18} electrons) passing a point in 1 sec.

5.7.1 The relationship between conventional and electron currents

By rewetting Equation 5.3, we get

$$I = \frac{q}{t} = \frac{ne}{t} = ei, \qquad where\ i = \frac{n}{t} \tag{5.5}$$

Equation (5.5) shows that the conventional current is related to the electron current by electron charge factor. Therefore, we can define both as follows

By applying the data given above, we can establish a value for the current I

$$\because I = ei$$
$$\therefore\ I = (1.6\times10^{-19}C)(10^{19}\,electron\,/\,\mathrm{sec}) = 1.6\,Amp$$

Apparently, this shows that the magnitude of the conventional current makes more sense than the electron current.

One further difference between the two currents is associated with their directions. When a battery is connected to the wire, the positive charges move, from positive electrode through the wire and to the negative electrode, in opposite directions to that of the negative charges (electrons). Upon this consideration, the conventional current was viewed as the flow of positive charges inside a metal. In measurement, a positive current is equivalent to the negative current meaning that their effects are exactly the same.

From now and on, we will stick with the idea that the electrical current inside a wire is due to the flow of positive charges moving in opposite direction to the electrons. Figure 5.15 depicts the positive charges moving with drift velocity v_d from the battery's positive terminal to the wire and bulb and back to the negative terminal

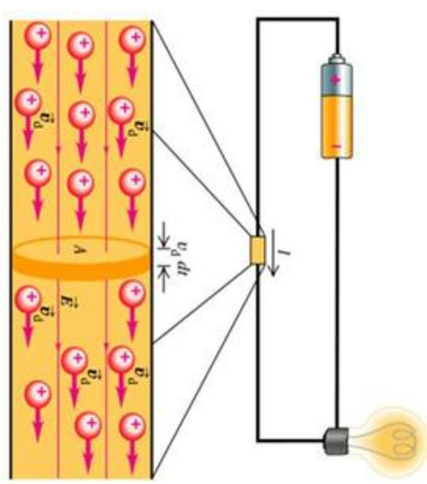


Figure 5.15: The conventional current. Positive charge move with drift velocity v_d and passing through a wire crossectional area A. The battery provides an electric field E.

In this course we will consider only one kind of current called ***direct current*** or simply DC in circuits. It is the current where the charged electrons flow in only one direction because the potential difference of the source is unchanging. The current that changes direction is called ***alternating current*** or AC. Usually, batteries produce DC current and generators produce AC current.

5.8 Electrical Resistance R

When electrons move in the wire they collide with the atoms of the wire and other electrons within the wire. Because of these collisions, the electrons lose energy, which appears as heat and they slow down. Similar to friction, this process of collision opposes the motion of electrons. This opposition to the flow of charge is called ***resistance*** *R*. The resistance slows down a current, the higher the resistance, and the lesser the current. The metric (SI) unit of resistance is the Ohm or the symbol Ω (omega).

5.9 imple Electrical ircuit

Typical simple electrical circuit consists of the following elements shown in Figure 5.16

- Source of energy and voltage such as a battery B
- Resistor, which is a wire or any electrical element such as a bulb with resistance *R*
- Wires to connect the source (battery) to *R*(s)

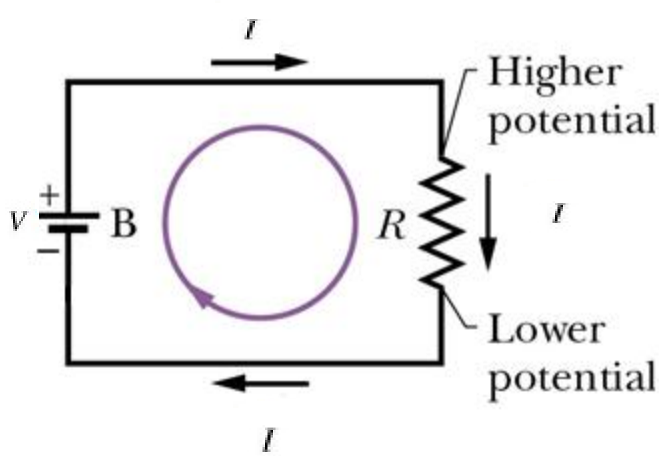


Figure 5.16: A simple electrical circuit. the circuit consists of source of voltage or energy, resistor(s), and wires.

Figure 5.16 implies the following

- The circuit current *I* is the conventional current directed as shown from positive terminal, to the wire, to the resistor *R*, and back to the negative terminal. This continues as long as the battery B is functioning
- The current *I* always entrer the resistor from the higher potential point and leaves at the lower potential point

- The potential difference or voltage a cross the resistor *R* equals the Battery's voltage *V*. This potential difference is responsible for the current flow thnrough the resistor *R*

5.10 Ohm's aw

Ohm's law states that: when a voltage *V* or potential difference ΔV is applied a cross a resistor with constant resistance *R*, there will be a current *I* that is directly proportional to ΔV . This can be expressed as

$$I \propto \Delta V, \quad or$$

$$I = \frac{\Delta V}{R} \tag{5.6}$$

Equation (5.6) is called Ohm's law. Ploting *I* versus ΔV gives a strsight line realtion as shown in Figure 5.17. This direct or linear realation between voltage and current indicates that the current increases when the voltage increase. From now and on, we will drop the Δ symbol on the potential difference and write Omm's law as $I = \frac{V}{R}$.

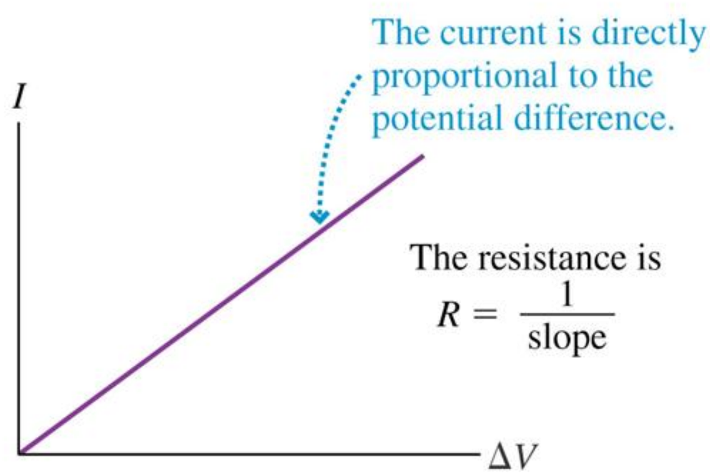


Figure 5.17: Ohm's law: For a conductor of constant resistance *R*, current *I* increase with voltage *V*. Credit: *Randall D. Knight* "*Physics for scientists and engineers a strategic approach*" by Pearson-Addison Wesley 2004.

Caution: many texts write Ohm's law as *V* = *IR*. This is misleading because it suggests that current produces or causes potential difference (voltage).

Example 5.6

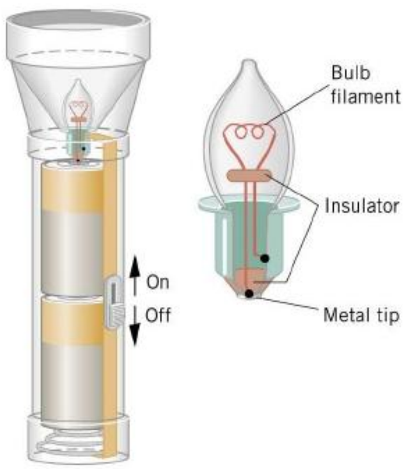
A flashlight bulb is connected to3.0 *V*. If the current through bulb is 15 mA (milliamp), what is its resistance?

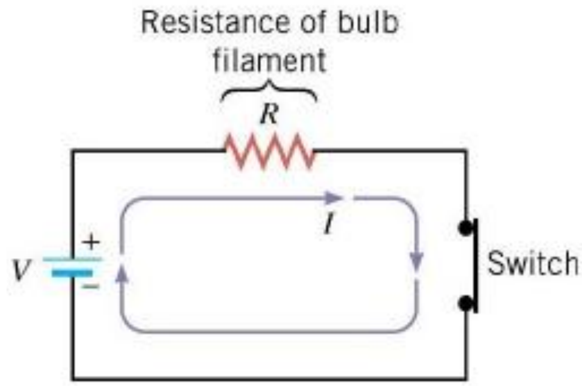
Solution

Given Data: $V = 3.0V,\ I = 15mA = 15\times10^{-3}A = 1.5\times10^{-2}A$

Wanted: R

Sketch a diagarm of the problem:





$$\because\ I = \frac{V}{R},\ \therefore R = \frac{V}{I} = \frac{3V}{1.5\times10^{-2}A} = 200\Omega$$

5.11 Electrical Power

The battery supplies energy $U = qV$ to charge q as it lifts the charge from the negative to the positive terminal. ***Power*** is the time required to supply this energy to the charge or the rate at which energy is transferred. This can be written as

$$P = \frac{energy}{time} = \frac{qV}{t} = (\frac{q}{t})V, \quad or \qquad (5.7)$$
$$P = IV$$

Example 5.7

A 90 Ω resistor is connected to a 120 V battery. How much power is delivered by the battery?

Solution

Given Data: $R = 90\Omega,\ V = 120\,volt$

Wanted: P

$$\because P = IV \ \& \ I = \frac{V}{R} \Rightarrow \therefore \ I = \frac{120V}{90\Omega} = 1.33A$$
$$\therefore \ P = (1.33A)(120V) = 160W$$

5.12. Types of Circuits: Series and Parallel Circuits

5.12.1The Series Circuit

A circuit with two or more resistors connected end to end without branching or junction points between them as shown in Figure 5.18 (A) is called a ***series circuit***. It has the following properties

- The current *I* is the same in the circuit, or $I = I_1 = I_2 = I_3 = ...$
- The source voltage *V* equals the sum of voltage drops in each element, or $V = V_1 + V_2 + V_3 + ...$
- The total resistance *R* of the circuit (equivalent resistance R_{eq}) equals the sum of all resistances in the circuit , or $R = R_{eq} = R_1 + R_2 + R_3 + ...$

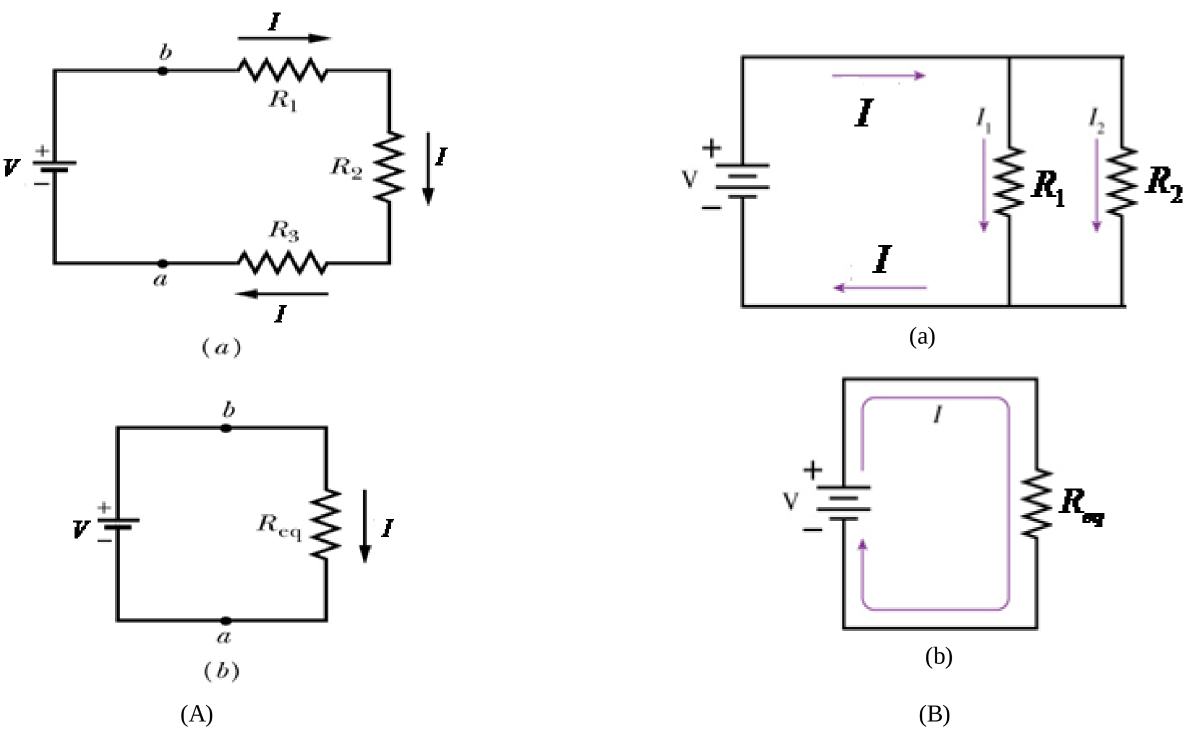


Figure 5.18: (A) Series circuit (a) and its equivalent circuit (b). (B) parallel circuit (a) and its equivalent circuit (b).

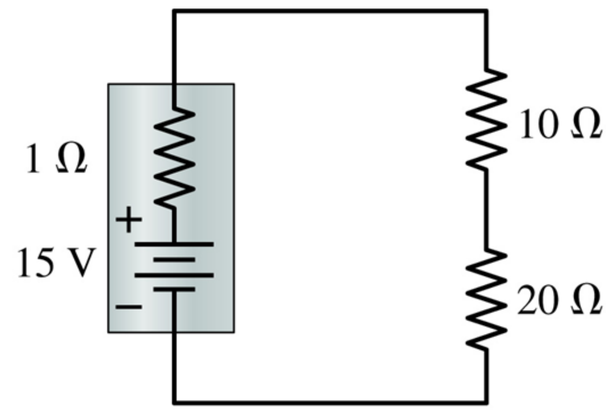
Example 5.8

The series circuit shown below consists of a 15 V battery with internal resistance of 1 Ω and two external resistors of 10 Ω and 20 Ω respectively. Find (a) the equivalent resistance, (b) the total current in the circuit, and (c) the voltage on each resistor.

Solution

Given Data: $V = 15V, R_1 = 1\Omega, R_2 = 10\Omega, R_3 = 20\Omega$

Wanted: $(a) R_{eq}, (b) I, (c) V_1, V_2, V_3$



$(a)\ R_{eq} = 1 + 10 + 20 = 31\Omega$

$(b)\ I = \dfrac{V}{R_{eq}} = \dfrac{15}{31} = 0.484\,Amp$

$(c)\ V_1 = IR_1 = (0.484A)(1\Omega) = 0.484V$

$V_2 = IR_2 = (0.484A)(10\Omega) = 4.84V$

$V_3 = IR_3 = (0.484A)(20\Omega) = 9.68V$

5.12.2 The parallel Circuit

A circuit with two or more resistors aligned side by side with their ends connected at two common points as shown in Figure 5.18 (B) is called a ***parallel circuit***. It has the following properties

- The total current I split at the upper common point (branching point) into currents I_1 and I_2, or $I = I_1 + I_2 + \ldots$. At the lower common point (recombination point), the two currents are recombined into current I

- Because the ends of all the resistors are connected to the same common points, the voltage across each resistor is the same and equals the source voltage, or $V = V_1 = V_2 = V_3 = \ldots$

- The total resistance R of the circuit(equivalent resistance R_{eq}) can be found from

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

Caution: The equivalent resistance in a series circuit is larger than the largest resistance in the circuit. The equivalent resistance in a parallel circuit is smaller than the smallest one in the circuit.

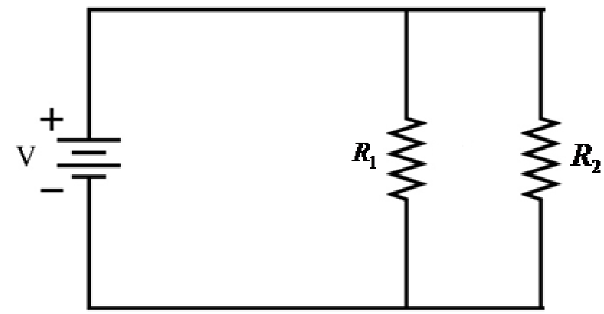
Example 5.9

For the parallel circuit shown below assume $R_1 = 3\Omega$, $R_2 = 6\Omega$, and $V = 9V$. Find (a) R_{eq}, (b) V_1 and V_2, and (c) I_1 and I_2

Solution

Given Data: $R_1 = 3\Omega$, $R_2 = 6\Omega$, $V = 9V$

Wanted: (a) R_{eq}, (b) V_1 and V_2, and (c) I_1 and I_2



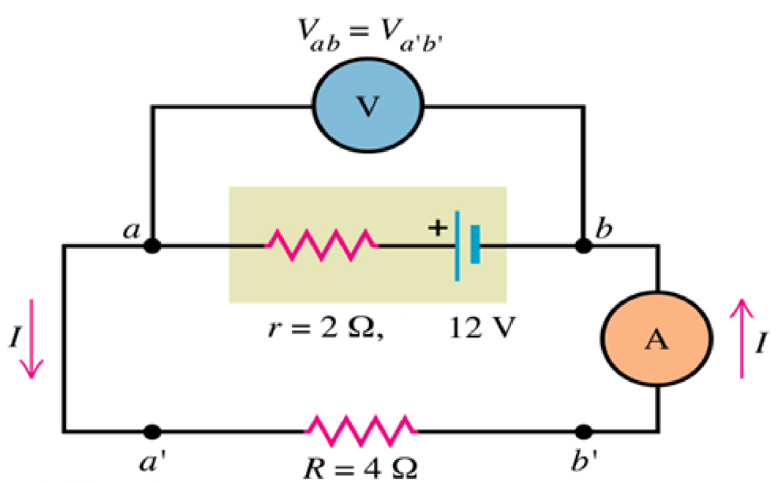
(a) $\frac{1}{R_{eq}} = \frac{1}{3} + \frac{1}{6}, \Rightarrow R_{eq} = \frac{3\times 6}{3+6} = 2\Omega$

(b) $V_1 = V_2 = 9V$

(c) $I = \frac{V}{R_{eq}} = \frac{9V}{2\Omega} = 4.5Amp, \quad I_1 = \frac{V_1}{R_1} = \frac{9V}{3\Omega} = 3Amp, \quad I_2 = \frac{V_2}{R_2} = \frac{9V}{6\Omega} = 1.5amp$

5.13 Electric Instrument

1. ***Voltmeter*:** it measures the difference in potential (potential drop or voltage) between two points in a circuit. It is represented by a circle with the letter V inside it as shown in Figure 5.19. Therefore, the voltmeter should always be connected in parallel with these two points as shown in Figure 5.19.



2. *Ammeter*: It measures the current in the circuit. Therefore, it should be connected in series in the circuit. Figure 5.19 shows the ammeter as represented by a circle with the letter A inside it.

Sumary of chapter 5

Electricity is natural force, which yield energy that runs machies and instrumnets. It originates inside matter through the charge carriers, namely the *electrons* and *protons.* Like charges repel each other and unlike charges attarct each other. Rubbing insulators with cloths like plastic with fure produces *staic electricity*, an immobile buildup of charge due to transfer of electrons from fure to the plastic. Both fure and plastic become charged objects. *Polarization* is a separation of positive and negative charge inside matter because of bringing a charged object close to a neutral one. Metals are good *conductors*. A conductor loke copper has free electrons and allows the free movement of free electrons through it. A neutral metal can be charged by *conduction* or *induction*. Conduction implies touching the neutral metal by a charged metal and induction implies bringing a charged metal close to the neutral metal to polarize it. The *electroscope* is a device used to detect and determine the identity of the charge on an object. *Coulomb's law* express the force between two stationary charges. It depends on the multiplication of the charges and inversely proportional to their distance. *Electrical current* is the organized motion of electrons inside a wire because of the effect of an *electric field* caused by a *potential difference* resulted from a source of energy like a *battery.* A battery is a device that separate charges from its terminals and supplies energy and potential difference inside wires to produce current. A *conventional current* is the flow of charges; it is defined as charge per unit time. Convention is adopted and suggests that it is the flow of postive charge. An electrical *circuit* provides a closed path to the conventional current. Typically, a circity consists of a source of energy like a battery and a load. The load consists of *resistors* and other elements that fed on electrical energy like a motor. A resistor is a circuit element like a lightbulb that reduces the current in the circuit. Usually, resistors are combined in *series* or in *parallel*. In a series circuit, the resistors are combined end to end without any junction or branching points inbetween so that current is conserved. A parallel circuit consists of resistors combined side by side to two common points so that the potential differnce between thire ends is conserved.

Basic Principles and facts

- Rubbing of two objects process is a charging process where conservation of charge apply
- Like charges repel and unlike charges attract each other
- Through a chemical reaction, a battery supplies separated charges with electrical potential energy
- Coulomb's forces are action and reaction forces

Basic equations

Coulomb's law: two charges $q_1$and q_2 separated by a distance *d* experience a force of repulsion or attraction

$$F_{1on2} = F_{2on1} = \frac{kq_1q_2}{d^2}$$

Ohm's law: the potential difference ΔV across a resistor of resistance *R* produces a current

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

Chapter 5 Worksheet

Part 1: Multiple choices

1. The atomic particle that carries a negative charge is called
   A. The electron
   B. The proton
   C. The neutron
   D. The atom

2. The atomic particle that carries a positive charge is called
   A. The electron
   B. The proton
   C. The neutron
   D. The atom

3. The force between two like charges is
   A. Attractive
   B. Repulsive
   C. Both repulsive and attractive
   D. There is no such force

4. By rubbing two objects we can charge
   A. A Battery
   B. A conductor
   C. An insulator
   D. Both insulator and a conductor

5. The process by which a metal is charged when it is touched by a charged object is called
   A. Static electricity
   B. Polarization
   C. Induction
   D. Conduction

6. The process by which a metal is charged when it comes near a charged object is called
   A. Staic electricity
   B. Polarization
   C. Induction
   D. Conduction

7. When two objects rubbed together like a comb and hair
   A. Protons transfer from one to another
   B. Atoms transfer from one to another
   C. Electrons transfer from one to another
   D. Neutrons transfer from one to another

8. Which of the following is an insulator
   A. Glass
   B. Copper
   C. Aluminum
   D. Water

9. When the distance between two charges is reduced into a half the force between them will be
   A. Reduced by a half
   B. Reduced by a ¼
   C. Doubled
   D. Increased by four times
10. According to Ohm's law, the potential difference across a conductor (wire) of resistance R
    A. Creates current
    B. Creates voltage
    C. Creates resistance
    D. All of the above

Part2: True/False. If the answer is false, then correct it.

1. Insulators allow the movement of free electrons inside them.
   A. True
   B. False
2. Insulators have free electrons and conductors do not.
   A. True
   B. False
3. Staic electricity is the buildup of charge as result of friction between two objects.
   A. True
   B. False
4. The total (equivalent) resistance in a series circuit is given by the sum of the inverse of the individual resistances.
   A. True
   B. False
5. The total (equivalent) resistance in a parallel circuit is given by the sum of the sum of the individual resistances.
   A. True
   B. False
6. The current in a parallel circuits is give by the sum of currents in the branches.
   A. True
   B. False
7. Batteries supply AC current.
   A. True
   B. False
8. Conventional current is the flow of negaqtive charge from the positive terminal, to the connecting wire, and back to the negative terminal of a battery.
   A. True
   B. False
9. Watt is unit of electrical energy.
   A. True
   B. False
10. It is a kind of misleading writing Ohm's law as $V = IR$
    A. True

B. False

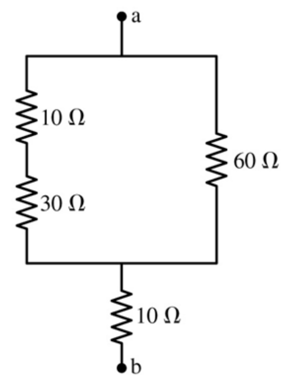
Part3: Review questions. Write your answers in your own notebook

1. What particles make up an atom?
2. Where are the protons and neutrons are located?
3. What charge does the neutron have?
4. The charge on electron is ____________ and the charge on the proton is ___________
5. The unit of charge is ___________. The unit of electrical current is____________.
6. The unit of power is____________. The unit of potential difference is ___________.
7. The instrument that measurses current is called___________. The instrument that measures potential difference (voltage) is called_____________.
8. What is the relationship between power, current, and voltage?
9. Describe the process of charging an insulator by a negative charge.
10. Describe the process of charging an electrscope by conduction.
11. Describe an electric field.
12. Describe the relationship between electron current and conventional current.
13. In which way does an ammeter should be connected in a circuit?
14. In which way does a voltmeter should be connected in a cricuit?
15. How does the current change in a circuit when the voltage is increased by factor2?
16. How does the current change in a circuit when the resistance increaqses by a factor 2?
17. Describe Ohm's law.
18. Describe Coulomb's law.
19. Distinguish between series and parallel circuits.
20. Describe grounding.

Part4: ecercises: solve problems in you own notebook.

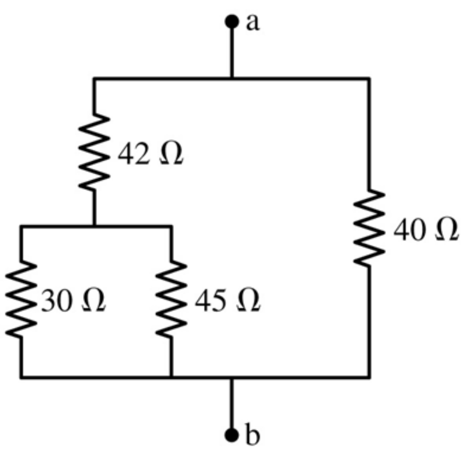
1. Two charges of -4μC each are 10cm a part. Find their interaction force.Is it repulsive or attractive? Explain.
2. The repulsive force between two identical charges is 20N when they are 6cm a part. Find the magnitude of each charge.
3. A charge of 250 μC ecerts a force of 2.50 x 10^{-2}N on a second charge of 50 μC. How far apart are the charges?
4. A resistor is connected to 115V. If it receives 8.75 Amp, find its resistance.
5. Four resistors of 2 Ω, 6 Ω , 10 Ω , and 3 Ω are connected in series to 12 V battery. Find the total resistance of the circuit. Find also the current.
6. A heater coil receives 8.7 Amp from a 110 V line. Find the power.
7. How much current will a 60 watt lamp recives from a 110 V line?
8. A hand drill receives 4 amp and has a resistance of 15 Ω. What power does it use?
9. 10 Coulombs of negative charge are transferred from object A to object B. What is the net charge on each object?
10. How many electrons are there in 10 μC of charge?

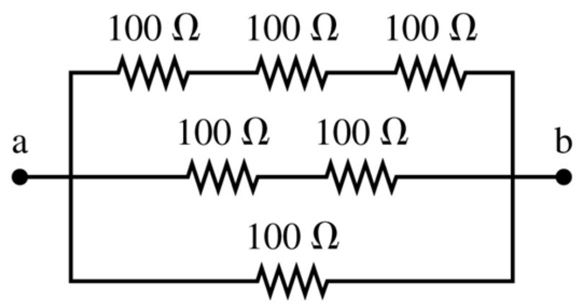
11. Find the equivalent resistance between the points a and b of the combination of resistors shown below



12. Find the current in ecercise 9 when the points a anb b are connected to a 12 V battery.

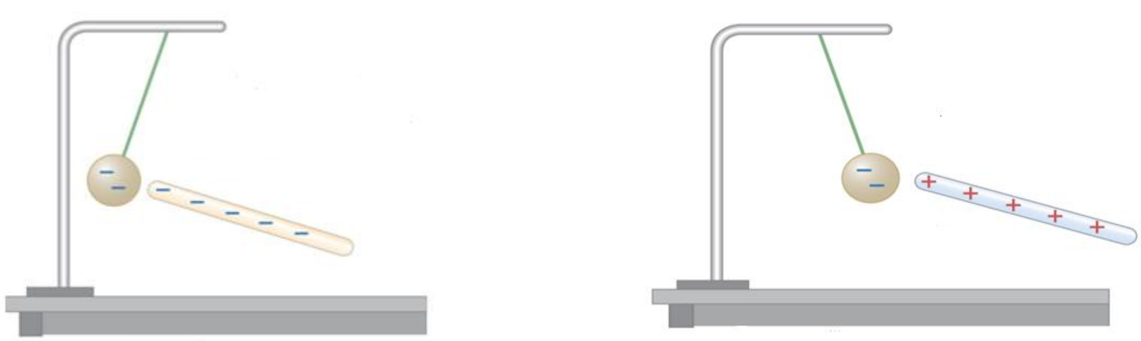
13. Find the equivalent resistance of the two combination of resistors shown below.





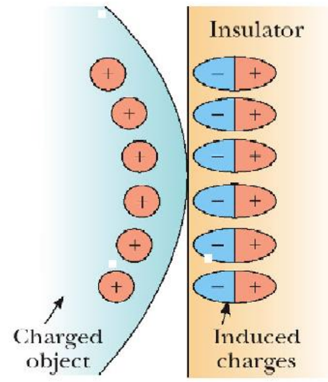
Part4: Descibe what you see: In you own words, describe and explain the following observations

1. A plastic charged rode and a charged ball.

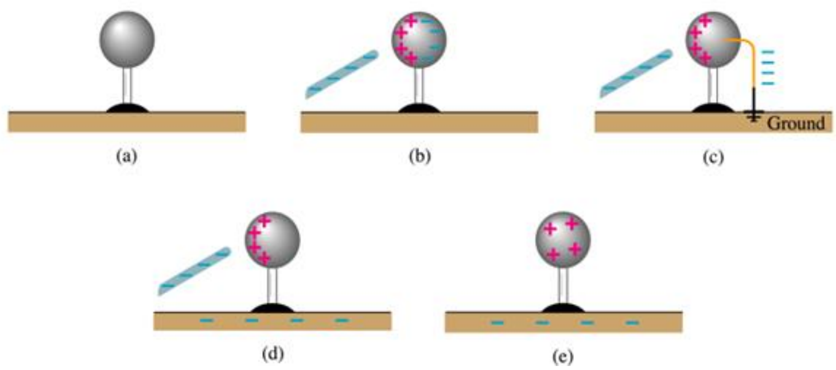


2. A comb and bits of paper

3. A charged object is brought cllose an insulator (wall)



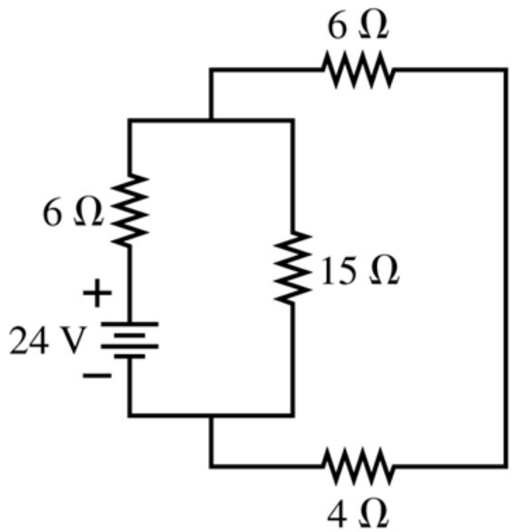
4. A neutral metal ball aqnd a charged object



5. A man and ballons

Part5: Challenge problems

1. In the circuit shown below find (a) the equivalent resistance (b) the current in the circuit, and (c) the voltage on the resisot



2. In the compound circuit shown below find (the current in the circuit and (b) the voltage on the resistance 4 Ω