2. Basic electrical theory and concepts

Overview

Purpose

The gas technician/fitter requires a basic knowledge of electrical theory in order to understand the operation of electrical components and circuits.

Objectives

At the end of this Chapter, you will be able to:

- describe atoms, electrons, and electricity;
- describe electrostatic charges and fields; and
- describe the production and use of electricity.

Terminology

Term	Abbreviation (symbol)	Definition
Atom		Smallest particle of matter that can take part in a chemical reaction
Conductor		Material through which electric current can pass
Electric current		Transfer of electrical energy from moving electrons
Electromagnetism		Phenomenon when any conductor of electric current acts like a magnet
Insulator		A substance or device that does not readily conduct electricity
Ion		An atom or molecule with a net electric charge due to the loss or gain of one or more electrons
Static electricity		Energy in the form of a stationary electric charge such as that stored in thunderclouds or friction-produced

7) What is the minimum distance from a natural gas meter at which arc-producing electrical equipment can be installed?
   a) 1 meter
   b) 48 inches
   c) 12 inches
   d) 2 meters

8) Correctly complete the following statement with the appropriate word provided: ___________ is when all energy sources including electrical, pneumatic, hydraulic, or gravitational are made inoperative.
   a) Low mechanical state
   b) Zero mechanical state
   c) Inoperative mechanical state

9) Are three- or four-way switches considered to be disconnecting means?
   a) Yes
   b) No

10) Who may remove a lock used to lock-out equipment?
   a) A locksmith
   b) The equipment manufacturer
   c) The person who installed the lock. In an emergency, a supervisor

11) Who has the authority to reenergize equipment that has been locked out?
   a) The equipment manufacturer
   b) The worker who had requested the de-energizing, or a supervisor
   c) An electrician

12) What must be obtained before electrical work can be performed on gas-fired equipment?
   a) A permit
   b) Electrical drawings
   c) Site drawings

13) Which electrical code rules apply to circuits supplying power to heating equipment that uses solid, liquid, or gaseous fuels?
   a) Rules 10-002 to 10-006
   b) Rules 2-318 to 2-320
   c) Rules 2-100 to 2-200
   d) Rules 26-802 to 26-808

14) What must be the electrical source for heating equipment rated 400 000 Btu/h and less?
   a) A multi-branch circuit
   b) A certified electrical cord
   c) A single branch circuit used for no other purpose

Atoms, electrons, and electricity

Atoms and molecules

Everything that has mass or occupies space is what you call matter. The smallest particle of matter that can take part in a chemical reaction is an *atom*. Atoms are the submicroscopic building blocks of matter. They combine to form larger particles called molecules. Atoms and molecules are much too small to be seen or weighed directly.

Atoms and molecules form various elements and compounds. An element is a substance made up of only one kind of atom. A compound contains more than one type of atom, chemically combined. Water is an example of a compound. Each water molecule is made up of one oxygen atom and two hydrogen atoms. To understand electricity, you must know something about the structure of atoms.

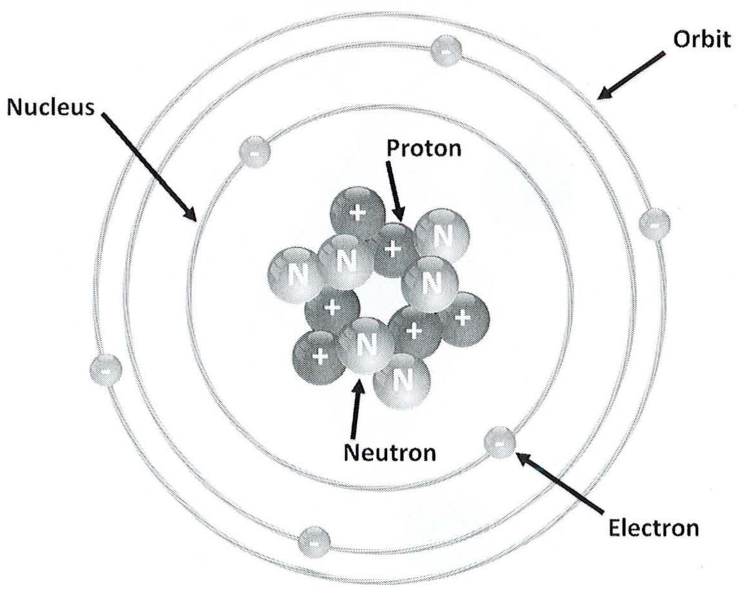
Atomic structure

Atoms are made up of smaller particles, called subatomic particles:

- neutrons;
- protons; and
- electrons.

Although scientists have found further subdivisions of these particles, it is only necessary for our understanding of electricity to focus on protons and electrons.

Figure 2-1
A carbon atom



The centre of the atom is the nucleus (plural nuclei), which houses protons and neutrons. Electrons revolve around the nucleus in orbits. See Figure 2-1, a diagram of a carbon atom.

The number of subatomic particles in an atom

The number of electrons, protons, and neutrons in the atoms of an element determines how that element behaves.

Atoms of different elements have different numbers of protons in their nuclei. This number is the atomic number that identifies that element. For example, the nucleus of a carbon atom always contains 6 protons, and you say that the atomic number of carbon is 6. The atomic number of helium is 2, and the atomic number of copper is 29.

Sizes of subatomic particles

Subatomic particles are extremely small. Electrons are about three times as large as protons, but they are 1840 times lighter. They are easy to move. Neutrons have about the same mass as protons.

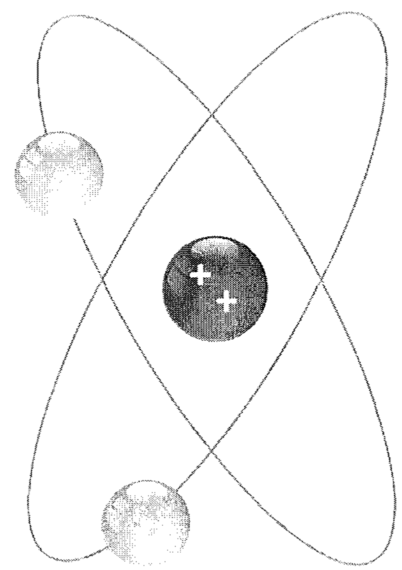
Electrical charges of subatomic particles

The electron carries the basic Unit of *electrical charge*. For historical reasons, an electron's charge is considered to be a *negative* (–) charge. Because it is free to move, an electron actively participates in the transfer of electrical energy.

The proton carries a *positive* (+) charge, opposite to that of an electron. It has the same size of charge as the electron's negative one. Protons are not directly active in the flow of electrical energy, but they do influence the flow of electrons.

The nucleus of an atom has an overall positive electrical charge due to the protons. The negatively charged electrons revolve around the positive nucleus. See Figure 2-2.

Figure 2-2
Negative electrons revolve in orbits around the positively charged nucleus



Atoms and ions

Under normal circumstances, the atom has equal numbers of protons and electrons. These charges cancel each other out, and the atom as a whole is electrically neutral.

An atom can receive a negative charge through the addition of electrons. It can receive a positive charge through removal of electrons. When charging an atom occurs these ways, the atom becomes *ionized* and is now an *ion*. For example, a positive ion is an atom that has had one or more electrons removed.

Since protons are firmly bound into the nucleus, only electrons can take part in ionizing the atom.

Conductors and insulators

Some materials, including copper and aluminum, have electrons that are easy to free. They are said to have *many free electrons* and are *conductors*. Conductors allow easy transfer of electrical energy.

Some other materials, such as glass and rubber, have electrons that are very difficult to free. They are said to have *few free electrons* and are *insulators*. Insulators block the transfer of electrical energy.

Electrostatic charges and fields

Electrostatic charges and fields are also known as static electricity. Static electricity is *energy in the form of a stationary electric charge such as that stored in thunderclouds or produced by friction*. For example, when you rub together certain pairs of materials (such as fur and a rubber rod), an electrostatic charge is produced. The friction produces heat energy that releases electrons from the atoms on the surface of one of the materials.

Electrical charges

An object may possess a positive electrical charge, a negative electrical charge, or it may be electrically neutral. The type of charge that an object has depends on the number of electrons and protons it has.

If it has…	**Then it…**
Fewer electrons than protons	Has a positive charge
More electrons than protons	Has a negative charge
The same number of electrons and protons	Is neutral

Law of electrical charges

A fundamental law governs the way charged particles behave:

Like charges repel and unlike charges attract.

Negatively charged particles repel other negatively charged particles. They tend to move away from each other. Similarly, positively charged particles repel each other. However, negatively charged particles *attract* positively charged particles. They tend to move toward each other.

Because of this law:

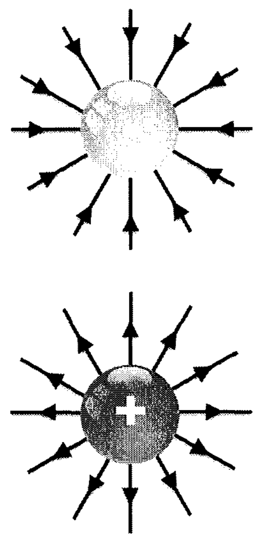
- Protons (+) and electrons (–) attract each other.
- Protons repel other protons.
- Electrons repel other electrons.

Electrostatic forces and fields

The electrical charges on protons and electrons are electrostatic charges. An electrostatic charge has an electrostatic field associated with it and, within this field, electrostatic forces occur. These forces are the forces of attraction and repulsion between charged particles.

Electrical diagrams show the lines of force around a negative charge as straight lines with arrows pointing toward the charge. See Figure 2-3a.

Figure 2-3
Lines of force around negative and positive charges



(a) Lines of force around a negative charge

(b) Lines of force around a positive charge

Diagrams show the lines of force around a positive charge as radiating outward from the charge. See Figure 2-3b.

Figure 2-4 shows how the lines of force around positively and negatively charged objects cause forces of attraction and repulsion.

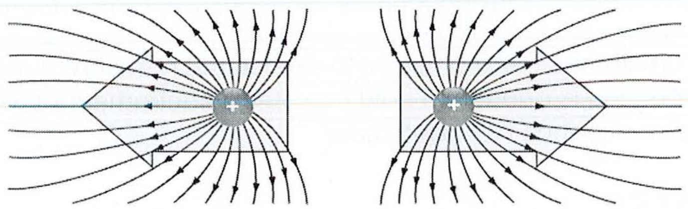
The strength of the forces of attraction and repulsion depends on:

- the amount of charge on each object; and
- the square of the distance between the objects.

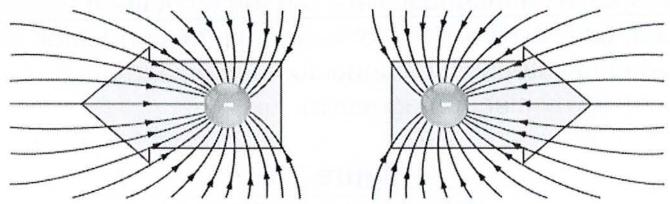
The greater the electric charges on the objects, the greater the electrostatic force.

Also, the closer the charged objects are to each other, the greater the electrostatic force.

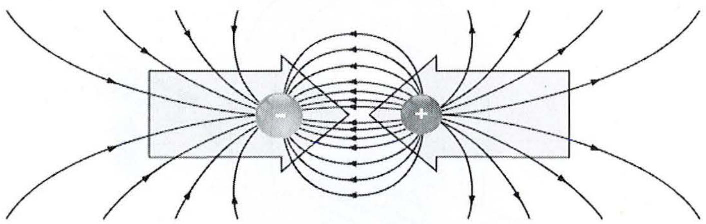
Figure 2-4
Lines of force in electrostatic fields of charged particles, showing the law of electrical charges



Positive charges repel each other



Negative charges repel each other



Positive and negative charges attract each other

Production and use of electricity

During removal of electrons from their atoms (so that they are free to move), the moving electrons may transfer electrical energy. The term *electric current* usually refers to this.

Production of electricity

The following are examples of ways to apply enough force to remove the electrons:

- heat—thermoelectricity;
- magnetism—electromagnetism;
- chemicals—electrochemistry;
- pressure—piezoelectricity; and
- light—photoelectricity.

Thermoelectricity

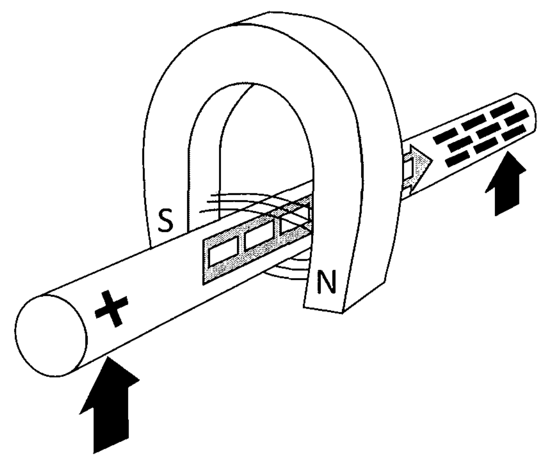
The application of heat to two different metals joined together leads to the transfer of electrons across the junction, resulting in one side becoming positive with respect to the other. This is the action of a *thermocouple*. Several thermocouples, when joined, form a *thermopile*.

Thermocouples often function as thermometers to detect and measure temperature. The current that a thermocouple produces is enough to hold in a small electromagnet within a gas valve, indicating the presence or absence of a pilot flame.

Electromagnetism

Magnetic force fields surround magnets, which have *magnetic poles* that attract or repel each other. When a conductor passes a magnetic field, the forces of the magnetic field act on the electrons in the conductor, causing them to move through the conductor. See Figure 2-5. The same thing happens if you hold steady the conductor in a moving magnetic field. An electric generator produces electricity by electromagnetism.

Figure 2-5
Electromagnetism



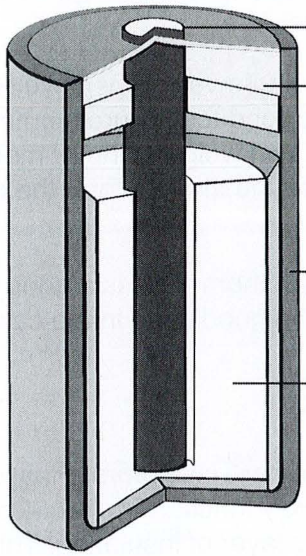
Electrochemistry

A flashlight battery is a common example of the electrochemical production of electricity. A battery is a group of *voltaic* cells. A voltaic cell is a product of immersing two different metal electrodes in a chemical solution called *electrolyte*. This creates a difference of potential between the two electrodes. *Potential difference* is the measure of the ability of a Unit of electrical charge to do a certain amount of work.

Chemical action that results in the transfer of electrons from one electrode to the other through the electrolyte causes the difference in potential. The electrode that gives up electrons becomes positively charged and the other electrode, which gains electrons, becomes negatively charged. Electrode terminals exist outside the cell. Connecting a wire across the terminals will lead to the flow of electric current between them.

Flashlight batteries are dry cells. They have a liquid electrolyte, but it combines with other materials to form a paste. This allows the use of the cell in any position. Figure 2-6 shows a typical dry cell battery. The zinc battery container is the negative electrode, and a carbon rod in the centre of the cell is the positive electrode. The space between the positive and negative electrodes contains a mixture of carbon, manganese dioxide, and electrolyte. The top of the cell has a seal to prevent evaporation, as the battery will not work when the electrolyte dries out.

Figure 2-6
An electrochemical dry cell battery



Piezoelectricity

Force from the application of pressure to certain crystal materials drives the free electrons out of orbit. Positive and negative charges build up on opposite sides of the material. You use this principle in such things as spark igniters for gas barbecues.

Photoelectricity

When light strikes certain materials (such as potassium and sodium), the energy from the light causes the atoms to release electrons. This is the photoelectric effect.

Electric current

In static electricity, electric charges are at rest. Static electricity normally does not perform useful work. To use electrical energy to do work, set the electrons in directed motion.

When you make electrons to move in the same direction, they produce an *electric current*. The flow of electric current carries energy that can perform work. The more electrons that move in the same direction, the greater the flow of current and the greater the amount of available energy.

Conducting and insulating materials

Conductors

Materials that conduct electricity well and have low electrical resistance are conductors. Most metals are good conductors, but some are better than others. Silver is the best pure metal conductor, with copper second. Because of its relatively low cost, copper is most commonly used for wires. Technicians use aluminum, also a good conductor, for high-voltage transmission lines because it is much lighter and cheaper than copper.

Copper conductors for transmission lines would require very expensive support structures. Aluminum must be very pure to be a good electric conductor. Pure aluminum is weak, and if uses itself in transmission lines, it could not support its own weight. One or more core strands of steel cable, with strands of aluminum cable wrapped around them to form the conductor, make transmission conductors.

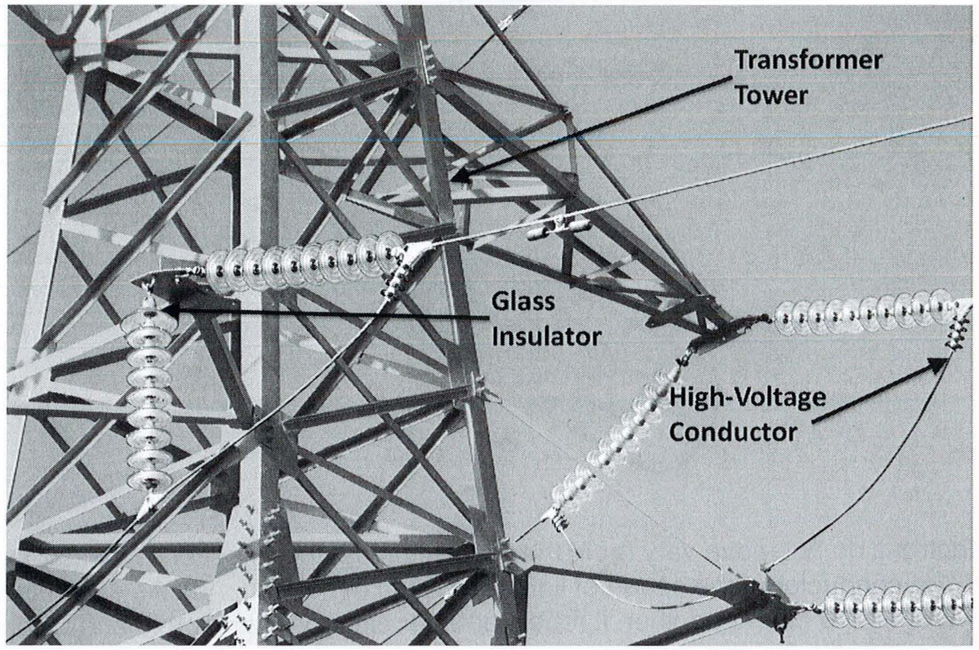
Conductors heat up when current is flowing through them. This is a good thing in the case of conductors that work as heating elements, but not a good thing in the case of using conductors in electrical transmission.

Insulators

Many materials do not conduct electricity well. They are insulators. Plastic, glass, and porcelain are poor conductors of electricity and are extensively function as electrical insulators. Household wiring consists of pure copper conductors a plastic layer of insulation. This insulation provides protection from electric shock and prevents short-circuiting of the system.

Lower voltages require less insulation, so relatively, you can use thin plastic. For higher voltages, thicker plastic insulation must be used. For very high voltages, plastic is not an adequate insulator. At very high voltages, porcelain, glass, air, or oil function as insulators. Figure 2-7 shows a transmission tower supporting a single conductor. A long glass holds away the conductor from the metal of the transmission tower. Glass is a good insulator and, in long lengths, it provides adequate insulation for very high voltages.

Figure 2-7
Conductors and insulators



If the voltage is high enough, electricity can pass through almost any insulator. Lightning, for example, is an electric current that passes through long distances of air, which is normally a poor conductor (a good insulator). To do this requires billions of volts of electrical pressure.

High-voltage electricity can *arc* or jump across an air gap from one point to another if the voltage between the two points is strong enough. For this reason, personnel must remain well clear of high-voltage equipment.

Electron movement in a conductor

In the atoms of a good electrical conductor (such as copper wire), free electrons are in constant but random motion. The nuclei stay in a relatively distinct pattern, but the free electrons change orbits at random and the atoms share the free electrons. *Metallic bonding* binds the atoms together.

Current flow

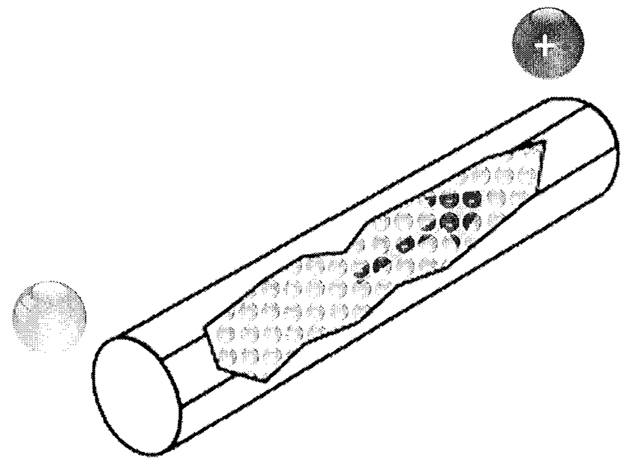
To produce a flow of electricity or current in a conductor, make the electrons move in a direction along the conductor by placing opposite (positive and negative) charges on the ends of the conductor. The free negative electrons move toward the positive charge and away from the negative charge. See Figure 2-8.

Direct current and alternating current

When current flows in a constant direction, it is a direct current (dc).

Alternating current (ac), on the other hand, regularly reverses direction and occurs during reversal of the polarity of each end of the conductor, which is always the case with house current.

Figure 2-8
Free electrons flow in the same direction in a conductor to produce electric current



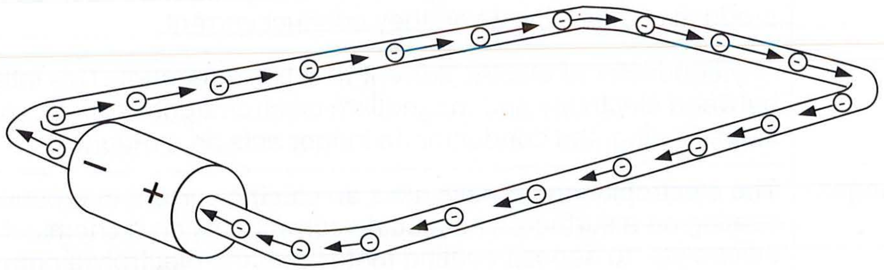
Individual electrons do not move very far in the conductor, but the effect of its electric current moves down the conductor at the speed of light (297 600 km per second). As each electron leaves its own orbit and enters another, it repels another electron out of orbit, and so on. The rapidly moving current is the *impulse* of these changes moving along the length of the conductor. This is similar to the impulse of falling dominoes moving the length of the row, while each domino makes only a slight movement.

Closed and open circuits

Placing a negative charge at one end of the wire repel away electrons to the other end of the wire. Current flows only until enough electrons accumulate at the other end to produce an equal charge. At that point, no further current flows, and there is static electric charge on the conductor.

For electric current to flow, there must be opposite charges at the ends of the conductor. Some kind of electrical energy source, such as a battery or generator, supplies these charges. This *completes* or *closes* the electrical *circuit*, allowing current to flow freely until interruption occurs. See Figure 2-9.

Figure 2-9
A complete or closed circuit



At the negative side of the electrical energy source, electrons are repelled in the wire. At the positive side, the source attracts electrons.

Conventional flow

Despite present knowledge about electron-flow, there has been an assumption that traditional current flows from positive to negative. This direction is conventional flow and is still common. For example, the rules for electromagnetism, a topic for later discussion, are based on conventional flow.

While current flows in the circuit, electrical energy can do work—for example, heating a lamp filament to give light. If the circuit breaks (*opens*) at any point, current stops flowing. An open circuit can accidentally result from breaks or intentionally from switches or disconnection. For example, when the filament in a lamp breaks or when the light switch is in the open position, the lamp no longer lights.

Using electricity

When electricity flows in a circuit, it can produce these useful effects:

Effect	Description
Heat	When electric current passes through a wire, the temperature of the wire rises, and heat transfer gives off energy. Many household appliances, such as toasters and electric heaters, use this effect. Good conductors such as copper produce less heat, while poor ones such as tungsten produce a lot of heat when they conduct current.
Magnetism	Any conductor of electric current acts like a magnet. This interaction between electricity and magnetism electromagnetism. When the current stops flowing, the conductor no longer acts as a magnet.
Chemical changes	The electroplating process uses an electric current to produce a metallic coating on a surface. The electric current acts on a chemical solution, the electrolyte, to deposit coating metal from the electrolyte onto the surface to be plated.

Assignment Questions – Chapter 2

1) Atoms are made of what three particles?
   a) Neutrons, protons, and electrons
   b) Neutrons, ions, and electrons
   c) Protons, electrons, and ohms

2) Which particle carries the basic Unit of electrical charge?
   a) Neutron
   b) Proton
   c) Electron
   d) Ion

3) How is an atom given a negative charge?
   a) By subtracting electrons
   b) By adding electrons
   c) By adding protons
   d) By subtracting protons

4) When is an object considered to be electrically neutral?
   a) When it has the same number of electrons and protons
   b) When the negative ions are removed
   c) When the neutrons have been removed

5) What is produced when electrons are made to move in the same direction?
   a) Ampere
   b) Ohm
   c) Electrical impedance
   d) Electrical current