EVALUATING ACADEMIC READINESS FOR APPRENTICESHIP TRAINING

Revised for

ACCESS TO APPRENTICESHIP

SCIENCE SKILLS
ELECTRIC FORCES

AN ACADEMIC SKILLS MANUAL
for
The Industrial Maintenance Mechanic Trades

This trade group includes the following trades:
Boiler Maker,
Facilities Maintenance Mechanic & Technician, and
Industrial Mechanic (Millwright)

Workplace Support Services Branch
Ontario Ministry of Education and Training

Revised 2011

In preparing these Academic Skills Manuals we have used passages, diagrams and questions similar to those an apprentice might find in a text, guide or trade manual.

This trade related material is not intended to instruct you in your trade. It is used only to demonstrate how understanding an academic skill will help you find and use the information you need.

SCIENCE SKILLS
ELECTRIC FORCES

An academic skill required for the study of the Industrial Maintenance Mechanic (Trades

INTRODUCTION

During a thunderstorm, we hear the thunder and see bright flashes of lightning. Lightning is a dramatic example of the reaction that occurs between nearby objects that have *opposite electrical charges*. The same charges that build up between the earth and clouds, resulting in the discharge of lightning, are responsible for the creation of an electric current. Both phenomena occur because objects can become electrically charged.

The operation of mechanical systems in industry relies on the use of electrical currents that move through conducting wire. Communications systems that direct the use of machinery also rely on conducting material such as wire and cable. Electrons move easily along these materials, transporting electricity and information when they flow through the conducting materials. Non–conducting materials such as plastic insulators are also needed to direct electrical signals through the system.

Understanding why and how electrons flow helps to explain why some materials make good conductors while other materials make good insulators. It also helps you recognize how to work safely around electricity.

This skills manual looks at some of the basic concepts related to electrical charges. This background information is useful in understanding more complex electrical circuits. The following topics are covered:

- Electrostatic charge
- Property of charge
- Creating an electric current
- Conductors and insulators
- Distribution of charges
- Potential difference
- Resistance in a circuit
- Electric fields

ELECTROSTATIC CHARGE

Electrons are subatomic particles that have a negative charge. Protons are also subatomic particles but their charge is opposite to the charge on electrons; they have a positive charge.

During a thunderstorm, opposite charges build up on the top and bottom of clouds. The positively charged area on the bottom of the cloud attracts negatively charged electrons on the ground below, causing large numbers of charged particles to build up. When the number of charged particles becomes large enough, they flow towards each other, causing a flash of lightning.

The attraction between your comb and your hair on a dry day illustrates the same phenomena. If you rub the comb and then hold it above your hair, your hair will be attracted to the comb and stick straight up. When a glass rod is rubbed, it builds up charges. An object such as a piece of paper will build up opposite charges when the glass rod is brought close. The area of charges on the paper will be attracted to the opposite charges on the rod, causing the paper to stick to the rod.

Charged objects are said to have an ***electrostatic charge***.

An electroscope, consisting of a ball of wood suspended on a string, is used to demonstrate the properties of electrostatic charges. The reaction of the ball to various materials shows that there are different types of charges.

- An electrified rubber rod is brought close to the ball; the ball is attracted to the rod and moves close to it.
- But if an electrified glass rod is held near the ball, the ball is repelled by the rod and swings far away.

From these observations, scientists figured there must be ***two*** kinds of charges. One type of charge was called negative, while the other was called positive. The two types of charges react to other negative and positive charges in different ways. Two similar charges repel each other while two opposite charges attract each other.

THE PROPERTY OF CHARGE

All matter is made of atoms. The atom consists of two main parts:

- A central ***nucleus*** containing ***protons*** and ***neutrons***.
- Around the nucleus are ***electrons,*** which orbit the nucleus in energy levels or shells.
- Electrons are free to move but the proton is held in the nucleus.
- An atom usually has the same number of electrons and protons but this can change.

Positive and negative charges

Protons and electrons possess the property of ***charge***, which means they exert a force of ***attraction*** or ***repulsion*** on each other. This charge is one of the basic forces of nature.

- Protons possess a charge called ***positive***.
- Electrons possess a charge called ***negative***.
- A negative charge is indicated by a minus sign (-).
- A positive charge is indicated by a plus sign (+).

*Charged particles are **attracted** to other particles with the **opposite** charge and **repelled** by particles with the **same** charge.* We say: Unlike charges attract, like charges repel.

Remember that a force is anything that tends to cause an object to move. Charges on electrons and protons exert a force that results in the following effects:

- Two electrons will repel each other because they are both negative.
- Two protons will also repel each other because they are both positive.
- The repulsion between two electrons or two protons is felt as a push. If they are free to move, this force will cause the two particles to move away from each other.
- An electron and a proton have opposite charges and, therefore, will attract each other.
- This attraction is felt as a pull towards each other. If they are free to move, this force of attraction will cause the particles to move towards each other.

Electroscopes

These properties can be seen on a larger scale if two light weight pith balls are suspended from the electroscope as in Figure 1. If both balls have negative charges, they repel each other and swing away as far as they can. If both balls have positive charges, the same thing happens – they repel each other and swing away. However, if balls on different electroscopes with opposite charges are suspended near each other, they will be attracted and swing as close as possible.

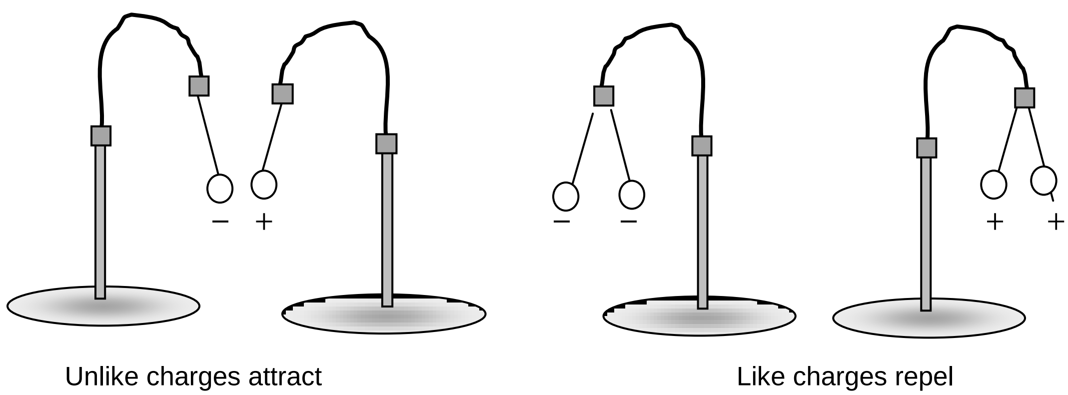


FIGURE 1: There are Two Kinds of Charges

If an atom has the same number of protons and electrons, the charges balance each other. The atom is neutral; it has no charge.

If there are more electrons than protons or more protons than electrons, the atom has a charge. If a large number of the atoms making up an object become charged, the object itself will become charged.

Electrons carry the charge

How do atoms, and large objects, become charged? The answer is found in the way electrons and protons behave. Protons are not free to move from the nucleus but an electron can move from one atom and go to another atom. If this happens, neither of the two atoms is neutral. One has a negative charge and one has a positive charge.

Note: *Electrons surround the nucleus in different energy levels called shells. Each shell has a maximum number of electrons that it can hold. Once the maximum number of electrons is reached in a shell, the leftover electrons move into the next shell. An atom is more stable when its outer shell is filled with the maximum number of electrons for that level.*

Atoms will make changes in their structure to get that stable arrangement of electrons.

- *Atoms with only a few electrons in the outer shell can give those electrons away.*
- *Atoms with an almost full outer shell can accept extra electrons.*
- *Atoms also share electrons.*

Since a proton is securely held in the nucleus by strong nuclear forces and only the electron is free to move, charges on objects can only come from a ***deficiency*** *(not enough) or an* ***excess*** *(more than enough) of* ***electrons****.*

A larger object becomes charged if many of its atoms gain or lose electrons. Since electrons are negatively charged, gaining electrons gives an object a negative charge. Losing electrons gives the object a positive charge. The charge on an isolated object is a static charge. It does not move from one area to another but is distributed around the object's surface.

In brief:

- Excess (more) electrons compared to the number of protons results in a negative charge.
- Fewer electrons compared to the number of protons results in a positive charge.

CREATING AN ELECTRIC CURRENT

To create an electrical current in a battery, negative and positive charges must first be collected on separate metal plates. This is done by accumulating atoms with an excess of electrons on the negative plate and accumulating atoms with a deficiency of electrons on the positive plate.

It takes energy to create a charged plate. Work must be done to move similarly charged particles closer together against the force of repulsion.

- In a lead battery, this energy is supplied when a chemical reaction takes place inside the battery.
- In a battery storing potential electrical energy generated by solar panels, the sun is the source of energy.

Dry cells

A simple battery is called a dry cell. Examining the way a dry cell works explains the basis of how an electrical current works. A dry cell consists of the following:

- A solution containing the substances that undergo the chemical reaction.
- A positive plate with a deficiency of electrons.
- A negative plate with an excess of electrons.
- A wire that connects the positively and negatively charged plates, allowing electrons to flow from one plate to the other.

- A switch that opens the circuit so electrons can flow.
- A device or load, such as a flashlight, is powered by the electrons.

Voltage
After the chemical reaction has occurred and caused opposite charges to build up on the plates, *the work done on the plates is stored as potential electrical energy that can be released to do electrical work.* The amount of electrical work the electrons can do if they are free to move is measured as ***voltage***.

***Voltage** is a measure of the ability to produce electrical energy.*

Electrical current
Electrons flow through a wire from the area of excess to the area of deficiency. This happens because the negatively charged electrons, crowded together and then repelled by their similar charges, feel a push away from each other. Since they are attracted to the positively charged plate, they move in that direction. The flowing electrons create an electrical current.

*An **electric current** consists of charged electrons moving through a conductor.*

In order for a current to flow between two plates, the electrons must be able to move from one plate to the other (Figure 2). The connecting wire must allow electrons to move through it freely. It must be a good conductor.

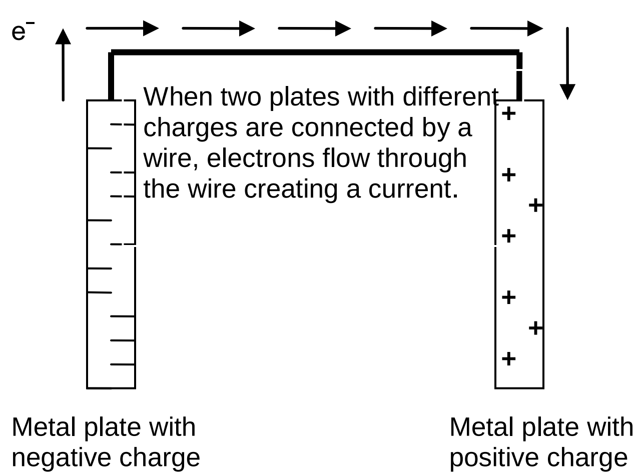


FIGURE 2: Creating an Electric Current

CONDUCTORS AND INSULATORS

Conductors
*A **conductor** is any material that allows the free movement of electrons.* Whether a material makes a good conductor or not depends on its atomic structure. Materials made from metal atoms that have few electrons in their outer shell make good conductors.

- Metal elements such as copper and aluminum have only a few electrons in their outer shell.

- These electrons are easily dislodged.
- The atoms in metal share these outer electrons as a cloud of free electrons that are free to move from atom to atom.
- This property makes metal elements good conductors.

The metals used to conduct electricity allow electrons to flow easily along their length.

- Silver is the best metal conductor but it is only used commercially in special circuits because it is expensive.
- Copper and aluminum are also excellent conductors.
- Most circuits use copper wire as it is plentiful and not too expensive.
- Aluminum is used when very lightweight lines are required. It is not used in household applications because it breaks when it is bent, resulting in arcing that can cause a fire.

Insulators

As important as conductors are for the transmission of electricity, insulators are also needed so that electricity can be conducted safely. *An **insulator** is a material which does not readily transfer an electric charge.*

- Where electrical conductors are connected to supporting structures, insulators prevent the current from flowing out where it is not wanted.
- Glass, ceramics, hard rubber, dry air and many plastics make good insulators.

Materials that make good insulators are usually made from atoms that have almost filled outer shells. These atoms hold on to their electrons very tightly and will even take electrons from other atoms. Unlike metals, they do not let their outer electrons flow to other atoms.

Semiconductors

A semiconductor falls halfway between conductors and insulators in its ability to conduct electrons. Most semiconductors are solids that have a crystal shape. The most common material used in semiconductors is silicon.

- Semiconductors are the foundation of modern electronics, including computers, phones and digital and analog integrated circuits.
- Microprocessor chips, transistors and LEDs are all based on semiconductor technology.

A silicon crystal is not a good conductor of electrons. However, it will bond with other atoms such as phosphorus or boron. When this happens, a phosphorus or boron atom replaces one of the silicon atoms in the crystal structure. This is called “doping”. When the silicon is doped with a small amount of an N-type material such as phosphorus or a P-type such as boron, the conductivity of the silicon crystal changes.

- The N-type phosphorus atom has 5 outer electrons while a silicon atom has 4.
  - When a phosphorus atom replaces a silicon atom in the crystal structure, there is 1 leftover electron that is free to move.
- The P-type Boron atom only has 3 outer electrons, so when it replaces a silicon atom, there is an electron “hole” left, which can also move from atom to atom.
  - The hole moves as a neighbouring electron jumps to fill it.

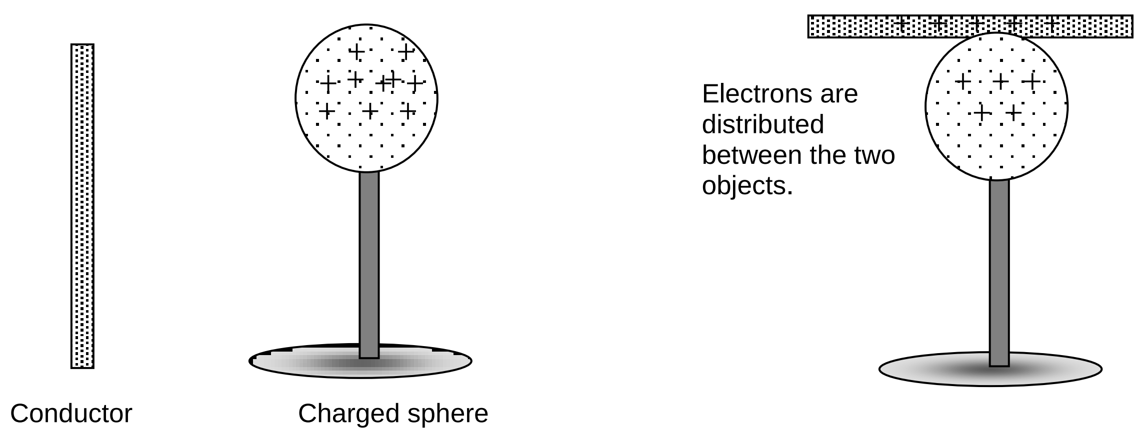
Phosphorus gives the silicon crystal a negative charge while boron gives the silicon a positive charge. When an N-type is put next to a P-type, the structure is called a junction. You can connect an N-type with a P-type in a junction and then connect the junction to a battery.

This connection can be formed in two different ways.

- If the N-type is connected to the positive terminal and the P-type is connected to the negative terminal of the battery:
    - The electrons from the N-type flow to the positive terminal, where the electrons cancel out the positive charges in the battery.
    - No more electrons flow because the system has become neutral.
- If you turn the battery around so that the N-type is connected to the negative terminal of the battery:
    - The free electrons in the N-type crystals are repulsed by the electrons in the battery and they flow the other way.
    - A current is created

DISTRIBUTION OF CHARGES

A good conductor does not resist the free movement of electrons. Since like charges repel, the free-moving, negatively charged electrons will spread evenly throughout a conductor to get away from each other as much as possible. In this way they distribute the charges equally over the material. If there is a source of positive charge, they will move in that direction. See Figure 3.



A charged object will share its charge when it comes in contact with a conductor.

FIGURE 3: Distribution of Charges:

If an uncharged conductor is brought into contact with a negatively charged object, which by definition has an excess of electrons, the free electrons will flow from the object to the uncharged conductor. The electrons will flow until both objects have the same distribution of electrons over their surface. Each will now share the positive charge as in Figure 3.

A charged object with a larger surface in contact with a smaller object will actually end up with a higher proportion of charge than the smaller object. The electrons distribute themselves, and their charges, throughout the objects until they are in equilibrium.

Grounding an Object

The earth is considered a limitless source of electrons and also an immense sink into which electrons can be poured.

- The earth is so large that countless electrons can pass into or out of it without changing its charge.
- It is too big to respond to any change (except in some limited areas such as when lightening occurs).
- Since the charge on an object has to be spread evenly throughout that object, any charge on a part of the earth gets lost and disappears as it is spread over the whole surface.
- Therefore, the amount of charge on the earth is considered to be zero.
- Any conducting object connected to the earth will reach an equilibrium with the earth.
- All its charge will empty into the earth.

*An object connected to the earth is said to be **grounded.***

> ***Note:*** *Lightning is an exception to this rule. An area of the earth can have some electrons move away as a result of the repulsion from a negative charge in the clouds. This charged area has been formed by induction. This local area then has a positive charge. The positive and negative charges attract each other, resulting in an arc of electrons that we call lightning.*

Conduction and induction

An object can be charged by making contact with an already charged body. It is called *charging by **conduction***.

- The electrons distribute their charge evenly between the two objects, considering them to be one object.
- This is how a dead battery is boosted.

An object can also be *charged by **induction*** when there is no actual contact between it and an already charged body.

- If a negatively charged rod is brought close to a neutral conductor, the electrons in the neutral conductor are repelled, away from the source of negative charge.
- This results in a positive charge in that area of conductor.

If the conductor is grounded, the repelled electrons will flow out into the earth.

- If the grounding wire is removed, and then the charged rod is removed, the conductor is left with a positive charge because of the lost electrons.
- This is another way plates in a simple dry cell can be charged.

ELECTRIC FIELD

A charged body exerts either an attractive or a repellant force over another charged body. In a spherical body, the charge is distributed evenly over the surface. Its force on another body is considered to be the same as if the charge were concentrated in the centre of the object. This imaginary point at which the charge is considered to be located is called the ***point charge***. The idea of a point charge is useful in doing calculations to find the force between charged objects.

The force between two point charges is directly proportional to the product of their magnitudes and inversely proportional to the square of the distance between them.

In other words:

- The larger the charges on two objects, the bigger the force they will exert to attract or repel each other; and
- The farther apart they are, the smaller the force they will exert.

POTENTIAL DIFFERENCE

Work *is done when a force acts on matter and changes its position or motion.* A negatively charged electron will cause another free electron to move away. We say that an electrostatic force acts on the second electron and changes its position.

As the electron moves, it in turn can transfer its motion into electrical work such as running a motor. (Of course, this actually takes a very large number of moving electrons.)

As we said, an electron normally moves away from the repulsive force of other electrons. To move electrons close together to create a negatively charge plate, they must be moved against the normal force of repulsion. Energy from some outside source has to be supplied to move the electrons close together. In a hydro-electrical generating station, energy is supplied by falling water. In a battery, it is supplied by the energy released when chemical bonds are broken.

In a battery, because the electrons on the negative plate want to flow away from each other to the positive plate, the two plates have a difference in ***electrical potential***. The work done to create the negative and positive charges is stored as an ability to do electrical work in the future. When the conducting wire is connected by some kind of switch, the electrons flow and do work such as turning on the ignition or running the lights.

Potential and kinetic energy

This concept is similar to that of potential and kinetic energy produced by the force of gravity. A ball at the top of a hill has more potential energy (it has more ability to move), than a ball at the bottom of a hill. The ball at the top has had work done to it to move it to the top of the hill against the force of gravity. This work is now stored in the ball as an ability to roll downhill sometime in the future. The two positions differ in potential energy.

In the same way, when opposite charges are created on two metal plates, the electrons crowded on the negative plates are like the ball at the top of the hill. They will flow to the positive charge if they are set free, just as the ball will roll down the hill if it is set free. The potential of the crowded electrons to do work is stored as electrical energy.

*The **potential difference** between two points in an electric field measures the work done to move a unit charges from the first point to the second*. It is called voltage and measured by the ***volt*** **(v)**.

Electromotive force
The ***voltage*** *of an electric power source measures the stored electrical energy that is available to do some kind of work*. It is a pressure or force, sitting there ready to move forward to do electrical work like starting an engine. For this reason, voltage is also called ***electromotive force*** or ***emf***.

Because the earth is a limitless source of electrons and also a limitless sink into which electrons can be emptied, the potential of the earth to be charged is considered to be zero.

All measurements of potential difference at any point in an electrical field, either negative or positive, are taken against the earth as reference point zero. So a 12 volt battery has a potential difference of 12 volts compared to the earth at 0 volts.

Work Done by Moving Electrons
When two plates with different charges are brought close together with an insulating material between them, the attractive forces between the two plates cause a potential difference, measured in volts, which can be available to do work. This potential difference can be made available as electrical energy because work has been done on the plates to charge them.

Current
If the plates are connected to each other by a wire, electrons will flow from the negative plate, which has excess electrons, to the positive plate, which is deficient in electrons. This flow of electrons creates a current.

*A **current** (I) is the rate of flow of electrons past a certain point through a conductor.* It is measured in ***amperes*** (a).

> **Example**: If a load, such as a light bulb, is connected to the wire, the moving electrons are able to use their electrical potential energy to do work on the load.
> - The electrical energy is changed into light and heat, causing light to be produced in the bulb.
> - The moving electrons in the wire carry electrical energy that can be used to produce heat, drive motors or create light. This concept is the basis of the electrical circuit.

The kind of basic circuit just described produces a ***direct current*** (dc). The current flows in one direction. This is the kind of current used in batteries.

A current can be moved more efficiently if the electrons alternate direction back and forth in the wires. This kind of current is called ***alternating current*** (ac). An alternator produces an alternating current which can be changed to a direct current.

RESISTANCE IN A CIRCUIT

Every electric circuit includes a wire and a device that consumes current to produce heat plus light or mechanical work. The energy-consuming devices, or loads, create an opposition to the flow of electrons in the circuit. Even wires that are good conductors provide some opposition to the flow of electricity. *This opposition to the flow of electricity is called **resistance**.*

The voltage, current and resistance of a circuit are closely related.

- ♦ In a basic electrical circuit, the power comes from differently charged electrochemical plates.
- ♦ The charges create electrical potential that is measured in volts (v).
- ♦ The charges or electrons flow along a wire from the negative terminal of the cell to the positive terminal.
- ♦ The current is the rate of flow of the charges past a certain point. It is measured in amperes (a).
- ♦ The load or resistance is measured in ohms (Ω).

Ohm's Law

It was discovered that the value of the resistance of a circuit is equal to the voltage divided by the amount of current. This ratio is known as **Ohm's law** which states that *the ratio of the voltage to the current is equal to the resistance of the circuit.*

The formula expressing this relationship is:

Resistance = voltage / current

CONCLUSION

The attraction between negatively and positively charged objects can result in a dramatic lightning discharge. This is the same force that causes electrons to flow in an electric circuit.

- Electrons and protons possess a property called charge that exerts a force on other charged particles.
- Electrons have a negative charge and protons have a positive charge.
- Particles or objects with the same charge repel each other.
- Objects with the opposite charge attract each other.

When an electron is moved against this force, work must be done on it by energy supplied from outside the electric field. The moved charge now has stored potential electrical energy.

- When many charges with potential electrical energy are connected by a wire to an area of less charge, they will flow along the wire to the area of less charge.

- This is because an object tries to distribute its charges evenly throughout its whole surface.
- If an electrical device or load is connected to the wire, the potential electrical energy in these flowing charges can do electrical work for us.
    - A light bulb connected to a circuit uses the electrical energy to raise the energy level of its tungsten filament. When the filament gets energized, it glows, producing light and heat.

All the work that electricity does for us is the result of the different charges on electrons and protons. These charges create a force that can be controlled and directed so we can change electrical potential energy into mechanical work, chemical transformations, light, sound and heat.

Answer the following questions. Answers are on the last page.

Match these terms with the statements below.

semiconductor	charge	negative	positive	conductor	attraction
grounded	insulator	electron s	current	resistance	proton

1. The flow of electrons through a conductor: ___________________________
2. A material that allows the free movement of electrons: __________________________
3. These subatomic particles surround the nucleus in shells: ____________________________
4. Subatomic particle with positive charge that is firmly held in the nucleus: _________________________
5. The property of electrons and protons that is felt as a force of attraction towards each other or a force of repulsion away: ______________________
6. An important material halfway between conductors and insulators in its ability to conduct electrons that is used in computer technology to direct the flow of electrons: ____________________________
7. Particles with opposite charges feel this kind of force: ___________________________
8. Type of charge on a proton: ______________________
9. Type of charge on an electron: ________________________
10. An object connected to the earth is said to be: ____________________
11. A material that does not allow the flow of a current: _____________________
12. Opposition to the flow of electricity: ________________________

Answer the following questions by writing true or false on the line.

13. Metals make good conductors because electrons can flow freely along their surface.________
14. If there is only one electron in the outer shell, the atom holds on to it very tightly. _________

15. Aluminum is the best wire to use to conduct electricity because it is plentiful and very safe. _________

16. Copper is the most commonly used conductor in electric circuits. __________

17. Charges on an object come from an excess or deficiency of electrons compared to the number of protons. __________

18. A charge on a spherical object is spread unevenly over that object. _________

19. When a charged object is connected to the earth, all its charge is lost as it is emptied into the earth and the object is said to be grounded. _________

ANSWER PAGE

1. current
2. conductor
3. electrons
4. proton
5. charge
6. semiconductor
7. attraction
8. positive
9. negative
10. grounded
11. insulator
12. resistance
13. True
14. False
15. False
16. True
17. True
18. False
19. True