CHAPTER ONE

What is Electricity?

The word "electricity" comes from the Greek word electron (ελεκτρου), which means "amber." Amber is a translucent yellowish mineral made of fossilized resin. The ancient Greeks used the words "electric force" in referring to the mysterious forces of attraction and repulsion exhibited by amber when it was rubbed with a cloth. They did not understand the nature of this force and could not answer the question, "What is electricity?" Today, we still cannot answer the question, although the success with which we have used electricity is obvious everywhere.

Although we don't really know what electricity is, we have made tremendous strides in harnessing and using it. Elaborate theories concerning the nature and behavior of electricity have been advanced, and they have gained wide acceptance because of their apparent truth—and because they work.

Scientists have found that electricity behaves in a consistent and predictable manner in given situations or when subjected to given conditions. Scientists, such as Faraday, Ohm, Lenz, and Kirchhoff, have described the predictable characteristics of electricity and electric current in the form of certain rules, or "laws." Thus, though electricity itself has never been clearly defined, its predictable nature and ease of use have made it one of the most common power sources in modern times.

By learning the rules, or laws, about the behavior of electricity, you can "learn" electricity without ever having determined its fundamental identity.

When you have finished this chapter, you will be able to:

- describe free electrons;
- describe conductors and insulators in terms of the movement of free electrons, giving examples of each;
- relate the action of free electrons to the phenomenon of static electricity;
- describe positive and negative charges;
- state the law of attraction and repulsion of charged bodies;
- explain Coulomb's Law of Charges; and
- describe the electric field associated with charged bodies.

Free Electrons

1. The classical approach to the study of basic electricity is to begin with the "electron theory." This encompasses the nature of matter and a fairly thorough discussion of molecules and atoms. Such an approach provides a good background for the essential point: Electric current depends on the movement of free electrons. In this book, the details of electron theory, such as atomic weights and numbers, are omitted so that we may move quickly to the points you really need to know for the study of electricity.

All matter is made of molecules, or combinations of atoms, that are bound together to produce a given substance, such as water or salt or glass. If you could keep dividing water, for example, into smaller and smaller drops, you would eventually arrive at the smallest particle that was still water. That particle is a molecule, which is defined as the smallest bit of a substance that retains the characteristics of that substance.

The molecule of water is known in chemical notation as H_2O. That means the molecule is actually made up of two atoms of the element hydrogen (H) and one atom of the element oxygen (O). These atoms, themselves, are not water but the separate elements of which the molecule of water is composed.

What is the relationship between atoms and molecules? ____________

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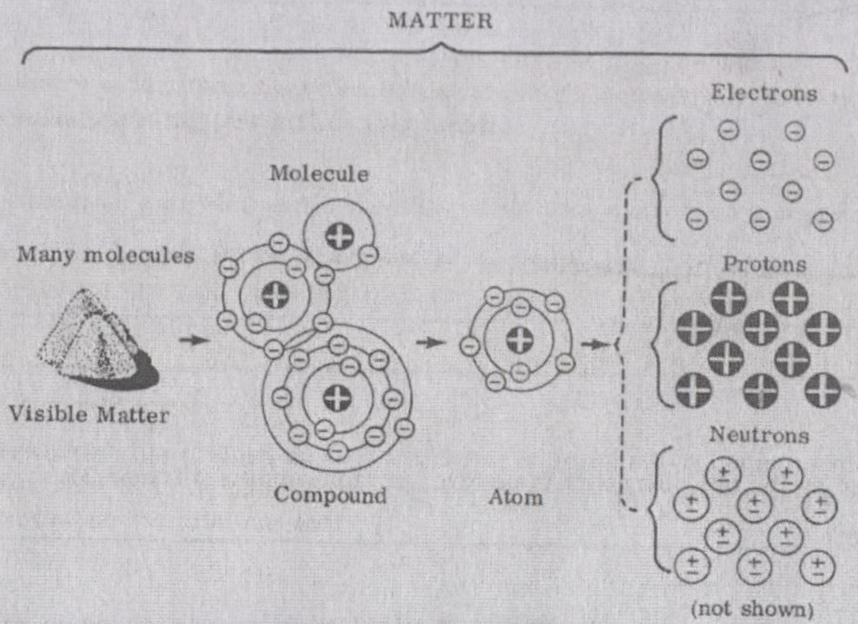
2. The ancient Greeks had conceived the idea of the atom, at least in theory. In fact, atom is a Greek word that means, roughly, "not able to be divided." Today we know that the atom is composed of even smaller particles. The most important of these are the proton, the electron, and the neutron. These particles differ in weight (the proton is much heavier than the electron) and charge. The weights of the particles need not concern you, but the charge is extremely important in electricity. Perhaps you have noticed that the terminals of the battery in your car are marked with the symbols "+" and "−" or even with the abbreviations POS (positive) and NEG (negative). Many batteries used in flashlights, small electronic calculators, and other devices have similar markings. The concepts of "positiveness" and "negativeness" will become clear later. For the moment, you only need to know that the proton has a positive (+) charge, the electron has a negative (−) charge, and the neutron is neutral, which means that its positive and negative charges are in balance. Practically speaking, we say that the neutron has no charge.

The following drawing shows the relationship of visible matter to molecules, atoms, and smaller particles: electrons, protons, and neutrons.

The drawing shows only the electrons and protons in the atoms, but every atom except hydrogen also contains neutrons.



List the three basic particles that make up the atom, and state the charge (negative, positive, or neutral) on each.

Particle	Charge
________	________
________	________
________	________

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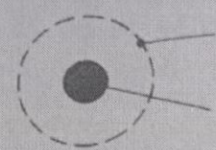
3. As the drawing in frame 2 indicates, the atom has a nucleus (or core) that is positive because it contains only protons and neutrons. Electrons are in orbit about the nucleus, in much the same way as the earth orbits around the sun. A stable atom has the same number of electrons in orbit as it has protons in the nucleus. The nucleus always (with one exception) contains neutrons, too, but we need not consider them for our purposes because they are always neutral. Since the negative charge of the electrons is balanced by the positive charge of the protons, the atom is electrically neutral. The following drawing shows a hydrogen atom, the only one that has no neutron, so its nucleus is a single proton.

Label the electron and the proton.



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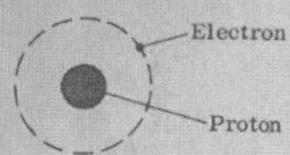

4. What is the net charge on the hydrogen atom shown in frame 3? ______

Why? ____

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5. Other atoms have more protons in the nucleus and more electrons in orbit. In fact, each atom has a different number of electrons and protons. In all cases, however, the electrons move around the nucleus of the atom in various orbits. Such electrons are not free: They are locked into the atom because they are attracted by the nucleus. They do not fall into the nucleus (as the earth does not fall into the sun) because their movement in orbit provides an equalizing centrifugal force.

Free electrons are produced when some force disturbs the stable relationship of electrons and protons in an atom. This force, which "knocks" electrons out of orbit, can be produced in a number of ways, such as: by moving a conductor through a magnetic field; by friction, as when a glass rod is rubbed with silk; or by chemical action, as in a battery. (The six principal methods of producing this force, called voltage, are described in Chapter 2.) The force "frees" the electrons from their atoms; these electrons are called free electrons. When an electric force is applied to a material such as copper wire, electrons in the outer orbits of the copper atoms are forced out of orbit and impelled along the wire. The electrons that have been forced out of orbit are called ______________________.

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6. The movement of free electrons along a wire is what we call electric current. It cannot exist where there are no free electrons. What are free electrons? ______________________________

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7. Explain in your own words the flow of electric current in a copper wire when an electric force is applied to the wire. ____________________

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Conductors and Insulators

8. Electric current moves easily through some materials but with greater difficulty through others. Let us see how the action of free electrons is related to current flow through these materials. Substances that permit the movement of a large number of free electrons are called conductors. Copper wire is considered a good conductor because it has many free electrons when an electric force is applied to it. Electrical energy is transferred through a conductor by means of the movement of free electrons that migrate from atom to atom inside the conductor. Each electron moves the very short distance to the neighboring atom, where it replaces one or more electrons by forcing them out of their orbits. The displaced electrons repeat the process in other nearby atoms until the movement is transmitted throughout the entire length of the conductor.

The movement of each electron takes a very small amount of time, but the electrical impulse is transmitted through the conductor at the speed of light, or 186,000 miles per second. To see how this is possible, imagine a line of billiard balls that almost, but not quite, touch. When the ball at one end is struck by the cue ball, the ball at the other end is knocked away from the line almost instantly. The force travels through the line of billiard balls much more rapidly than each individual ball moves. This is basically how the electrical impulse travels. (Keep this in mind later in the book, when events in an electrical circuit seem to occur simultaneously.)

Does electric current more closely resemble the actual movement of free electrons or the impulses transmitted as the electrons bounce against one another? ____________________

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9. Silver, copper, and aluminum all have many free electrons (the electrons are said to be "loosely bound") and are thus good conductors. Copper is not as good a conductor as silver, but it is the most commonly used material for electrical wiring because it is a relatively good conductor and is much less expensive than silver. Here are six metals listed in the order of the ease with which electrons are displaced from the atoms:

silver
copper
aluminum
zinc
brass
iron

If we say that silver is a better conductor than iron, what do we mean?

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10. Some substances, such as rubber, glass, and dry wood, have very few free electrons; the electrons are said to be "tightly bound." Such substances are poor conductors and are usually called insulators. Circle the material that is the best insulator among those named:

silver glass zinc brass

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11. A good conductor, then, has many free electrons, while a good insulator has few free electrons. Dry air, glass, mica, rubber, asbestos, and bakelite are all good insulators. If we say that dry air is a better insulator than bakelite, what do we mean? ____________________

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12. Write the materials listed below in the appropriate columns on the following page as either conductors or insulators. (Don't worry about the exact order.)

glass silver rubber dry air copper brass mica

Conductors	Insulators

13. Define a good conductor. ______________________________

14. Define a good insulator. ______________________________

15. Name three materials that are good conductors. ______________

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16. Name three materials that are good insulators. ______________

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Static Electricity

17. Static electricity is found in nature, so we shall examine this phenomenon before we study "man-made" electricity. One of the fundamental laws of electricity must be clearly understood to understand static electricity: Like charges repel each other and unlike charges attract each other.

A positively charged particle and a negatively charged particle will tend to move toward one another. This is true even in a single atom. What kind of particle will a proton attract, and why? Write your answer in the blank on the next page.

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18.

Why is there a force of attraction between the protons in the nucleus and the electrons in orbit? ______________________________

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19. Will a proton attract or repel another proton? ____________ Why?

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20. Two particles can have <u>unlike</u> charges even if neither is positive (or if neither is negative). A neutron is neutral; that is, it is neither negative nor positive. A proton is more positive than a neutron, so the two particles have unlike charges. Do the electron and the neutron have like or unlike charges? ____________ Why? ____________________

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21. Two neutrons will neither attract nor repel each other, because they are neutral; that is, they have no charge. For each pair of particles listed on the following page, state whether the particles will attract or repel each other.

(1) proton and electron ________________

(2) proton and neutron ________________

(3) electron and neutron ________________

(4) electron and electron ________________

(5) proton and proton ________________

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22. State in your own words the law of attraction and repulsion. ________

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23. Let us begin our study of static electricity with an experiment you can try right now. Tear up some paper into small bits and place them on a table or other hard, nonconducting surface. Now run a comb rapidly through your hair a few times, then move the comb near the bits of paper.

What happened? ________________________________

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24. The experiment you have just made is a demonstration of <u>static electricity</u>. When two bodies of matter have unequal charges and are near one another, an electric force (the force of attraction or repulsion) is exerted between them. But, because they are not in contact—or are not connected by a good conductor—their charges cannot equalize. When such an electric force exists, and current cannot flow, it is called <u>static electricity</u>. "Static" means "not moving." The electric force that exists under these conditions is also called an <u>electrostatic</u> force. What two conditions are necessary for static electricity to exist? ________________

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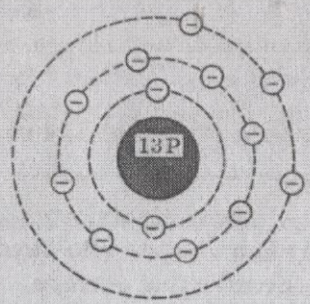
25. Each atom, in its natural—or neutral—state, has the proper number of electrons in orbit about its nucleus. That is, it has the number of electrons that helps to give the element its identity. Thus, the whole body of matter composed of neutral atoms will also be electrically neutral. Matter in this neutral state is said to have no charge and it will neither attract nor repel other neutral matter in its vicinity.

The atom of each element, in the neutral state, has a different number of electrons in orbit. Hydrogen has one, helium has two, etc. A model of an aluminum atom is shown below. It has 13 electrons in orbit balanced by 13 protons (P) in the nucleus. The nucleus also contains neutrons, but they need not concern us because they are electrically neutral.



The aluminum atom shown is electrically neutral. Why? ______________

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26. But the three electrons in the outer orbit are easily displaced. If one (or more) of the electrons is knocked out of orbit, what is the charge on the atom? ______________ Why? ______________________

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27. Most substances, such as the hair, paper, and comb used in your experiment, are compounds rather than elements. That is, they are composed of atoms of various elements bound together in molecules of the substance. Their electrons are not easily displaced by an electric force. (You might have guessed that hair, paper, and combs are all relatively good insulators.) But the electrons can be displaced by friction, and this is what happened when you combed your hair vigorously in the experiment.

At the beginning of the experiment, your hair, the comb, and the paper were all electrically neutral. When you combed your hair, friction displaced electrons from your hair, and they were collected on the comb. At that point, what was the charge on the comb? ______________ Why? ____

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28. After the electrons were accumulated on the comb, bits of the neutral paper were attracted to the comb. Why? ______________ ____

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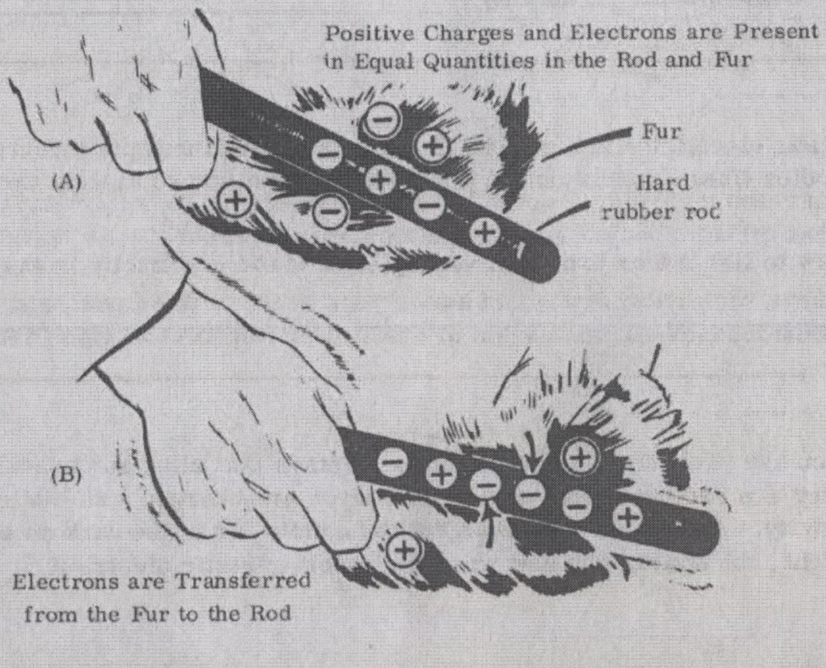
29. One of the easiest ways to create a static charge is by friction. Two pieces of matter are rubbed together, and electrons are "wiped" off one and deposited on the other. The materials used can't be good conductors; if they were, an equalizing current would then flow easily in and between the conducting materials. A static charge is most easily obtained by rubbing a hard nonconducting material against a soft or fluffy nonconductor.

The drawing below illustrates how electrons are displaced from a piece of fur and deposited on a hard rubber rod.



In the case just illustrated, electrons are transferred from the fur to the rod because they are more easily displaced from the fur. When the hard rubber rod is rubbed with the fur, the rod accumulates electrons. Since both fur and rubber are poor conductors, little equalizing current can flow, and an electrostatic charge is built up. When the charge is great enough, equalizing current will flow regardless of the poor conductivity of the materials. This current may cause a crackling sound, and if it is dark, sparks can be seen.

If a body with a positive charge (too few electrons) comes into contact with a body that has a negative charge (too many electrons), an electric current will flow between the two bodies. Electrons will leave the negatively charged body and enter the positively charged body. The electric current will continue to flow until the charges of the two bodies are equal.

When a body has too many electrons, these electrons do not go into orbit around individual atoms. They are free electrons that give the material an overall negative charge.

When the electric current flows to equalize the charges on the two bodies, static electricity is said to be "discharged." The bodies do not need to touch if the difference between the charges is great enough. An example of this is the lightning that leaps between clouds or between a cloud and the earth during a thunderstorm.

Perhaps you have walked across a carpet and then have touched a bit of metal or even another person, at which time you experienced a slight shock. If so, it is because your body had acquired a negative charge, which could not be dissipated. Later, the shock resulted from the current flow when a touch allowed the charges to equalize. When the static electricity was discharged, the charges were equalized.

What is static electricity? ______________________________

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30. Try to list one or two other examples of static electricity in everyday life.

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We have seen how the behavior of charged bodies is related to static electricity. We shall examine electric fields and then continue the study of charged bodies in the next two sections.

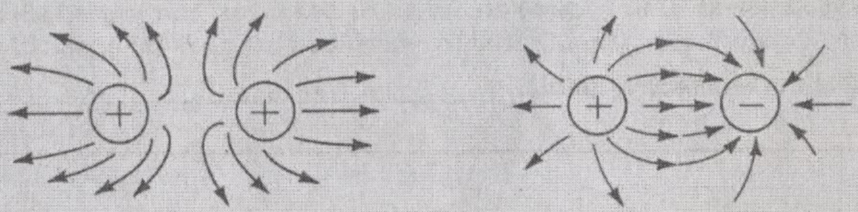
If you plan to take a break pretty soon, do it now.

Electric Fields

31. The space between and around charged bodies, in which their influence is felt, is called an electric field. (It may also be called an "electrostatic field," a "force field," or a "dielectric field.") The field always emanates from material objects and extends between bodies with unlike charges. The fields of force spread out in the space surrounding their points of origin, constantly diminishing as the distance from those points increases.

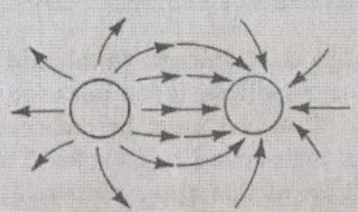
The field about a charged body is generally represented by lines called electrostatic lines of force. The lines represent the direction and strength of the field. Since a field can exist between a charged body and a neutral body, "positive" can mean "less negative," and "negative" can mean "less positive."

The drawing below represents two pairs of charged bodies. One pair has a positive (+) charge on each body (like charges), while the other pair has a positive charge on one body and a negative (–) charge on the other (unlike charges). The lines of force are indicated in each case.



This system of representing lines of force is merely a convention. Although we can measure an electric field, we do not know its exact nature.

Show the charge on each body shown below by drawing the symbol for either positive or negative. (There is more than one correct answer.)



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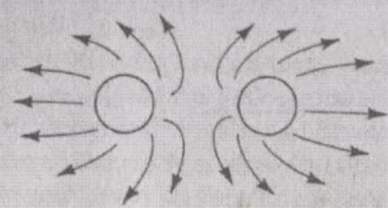
32. Show the charge on each body shown below as either positive or negative. (There is more than one correct answer.)



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33. As the electric lines of force travel out into space, does strength of the field increase or decrease? ____________________

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34. What is an electric field? ____________________
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Next we shall study Coulomb's Law of Charges, which describes in more detail the force that exists between charged bodies.

Coulomb's Law of Charges

35. The Frenchman Charles A. Coulomb developed the law that governs the amount of attracting or repelling force between two electrically charged bodies in free space. This law must be understood before we study electric current, which is introduced in Chapter Two. Coulomb's formulation, known as Coulomb's Law of Charges, states:

> Charged bodies attract or repel each other with a force that is directly proportional to the product of their charges and that is inversely proportional to the square of the distance between them.

This law seems complicated, but it can be broken down into two factors:

1. The attracting or repelling force depends on the strength of the charges on the two bodies.
2. It also depends on the distance between the bodies.

Coulomb's Law of Charges takes into account what aspects of any two charged bodies? ______________________________

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36. Coulomb's Law says that the force is directly proportional to the product of the charges on the two bodies. That is, the charge of the first body is multiplied by the charge of the second body. Without worrying about the exact amount of the charges, let's give them number values. The first body has a charge of 2 and the second has a charge of 3. With these numbers assigned, the force is directly proportional to a product of

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37. If the charges are increased so that their product is 12 instead of 6 (while the distance between the bodies remains the same), the force will be

______________ as much.
(half/twice)

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38. The force is directly proportional to the product of the charges, but it is inversely proportional to the square of the distance. "Inverse" is the opposite of "direct." In mathematics, an inverse relationship is shown as a reciprocal. For example, 1/4 is the reciprocal of 4, 1/5 is the reciprocal of 5, etc. The inverse of 2 is 1/2. What is the inverse of 4?

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39. The "square" of the distance merely means the distance multiplied by itself. If the distance between two objects is 3 meters, for example, the square of the distance is 9 meters. If the distance between two objects

is 4 centimeters, what is the square of the distance?

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40. This inverse/square formula is common to all known electromagnetic phenomena. If the distance from a light source, for example, is doubled, the illumination is quartered. Assume that the distance between two charged bodies is 1 centimeter. If the charge on each body remains the same, but the distance is increased to 2 centimeters, the attracting or repelling force is (1/2, 1/4, 1/8) __________ what it was before.

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41. The force between charged bodies can be calculated using Coulomb's Law. However, you are not required to learn the mathematics for doing so in this book. For now, you need only a general understanding of the relationship between charged bodies.

    If the total charge on two charged bodies is increased, and the distance between them remains the same, is the force increased or decreased?

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42. If the total charge remains the same and the distance between the bodies is increased, is the force increased or decreased? ________________

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In this chapter you have learned the nature of free electrons, on which electric current depends. You have learned why some materials are good conductors and some are not. You have learned the nature of static electricity and how to produce it. You have also learned how charged bodies attract or repel each other. Finally, you have learned how electric fields behave and have been introduced to Coulomb's Law of Charges.

When you feel you understand all the material in this chapter, turn to the Self-Test.

Self-Test

The following questions will test your understanding of Chapter One. Write your answers on a separate sheet of paper and check them with the answers provided following the test.

1. Name the particle in an atom that has each of the following charges: (a) positive; (b) negative; (c) neutral.
2. What are free electrons?
3. Explain in your own words the flow of electric current in a copper wire when an electric force is applied to the wire.
4. Define a good conductor.
5. Define a good insulator.
6. Give three examples of good conductors.
7. Give three examples of good insulators.
8. State the law of attraction and repulsion of charged bodies.
9. What is static electricity?
10. What is an electric field?
11. According to Coulomb's Law of Charges, what two factors affect the force between two charged bodies?
12. State whether the force between two charged bodies will increase or decrease under each of the following conditions.
    (a) The charge is increased while the distance remains the same.
    (b) The distance is increased while the charge remains the same.