

CHARGE AND CURRENT

Since the early discoverers of electricity couldn't visualize it, they equated it to water flow. They called electrical flow "current" (not terribly original, but it gets the point across). If there is no electrical pressure difference, there will be no electric current flow. An electric current performs the work. Though there are many explanations for the actual constitution of current flow, the concept we will stick to is that an electrical current is "a movement of charge." There are two (and only two) types of charges: *negative* and *positive*. Whether an item has a net negative or net positive charge depends on who is observing it and what their net charge might be. Figure 1–2 illustrates the importance of having a 0 charge reference.

In Figure 1–2, it is easy to see that the plates marked negative and positive will have a difference in charge between them and that if you observe the negative plate from the positive, it is indeed negative. The same can be said for observing the positive plate from the one marked negative; it is indeed positive. But what about observing from the more and less positive plates? If you use the less positive plate as your reference, then the more positive will be positive. However, if you observe the less positive plate using the more positive plate as your reference, it will appear to be negative. But they are both positive, no? Actually, the observation that both are positive could only come from an independent observer, one with a different (and presumably more negative) reference relative to the two positive objects. *All things are relative*. This is another point that you will need to remember throughout measurement. You must establish a reference. Though the reference may appear to be charged when observed from an independent location, the reference is our zero, so we may only determine the charge differences relative to our reference.

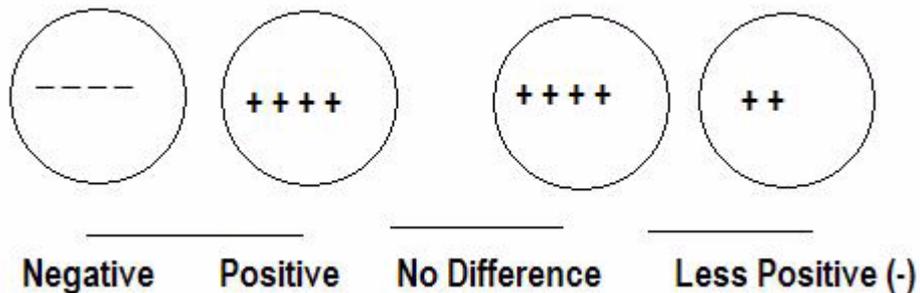


Figure 1–2 Difference in charge.

THE COMPLETE PATH

For an electrical current to flow a complete path must exist from the point of high to the point of low pressure. This is different than our water tower analogy, yet it is still easy to understand. In order to conduct electricity, conductors are used—the pipes in the water tower analogy. *Conductors* are made of materials that easily pass electrical charges. *Insulators* are made of materials that will not easily conduct electricity. Conductors such as wires are usually made of metals such as copper or aluminum. Insulators are made of materials like rubber, plastic, and some ceramics. Insulated wires (the most common kind) have an insulator wrapped around the wire to keep the charges from contacting the environment. Figure 1–3 illustrates the need for a complete conductive path.

The source develops the electric pressure or potential (difference in charge). This source could be a battery, generator, or any method for generating a difference in charge. Again, this difference in charge is known as “potential.” In fact, it has a more formal name: “electromotive force” or “emf.” It is the electrical pressure that will cause current to flow in the conductors (drawn as connecting lines in Figure 1–3). There must be a conductive path from the negative to the positive side of the source through the load. If this is not so, then there will be no way to equalize the difference in charge and nothing to relate one terminal to the other. If you are at the positive terminal and measure the difference along the conductor to the positive end of the load, you will detect no difference in charge. (Note: This may not be precisely true depending on the measuring equipment you use—as we explain in later sections. For our purposes here, however, any difference will be insignificant). The same can be said for the negative terminal of the source through the conductor to the negative terminal of the load. Notice in Figure 1–3 that the entire potential is across the load.

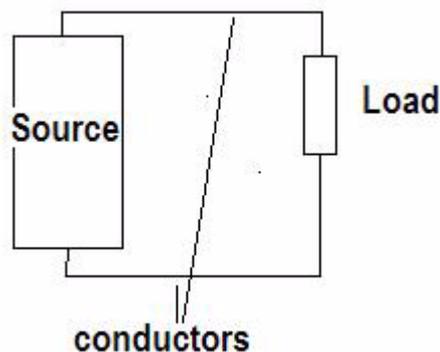


Figure 1–3 The complete conductive path.

Now the potential can do work. Whatever the load is (heating a resistance, turning a motor, etc.), energy will be used. This is work. There is one hard and fast rule for energy: "there is no free lunch." In other words, anything that is moved, heated, cooled, or changed in one way or another, generally involves work, and the energy to perform that work must be provided.

REVIEW

For work to be performed the energy must be available to perform that work. In order for an electric current to flow there must first be a potential difference, an electromotive force. This force can move charges through conductors. Conductors conduct charges easily, insulators do not. For a potential to cause an electric current a complete conductive path must exist between the negative and positive terminals of the source.

ELECTRICAL UNITS

We have discussed the big picture, so now some of the fine details must be explained. We will use standard units of measurement so that independent measurements can be related and have the same meaning. Three of these units are in common use: the *volt*, which is a measure of the electrical pressure; the *amp*, a measure of electrical current; and the *ohm*, a measure of electrical resistance. The following terms are the foundation of any electric study.

JOULE

The basic unit of energy is the "joule," whose symbol is J. This is a very small unit of energy; several hundred thousand joules are required just to operate an incandescent lamp over an hour or so. Note that the energy required to do work and the amount of work performed is one and the same. If it takes 250,000 joules an hour to power an incandescent lamp, then the energy required was 250,000 joules an hour, and the work performed was 250,000 joules an hour. If all this energy were converted into light, the lamp would be 100 percent efficient. It is not, however, so the total energy required is the work required to light the lamp plus the work wasted (usually as heat).

COULOMB

The basic unit of electrical charge is the "coulomb," whose symbol is C. A coulomb is defined as a number of electrons. The electron is an entity that has one negative charge, the smallest amount of charge measurable. Theoretically, this amount of charge is indivisible. In other words, there

are no half electron charges (actually, there *are* theorized partial charges in modern atomic physics, but the electron is the smallest negative charge for our purposes). A coulomb is the amount of charge represented by 6,250,000,000,000,000,000 electrons. Though this may seem a large number, it is not, as electrons, along with their charge, are really quite small.

CHARGE

Charge (symbol Q) is measured in coulombs. Stated arithmetically, for example, if $Q = 15\text{C}$, this means the amount of charge is 15 coulombs. (Don't even think of doing it in electrons).

CURRENT

The actual electrical flow (movement of charges) is defined as 1 coulomb past a point in 1 second and is called an “ampere” (named after André Ampère). In North America, contemporary usage shortens this term to “amp.” The symbol for current is I, which stands for *intensity of electrical current*. Current is measured in amperes, whose symbol is A. Stated arithmetically, if $I = 5\text{A}$, this means the current is 5 amps. It is important to note that *time* has become one of the variables now. Amperes are stated in coulombs per second. So it could be stated arithmetically as $I = Q/\text{time}$, where Q is charge in coulombs, and time is in seconds.

ELECTROMOTIVE FORCE

The pressure that causes current to flow is called electromotive force (emf). Emf is measured in “volts,” whose symbol is V (named after Alessandro Volta). Since we need to determine (by using the volt) how much “potential” energy there is in a difference of charge, two of the terms already introduced will suffice. The joule is a basic unit of energy, the coulomb is the basic unit of charge, and since the electrical pressure is the energy in a difference of charge, it may be stated arithmetically as:

$$V \text{ (volts)} = \text{energy (in joules)}/\text{charge (in coulombs)}$$

Or in words as: a 10-volt battery means that each coulomb of charge provides 10 joules of energy (or work). By rearranging the relationship to show work (or energy), it becomes:

$$\text{WORK} = \text{VOLTS} \times \text{CHARGE}$$

WATTS

Since we use the joule as the basic unit of energy, joules per second would be an appropriate measure of the energy required of an electrical current. Joules per second are known as “watts” (named after James Watt). A watt is a measure of power. Arithmetically stated:

$$P \text{ (power)} = \text{energy (work)}/\text{time (seconds)}$$

Note that if we combine our previous work, that is, I is Q (charge in coulombs) per second, and EMF (volts) = $Work/Charge$ or $Work/Q$, we get:

$$V \text{ (volts)} = \text{joules}/Q$$

$$I \text{ (amps)} = Q/\text{second}$$

$$\text{watts (power)} = \text{joules}/Q \times Q/\text{second} \text{ or } \text{watts (power)} = \text{joules}/\text{second}$$

All this means that power in an electrical circuit is determined by:

$$W \text{ (watts)} = E \text{ (volts)} \times I \text{ (amps)}$$

RESISTANCE

Charges go easily through conductors, though there is some opposition. When it comes to insulators, however, charges are presented with great opposition in flowing through the material. The opposition to current flow is known as *resistance*. All conductors have resistance; all insulators have resistance. The only substances that don't have resistance are superconductors, and they are not the subject of this text. The ease with which a charge may pass energy in a conductor is called (of all things) *conductance*. Resistance is its opposite (actually its reciprocal). The unit of resistance is the “ohm”—named after Georg Ohm. The unit of conductance is the “mho.” (There is no George Mho, but what is *mho* spelled backward? And you thought scientists didn't have a sense of humor.) A conductor will have very few ohms of resistance—in many cases so few as to be negligible. A good insulator will have many millions of ohms. Therefore, a conductor has few ohms, an insulator many. This means that a conductor will easily pass electrical current, whereas an insulator won't.

ANOTHER REVIEW

Of all the quantities discussed in this chapter, three are used most often in electrical measurement:

volt—the unit of electrical pressure

amp—the unit of electrical current

ohm—the unit of opposition to electrical current

A path with very few ohms will easily pass electrical current. A path with many ohms will pass very little electrical current. Power (as measured in watts) is equal to pressure (volts) \times current (amps)

SAFETY

It has been said before and will be repeated here: A little knowledge is a dangerous thing. Attempting to measure electrical properties can be dangerous. You cannot see electricity or even sense its potential until you are well into a danger zone. Electricity is energy. Like fire, it is both useful and dangerous. Since you cannot see electric potentials and currents without the aid of test equipment, you must *know* beforehand what it is you are trying to accomplish. Though the author of this book cannot foresee all instances and circumstances that you may be thrust into, *safety* is a big concern underlying all the procedures described in this text. *You must respect electricity.* Nonchalance and abuse will sooner or later cause you injury.

You (in the atoms and molecules that make up your very self) are electrical in nature. Biochemical (synapse) currents determine your every movement (voluntary and involuntary). If you allow an electrical path through your body, even a quite small amount of current, many of your body's nerve patterns can be disrupted, particularly those of the heart. Skin burns are bad enough, but to have your heart stop or beat abnormally is life threatening. Be careful. If you follow the guidelines below you will avoid most problems:

1. *Know* the potentials involved and where they are present, and *know* what and how to measure the electrical properties in question.
2. *Do not* allow your skin to contact any current-carrying conductor.
3. *Keep* one hand in your pocket when measuring high potentials.
4. *Do not* attempt to measure high or unknown potentials *unless* you have received the appropriate training and have the appropriate safety equipment.

5. *As a rule*, when measuring potentials marked high (or unknown), *always* have a safety observer on hand to watch.
6. *Consider* any circuit as active unless you *personally* have disconnected it, tagged it as such, and locked it in such a way that no one but you can turn it on again.

Other precautionary measures will be explained throughout the text. Remember, however, that *you have the ultimate responsibility* to know what is on, what is off, what the potentials are, and what the safe procedures are. After all, it is your life!

QUESTIONS

1. Who has the ultimate responsibility for *your* safety?
2. You are handed a voltmeter. Can you assume that this meter can safely measure any of the potentials in your area?
3. Nonchalance and disrespect for electricity will normally result in a _____.

VOLTS, AMPS, AND OHMS

Recall that volts are the measure of the potential (electrical pressure) that exists between two points, and *amps* are the measure of the amount of current (charge) that the potential can push through the resistance (measured in *ohms*) of a complete path for current flow. A circuit is one or more paths of current flow designed to accomplish some particular function.

STEADY VOLTAGE

If a potential is held steady (kept at the same value) for a complete path, a certain amount of current will flow. If the resistance in the path is increased (more ohms) and the pressure is the same, the current will decrease (fewer amps). As an example, Figure 1–4 illustrates a circuit (one complete path of current flow, in this case).

Assume that the source is 12.6 volts (just like the battery in your car). Assume as well that the load resistance is 12.6 ohms. The amount of current in the circuit is 1 amp. If the source remains the same (12.6 volts) and the resistance is increased (doubled) to 25.2 ohms, the current will be cut in half to 1/2 amp. If the resistance is cut in half to 6.3 ohms, then

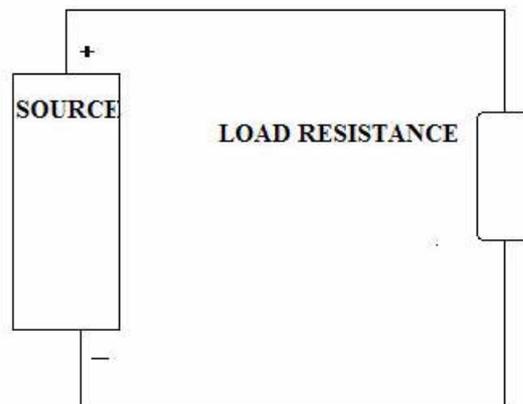


Figure 1–4 A complete circuit.

with the source remaining steady (at 12.6 volts) the current will increase to 2 amps. To summarize:

- If the voltage is held steady and the *circuit resistance increases*, the *current in the circuit decreases*
- If the voltage is held steady and the *circuit resistance decreases*, the *current in the circuit increases*

OHM

An ohm is described as that resistance through which 1 volt will push 1 amp. In circuits that pass large currents, there will be very few ohms—in fact, maybe even fractional ohms. In those circuits where small currents are used (as is the case in most electronics) the resistance varies from a few ohms to many millions of ohms.

While a million ohms may often be used in electric circuits, most currents are fractions of an amp. In order to make the volt, amp, and ohm usable (not too many zeros and certainly not too many zeros after a decimal point), prefixes are used.

PREFIX

The following metric prefixes are used in almost all measurements. An easy way to remember the powers of ten is that the superscript number (exponent) is the number of zeros following the 1. For negative numbers, remember that this number is divided into 1, which explains why it has the negative sign. The prefixes are:

Prefix	Power of Ten	Symbol	Arithmetic
giga	1×10^9	G	(1×1000000000)
mega	1×10^6	M	(1×1000000)
kilo	1×10^3	K	(1×1000)
milli	1×10^{-3}	m	$(1 \times 1/1000)$
micro	1×10^{-6}	μ	$(1 \times 1/1000000)$
nano	1×10^{-9}	n	$(1 \times 1/1000000000)$
pico	1×10^{-12}	p	$(1 \times 1/1000000000000)$ (pico was formerly micro-micro)

SAMPLE CONVERSIONS FOR VOLTS

1. To convert from volts to kilovolts, move decimal point three places to the left:

$$\text{XXXX.00 V} = \text{X.XXX KV}$$

$$\text{Example: } 1230 \text{ volts} = 1.230 \text{ KV}$$

2. To convert from volts to millivolts, move decimal point three places to the right:

$$0.\text{XXX V} = \text{XXX mV}$$

$$\text{Example: } 0.123 \text{ V} = 123 \text{ mV}$$

3. To convert from volts to microvolts, move decimal point six places to the right:

$$0.\text{XXXXXXX} = \text{XXXXXXX } \mu\text{V}$$

$$\text{Example: } 0.00123\text{V} = 1,234 \mu\text{V}$$

4. To convert from millivolts to microvolts, move decimal point 3 places to the right:

$$0.\text{XXX mV} = \text{XXX } \mu\text{V}$$

$$\text{Example: } 0.123 \text{ mV} = 123 \mu\text{V}$$

5. To convert from microvolts to millivolts, move decimal point three places to the left:

$$\text{XXX } \mu\text{V} = 0.\text{XXX mV}$$

$$\text{Example: } 123 \mu\text{V} = 0.123 \text{ mV}$$

6. To convert from millivolts to volts, move decimal point 3 places to the left:

$$0.\text{XXXmV} = 0.000\text{XXX V}$$

$$\text{Example: } 123 \text{ mV} = 0.123 \text{ V}$$

7. To convert from kilovolts to volts, move decimal point three places to the right:

$$0.\text{XXX KV} = \text{XXX V}$$

$$\text{Example: } 0.123 \text{ KV} = 123 \text{ V}$$

VOLT CONVERSION EXERCISES

Convert the listed voltage into other units:

	KV	V	mV	μV
1		10.0		
2	.025			
3			780	
4				100
5	1.0			
6		5.06		
7			3570	
8				65000
9		13.6		
10			551	

SAMPLE CONVERSIONS FOR AMPS

1. To convert from amps to milliamps, move the decimal point three places to the right:

$$0.XXXXXX = XXX.XXX \text{ mA}$$

$$\text{Example: } 0.020 \text{ A} = 20 \text{ mA}$$

2. To convert from amps to microamps, move the decimal point six places to the right:

$$0.XXXXXX = XXXXXX \mu\text{A}$$

$$\text{Example: } 0.020 \text{ A} = 20,000 \mu\text{A}$$

3. To convert from milliamps to microamps, move the decimal point three places to the right:

$$0.XXX \text{ mA} = XXX \mu\text{A}$$

$$\text{Example: } 0.22 \text{ mA} = 220 \mu\text{A}$$

4. To convert from microamps to milliamps, move the decimal point three places to the left:

$$XXX \mu\text{A} = 0.XXX \text{ mA}$$

5. To convert from milliamps to amps, move the decimal point three places to the left:

$$0.XXX \text{ mA} = 0.000XXX \text{ A}$$

$$\text{Example: } 250 \text{ mA} = 0.250 \text{ A}$$

AMPERE CONVERSION EXERCISES

Convert the listed amperage into other units:

SAMPLE CONVERSIONS FOR OHMS

1. To convert from megohms to kilohms, move the decimal point three places to the right:

$$0.XXXXXX \text{ (M}\Omega\text{)} = XXX.XXX \text{ K}\Omega$$

$$\text{Example: } 0.24 \text{ M}\Omega = 240 \text{ K}\Omega$$

	A	mA	μ A
1	20.0		
2		380	
3			40
4	5.18		
5		7570	
6			43000
7		12.6	
8			951

2. To convert from megohms to ohms, move the decimal point six places to the right:

$$0.XXXXXXX \text{ (M}\Omega\text{)} = XXXXXXX \Omega$$

$$\text{Example: } 0.24 \text{ M}\Omega = 240,000 \Omega$$

3. To convert from kilohms to ohms, move the decimal point three places to the right:

$$0.XXX \text{ K}\Omega = XXX \text{ Ohms}$$

$$\text{Example: } 12 \text{ K}\Omega = 12,000 \Omega$$

4. To convert from ohms to kilohms, move the decimal point three places to the left:

$$XXX \text{ Ohms} = 0.XXX \text{ K}\Omega$$

$$\text{Example: } 470\Omega = 0.47 \text{ K}\Omega$$

5. To convert from kilohms to megohms, move the decimal point three places to the left:

$$0.XXX \text{ K}\Omega = 0.000XXX \text{ M}\Omega$$

$$\text{Example: } 6.8 \text{ K}\Omega = 0.0068 \text{ M}\Omega$$

OHM CONVERSION EXERCISES

Convert the listed resistance into other units:

	MΩ	KΩ	Ω
1	2.0		
2		280	
3			40
4	0.520		
5		3530	
6			43000
7		10.6	
8			951

CHAPTER REVIEW

In this unit, we have discussed the very basics of electricity. Several facts stand out:

1. Safety is an implicit part of electrical measurement.
2. For current to flow, there must be a difference in potential and a complete circuit path.
3. The most often measured (and used) electrical variables are electromotive force (emf) in *volts*, current in *amps*, and resistance in *ohms*.
4. There is a relationship between the amount of potential (volts), the resistance of a complete circuit (ohms), and the amount of current flowing in the circuit.
5. Various prefixes are used to ensure that measured variables will have no more than three or four significant figures (i.e., 1.56 Megohms instead of 1,560,000 ohms).

CHAPTER EXERCISES

1. Electromotive force is another name for electrical _____.
2. For electrical current to flow in a circuit, two things are necessary (select the two from this list).
 - a. source potential
 - b. load
 - c. complete path
 - d. high resistance

3. An insulator will conduct [*more/less*] current than a conductor.
4. A zero reference is needed to determine how much _____ exists between a charged object and the reference.
5. Which actually performs the work: electromotive force or current?
6. If you have a 10 volt source and a 5 ohm load, with a complete circuit, how much current will flow?
6. If you change the load to 10 ohms, will more or less current flow?
7. If you again change the load to 2 ohms, will more or less current flow than in question 6?
8. Given 230 volts and a 70 amp load, what power is being used?
9. If an incandescent lamp is rated at 100 watts for 120 volts, what is the current required to operate the lamp (disregard inefficiency).

Answers to chapter exercises will be found at the back of this book.

CONCLUSION

If you are having difficulty understanding the concepts outlined in this chapter, reread the unit carefully. If you still have questions, seek out your advisor, supervisor, or a person you know who has a good working knowledge of this subject and discuss your problems. Unanswered questions remain that way unless you seek out their answers. This chapter is important, as all other chapters in this text will be built on these basic principles. Answers to the review questions as well as the conversion exercises can be found at the end of this book.

For further information on these topics, open your Internet browser and search for the following terms in an online search engine:

volts

amps

ohm

charge

electrical current

Volta

Ampère

joule

electron