Lesson A4–3

Measuring and Calculating Electricity

Unit A. Mechanical Systems and Technology

Problem Area 4. Electrical Systems

Lesson 3. Measuring and Calculating Electricity

New Mexico Content Standard:

Pathway Strand: Power, Structural and Technical Systems

Standard: **X:** Use available power source to plan and apply control systems.

Benchmark: **X-A:** Measure with selected instruments to demonstrate knowledge of basic electricity.

Performance Standard: **1.** Show proficiency in use of various meters. **2.** Discuss importance of and techniques for grounding. **3.** Show understanding of codes and regulations. **4.** Discuss various energy sources.

Student Learning Objectives. Instruction in this lesson should result in students achieving the following objectives:

1. Define and safely measure voltage, amperage, resistance, watts, kilowatts, and kilowatt-hours.
2. Solve circuit problems using Ohm's Law.
3. Describe the mathematical relationship between voltage, amperage, and watts in AC circuits.
4. Determine the cost of various electrical devices, knowing their wattage rating and the cost of electricity.

List of Resources. The following resources may be useful in teaching this lesson:

Recommended Resources. One of the following resources should be selected to accompany the lesson:

Burke, Stanley R., and T.J. Wakeman. *Modern Agricultural Mechanics.* Danville, Illinois: Interstate Publishers, Inc., 1992. (Textbook, Chapter 18)

Johnson, Donald M., et al. *Mechanical Technology in Agriculture.* Danville, Illinois: Interstate Publishers, Inc., 1998. (Textbook, Chapter 3)

Phipps, Lloyd J., et al. *Introduction to Agricultural Mechanics,* Second Edition. Upper Saddle River, New Jersey: Prentice Hall Interstate, 2004. (Textbook, Chapter 17)

Other Resources. The following resources will be useful to students and teachers:

McKenzie, Bruce A., and Gerald L. Zachariah. *Understanding and Using Electricity.* Danville, Illinois: Interstate Publishers, Inc., 1982. (Textbook, Unit 2)

Phipps, Lloyd J., and Carl L. Reynolds. *Mechanics in Agriculture.* Danville, Illinois: Interstate Publishers, Inc., 1992. (Textbook and Workbook, Chapter 38)

Richter, H.P., and W. Creighton Schwan. *Wiring Simplified.* Minneapolis, Minnesota; Somerset, Wisconsin: Park Publishing, Inc., 1996.

Surbrook, Truman C., and Ray C. Mullin. *Agricultural Electrification*. Cincinnati, Ohio: South-Western Publishing Co., 1985. (Textbook, Unit 2)

VAS U3003c. *Planning for Electrical Wiring.* Urbana, Illinois: Vocational Agriculture Service.

List of Equipment, Tools, Supplies, and Facilities

Writing surface
Overhead projector
Transparencies from attached masters
Copies of student lab sheets
Multimeter
Table from NEC on Allowable Current-Carrying Capacities of Insulated Conductors

Terms. The following terms are presented in this lesson (shown in bold italics):

Ammeter
Amperes (amps)
Electromotive force (emf)
Energy

Kilowatt
Kilowatt-hour (kW-hr)
Multimeters
Ohm's Law
Ohmmeter
Ohms
Power
Power equation
Resistance
Volt
Voltmeter
Watts
Work

Interest Approach. Use an interest approach that will prepare the students for the lesson. Teachers often develop approaches for their unique class and student situations. A possible approach is included here.

Ask students if they or one of their parents have ever been using several appliances in the kitchen and had a circuit breaker trip or a fuse blow. Ask students to determine how many different outlets they have in their kitchen and if they know how many different circuits are used to run electricity to those outlets. Have them try to determine why a circuit breaker would trip or a fuse blow. Ask if it matters what size wire is used to wire outlets and if it matters how many outlets are on a circuit.

Summary of Content and Teaching Strategies

Objective 1: Define and safely measure voltage, amperage, resistance, watts, kilowatts, and kilowatt-hours.

Anticipated Problem: What is the definition of and how do you safely measure voltage, amperage, resistance, watts, kilowatts, and kilowatt-hours?

I. When using electricity, there is a direct relationship between voltage, amperage, and resistance as well as a relationship between voltage, amperage, and watts.

A. Voltage is the ***electromotive force (emf)*** that causes electrons to flow through a conductor. It can be thought of as the pressure that causes the electrons to flow. In a DC circuit, the electrical source produces a constant voltage with respect to time. However, in an AC circuit, the voltage is zero at the beginning of a cycle, builds to a maximum positive value, decreases to zero, then builds to maximum negative value before again returning to zero. The unit of measurement for voltage is the ***volt***. One volt is defined as the amount of electrical pressure required for one ampere of current to flow in a circuit having one ohm of total resistance. A ***voltmeter*** is used to measure voltage. It is connected between two conductors or across the terminals of a device that uses electricity.

B. Electrical current is the flow of electrons through a circuit. The rate of electrical current flow is measured in ***amperes*** or amps. One ampere of electrical current flows in a circuit when 6.28×10^{18} electrons flow past a certain point each second. An ***ammeter*** is used to measure amperage in a circuit. On an AC circuit, a clamp-on ammeter is clamped around one of the circuit's conductors to obtain a reading.

C. ***Resistance*** is the characteristic of any material that opposes the flow of electricity. All materials, even conductors, have some resistance to the flow of electrons. Conductors, such as copper and aluminum, have very low resistance, while insulators, such as rubber and porcelain, have very high resistance. Resistance is measured in units called ***ohms***. Resistance of a specific conductor will vary based on its length, cross-sectional area, and temperature. The longer the conductor, the more resistance in that conductor. The smaller the cross-sectional area of a conductor, the more resistance in that conductor. As the temperature of a conductor increases, so does the resistance in that conductor. Resistance is measured using an ***ohmmeter***. Always measure resistance with the circuit de-energized.

D. Meters that measure two or more electrical characteristics are called ***multimeters***. They will measure voltage, resistance, and current flow or amperage.

E. Electrical power is measured in ***watts***. ***Power*** is the rate at which work is done. As the time required for doing a certain amount of work decreases, the power required will increase. ***Work*** is the movement of a force through a distance. When electrons move through a circuit to light a bulb, produce heat in a heater, or cause a motor to operate, work is being done. The watt is a very small unit of power, so the kilowatt is often used instead. One ***kilowatt*** is equal to 1,000 watts. With electricity, 746 watts of electrical power are required to equal one horsepower of mechanical power.

F. Electrical power, given either as watts or kilowatts, does not include the element of time. ***Energy*** is different from power in that energy includes the element of time. Electrical energy used is measured by the ***kilowatt-hour (kW-hr)***. One kilowatt-hour is equivalent to using 1 kilowatt of power for a one hour period of time. Electricity is sold by the kilowatt-hour. Utility companies install a kilowatt-hour meter at each electrical service site to determine electrical usage, which is then used to determine the cost of electrical power used.

Using TM: A4–3A and the notes above, discuss the various terms associated with measuring electricity. It may be helpful to students to compare electricity to a water system, where voltage would be like the pressure causing the water to flow through the pipes. Amperage would be comparable to the number of gallons flowing through a particular point at a given time. And resistance would be comparable to the resistance in the pipe that would interfere with the flow of water in that pipe. Students may also refer to pages 40–48 in Mechanical Technology in Agriculture for further explanation of terms and explanation of how to use the multimeters.

Objective 2: Solve circuit problems using Ohm's Law.

Anticipated Problem: How do you solve problems using Ohm's Law?

II. ***Ohm's Law*** is a formula defining the relationship between voltage, current, and resistance. Ohm's Law will allow you to determine an unknown value if two of the values are known or can be measured.

A. In order to use Ohm's Law we need to use symbols that will be used in the formula. Let E represent voltage, (E is short for electromotive force). Let I represent current measured in amperes. Let R represent resistance measured in ohms. The relationship between E, I, and R is: $E = I \times R$. Assume that 10 A of current flows in circuit having a total resistance of 11 ohms. What is the source voltage? Using the formula: $E = I \times R$, $E = 10$ A $\times$ 11 ohms. Thus, $E = 110$ volts.

B. Assume that you know amps and volts, you can calculate resistance by rearranging the formula to be $R = E \div I$. Assume that there are 6 amps of current flowing through a 120 volt circuit. What is the resistance? Using the formula, $R = 120$ volts $\div$ 6 amps $= 20$ ohms.

C. Assume that you know volts and resistance, you can calculate amperage by rearranging the formula again to $I = E \div R$. Assume that you need to know how much current is flowing through a 115 volt circuit containing 25 ohms of resistance. What is the amperage of the circuit? Using the formula, $I = 115$ volts $\div$ 25 ohms $= 4.6$ amps

Teach students the appropriate symbols used to represent volts, amps, and resistance. Write the equation of Ohm's law on the board and discuss the relationship of each part of the equation. Use TM: A4–3B to show students an easy way to remember the relationship between each of the factors. Use the examples given in the notes to help students work with the various equations.

Objective 3: Describe the mathematical relationship between voltage, amperage, and watts in AC circuits.

Anticipated Problem: What is the mathematical relationship between voltage, amperage, and watts in AC circuits?

III. The ***power equation*** is a formula that defines the relationship between watts, amps, and volts. This equation is particularly useful in determining how large a circuit should be and what size wire and circuit breaker or fuse size is necessary to provide electricity to various circuits. As with Ohm's Law, the power equation allows you to determine an unknown value if two of the values are known or can be measured.

A. The symbols used in the power equation are P for watts (P represents power), I for amps, and E for volts. The relationship between P, I, and E is: $P = I \times E$. Assume that .83 amps of current flows through 120 volt circuit. How many watts of electrical power are being used? Using the formula: $P = .83$ amps $\times$ 120 volts $= 99.6$ or 100 watts of power.

B. Assume that you know watts and voltage, you can calculate how many amps by rearranging the formula to: I = P ÷ E. Assume that there are 5, 100 watt light bulbs being operated on a 115 volt circuit. How many amps of current are flowing through the circuit? I = 500 watts ÷ 115 volts = 4.35 amps of current.

C. Assume that you know amps and watts, you can calculate how many volts are in the circuit by rearranging the formula to E = P ÷ I. Assume that there is a 1200 watt coffee pot pulling 10 amps. What is the source of voltage? E = 1200 watts ÷ 10 amps =120 volts.

D. In order to determine the wire size and then the circuit breaker or fuse size, one needs to know what electrical devices or appliances might be operated on a given circuit. We know the voltage source and you can find the wattage rating on the nameplate of each appliance or device being used. From this we can determine how many amps of current would flow through the circuit using the power equation. For example, assume that you plan to use a toaster rated at 1100 watts and a frying pan rated at 1200 watts on the same 120 volt circuit using copper wire. What size wire and what size circuit breaker should be used for that circuit? First, determine how many amps will flow through the circuit using the power equation. I = P ÷ E. I = 2300 watts ÷ 120 volts = 19.2 amps. Now you must refer to a table in the National Electric Code for allowable current-carrying capacities of insulated conductors. According to the table, you must use AWG #12 wire, which is rated for 20 amps. From this, you should also know that a 20 amp circuit breaker is necessary.

Teach students the appropriate symbols used to represent watts, amps, and volts. Write the power equation on the board and discuss the relationship of each part of the equation. Use TM: A4–3C to show students an easy way to remember the relationship between each of the factors. Use the examples given in the notes to help students work with the various equations. Have students complete LS: A4–3A, which will give them experience in working with the various equations. Explain to students that when wiring a circuit at home and the maximum load in watts is determined, the size of conductor necessary to carry that load could also be determined, along with the size of circuit breaker or fuse needed to protect that circuit. It is also necessary to point out that certain codes must be followed in choosing the correct conductor size for various electrical applications.

Objective 4: Determine the cost of various electrical devices, knowing their wattage rating and the cost of electricity.

Anticipated Problem: How do you determine the cost of using electrical devices when you know the wattage rating and the cost of electricity?

IV. In order to determine the cost of using various electrical appliances or devices one must know the wattage rating of those appliances, which should be found on the nameplate and know the cost of electricity, which can be found from your electric bill or contacting your local electricity provider.

A. The number of watts used, is the wattage on the nameplate, if that appliance were used for one full hour. For example, if a 100-watt light bulb were burned for eight hours, it would use 800 watts (100 watts × 8 hours). In order to determine cost, we must convert this to kilowatt-hours. To do this divide the number of watts by 1000, the number of watts in a kilowatt. In this example, 800 ÷ 1000 = .8 kilowatt-hours. Assume that electricity costs $.08 per kilowatt-hour, the cost of burning a 100-watt light bulb for eight hours would be .8 kilowatt-hours × $.08 = $.064.

B. Determine the cost of operating a refrigerator rated at 500 watts for one week, assuming that it is actually cooling only 4 hours per day. To solve, take the watts (500) times the number of hours per day (4) times the number of days in a week (7) ÷ 1000 (the number of watts in a kilowatt). Kilowatt-hours = 500 watts × 4 hours per day × 7 days per week ÷ 1000 watts per kilowatt = 14 kilowatt-hours. If electricity costs $.08 per kilowatt-hour, the total cost operating the refrigerator for one week is 14 kilowatt-hours × $.08 = $1.12.

Use the notes above to explain how to determine the cost of electricity used by various devices. It would be helpful to have students bring to class a copy of their electricity bill from home so you can use real prices. This is also a good time to show students how to read an electric bill. Otherwise, contact a local power company for current rates. Use the examples given in the notes to work through a couple of example problems. Have students come up with some example problems from situations at home or make up possible situations. Students should complete LS: A4–3B to better understand how to determine cost of operating electrical devices.

Review/Summary. Use the student learning objectives to summarize the lesson. Have students explain the content associated with each objective. Student responses can be used in determining which objectives need to be reviewed or taught from a different perspective. Questions at end of chapters in the textbook may also be used in the review/summary.

Application. Application can involve the following student activities using attached lab sheets:

Electrical Problems Using Ohm's Law and the Power Equation—LS: A4–3A

Measuring and Calculating Electricity—LS: A4–3B

Evaluation. Evaluation should focus on student achievement of the objectives for the lesson. Various techniques can be used, such as student performance on the application activities. A sample written test is attached.

Answers to Sample Test:

Part One: Matching

1=e, 2=b, 3=f, 4=d, 5=a, and 6=c

Part Two: Completion

1=voltmeter
2=1,000
3=amps, volts
4=amperage
5=watts, amps, volts

Part Three: Short Answer

1. P=watts
   I=amps
   E=volts
   R=ohms
2. I=P/E   I=300/120=2.5 amps
3. E=P/I   E=1,500/13.6=110 volts
4. R=E/I   R=115/14.5=7.9 ohms
5. (2)(75 watts)=150 watts/hour
   24 hours/day × 30 days = 720 hours
   150 watts/hour × 720 hours = 108,000 watts/1,000 watts/kilowatt-hour = 108 kwh
   108 kwh × $.07/kwh = $7.56 to have lights left on for 30 days
6. P=(I)(E) P=(17.5)(120) = 2100 watts

Sample Test Name________________________________

Test

Lesson A4–3: Measuring and Calculating Electricity

Part One: Matching

Instructions. Match the term with the correct response. Write the letter of the term by the definition.

a. resistance
b. watts
c. ohms
d. amperes
e. multimeter
f. electromotive force

_______ 1. A device used to measure two or more electrical characteristics.

_______ 2. Term used to measure electrical power.

_______ 3. Referred to as voltage. It is what causes electrons to flow through a conductor.

_______ 4. A measure of the rate of electrical current flow.

_______ 5. The characteristic of any material to oppose the flow of electricity.

_______ 6. Term used to measure the amount of electrical resistance.

Part Two: Completion

Instructions. Provide the word or words to complete the following statements.

1. A ________________________ is used to measure voltage in a circuit.
2. A kilowatt-hour is equivalent to using ________________ watts for one hour of time.
3. Ohm's Law is an equation used to describe the relationship between ohms, ____________________________, and ________________________.
4. An ammeter is used to measure ______________________ in a circuit.
5. The power equation is used to describe the relationship between ________________, ____________________, and ____________________.

Part Three: Short Answer

Instructions. Provide information to answer the following questions.

1. What term is associated with each of the following used in the Power Equation and Ohm's law?

   P=__________________________

   I=__________________________

E=__________________________

R=__________________________

2. Given a 120 volt circuit with three 100 watt light bulbs, how many amps of current are flowing through the circuit?

3. How many volts would be in a circuit that has electrical devices using a total of 1,500 watts with 13.6 amps of current?

4. How many ohms of resistance are in a 115 volt circuit that is using 14.5 amps of current?

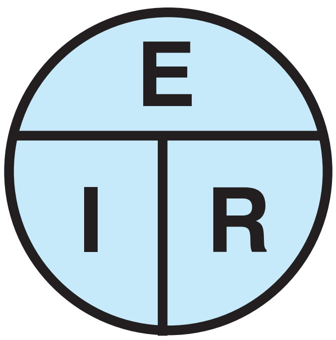
5. How much would it cost if you accidentally left two 75 watt light bulbs turned on in an attic for a period of 30 days, assuming that electricity cost $.07 per kilowatt-hour?

6. How many watts of electricity are being used on 120 volt circuit that is using 17.5 amps of current?

ELECTRICAL TERMS

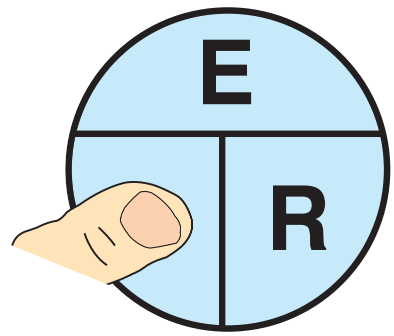
1. Electromotive force—electrical pressure that causes electrons to flow, often called voltage
2. Amperes—the rate of electrical current flow
3. Ohms—units used to measure resistance within a conductor
4. Watts—a measure of electrical power
5. Kilowatt—equal to 1,000 watts
6. Kilowatt-hour (kW-hr)—measure of electrical energy used for 1 hour of time

OHM'S LAW



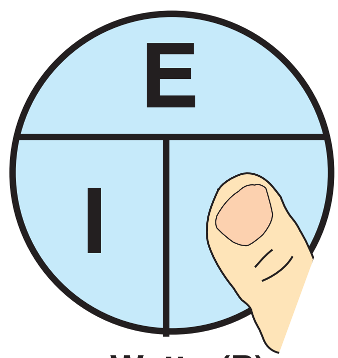
OHM'S LAW

To find Current (I):



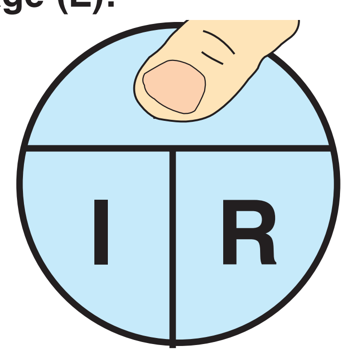
$$\text{Current (I)} = \frac{\text{Volts (E)}}{\text{Ohms (R)}}$$

To find Resistance (R):



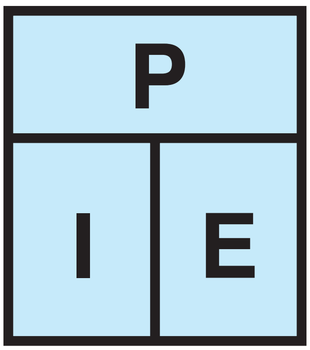
$$\text{Resistance (R)} = \frac{\text{Watts (P)}}{\text{Voltage (E)}}$$

To find Voltage (E):



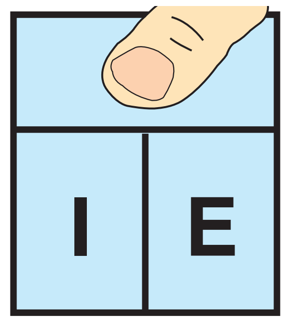
$$\text{Voltage (E)} = \text{Current (I)} \times \text{Resistance (R)}$$

POWER EQUATION



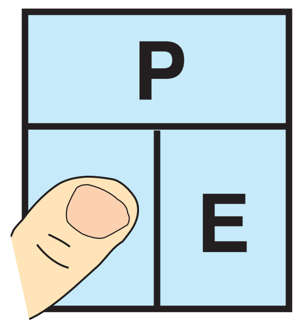
POWER EQUATION

To find Power (P):



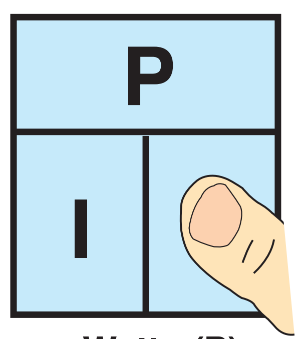
Watts (P) = Current (I) × Voltage (E)

To find Current (I):



$$\text{Current (I)} = \frac{\text{Watts (P)}}{\text{Voltage (E)}}$$

To find Voltage (E):



$$\text{Voltage (E)} = \frac{\text{Watts (P)}}{\text{Current (I)}}$$

LS: A4–3A Name________________________________

Lab Sheet

Electrical Problems Using Ohm's Law and the Power Equation

Purpose: Students will learn the relationships between watts, volts, amps, and ohms by using the Power Equation and Ohm's Law to calculate various electricity problems.

1. Determine how many amps of current are flowing through a 120 volt circuit that is using 1,650 watts of electricity.
2. How many volts are required in a circuit that uses 9.6 kilowatts of power with 40 amps of current flowing?
3. How many ohms of resistance are in a toaster on a 120 volt circuit that has 6.7 amps of current flowing?
4. How many watts of power are being used in a 240 volt circuit that has 36 amps of current flowing?
5. How many amps of current are there in a 100 watt light bulb on a 120 volt circuit?
6. Given an appliance that has 12.8 ohms of resistance, how many amps of current are flowing in a 120 volt circuit?

Lab Sheet Key

Electrical Problems Using Ohm's Law and the Power Equation

Purpose: Students will learn the relationships between watts, volts, amps, and ohms by using the Power Equation and Ohm's Law to calculate various electricity problems.

1. I=P/E I=1,650 watts/120 volts=13.75 amps
2. E=P/I E=9,600 watts/40 amps=240 volts
3. R=E/I R=120 volts/6.7 amps=17.9 ohms
4. P=I × E P=36 amps × 240 volts=8,640 watts
5. I=P/E I=100 watts/120 volts=.83 amps
6. I=E/R I=120 volts/12.8 ohms=9.4 amps

 Name__________________________________

Lab Sheet

Measuring and Calculating Electricity

Purpose: Students will learn the how to determine the cost of using various electrical devices.

1. How many kilowatts of electricity are used in one week when a 5,000 watt clothes dryer is used for 2 hours per day?

2. How much would it cost to watch your television for one week if you averaged watching it for 5 hours per day? The television is rated at 250 watts and electricity costs $.07/kwh.

3. How much does it cost to operate a food freezer for one month (30 days) if it averages 6 hours of operation per day? The freezer is rated at 650 watts and electricity costs $.09/kwh.

4. How much does it cost to keep a swine confinement building lighted at night for one year (365 days) if the lights are kept on an average of 10 hours per day? There are six 150 watt light bulbs used for lighting and electricity costs $.12/kwh.

5. How much does it cost to operate computer monitor that is left on continuously for 1 month (30 days) if it is rated at 1.6 amps on a 120 volt circuit? Assume electricity costs $.07/kwh.

6. Determine the cost of operating a 600 watt sump pump in an aquaculture system if the pump is used continuously for 9 months. Electricity costs $.08/kwh.

Lab Sheet Key

Measuring and Calculating Electricity

Purpose: Students will learn the how to determine the cost of using various electrical devices.

1. 5,000 watts × 2 hours/day × 7 days/week=70,000 watts/1,000 watts/kwh=70 kwh
2. 250 watts/hour × 5 hours/day × 7 days/week=8,750 watts/1,000 watts/kwh=8.75 kwh
   8.75 kwh × $.07/kwh=$.61/week
3. 650 watts/hour × 6 hours/day × 30 days/month=117,000 watts/1,000 watts/kwh=117 kwh
   117 kwh × $.09/kwh=$10.53/month
4. 6 bulbs × 150 watts × 10 hours/day × 365 days/year= 3,285,000 watts/1,000 watts/kwh=3,285 kwh
   3,285 kwh × $.12/kwh=$394.20/year
5. P=I × E P=1.6 amps × 120 volts=192 watts
   192 watts × 24 hours/day × 30 days/month=138,240 watts/1,000 watts/kwh=138.24 kwh
   138.24 kwh × $.07/kwh=$9.68/month
6. 600 watts × 24 hours/day × 30 days/month × 9 months=3,888,000 watts/1,000 watts/kwh=3,888 kwh
   3,888 kwh × $.08/kwh=$311.04