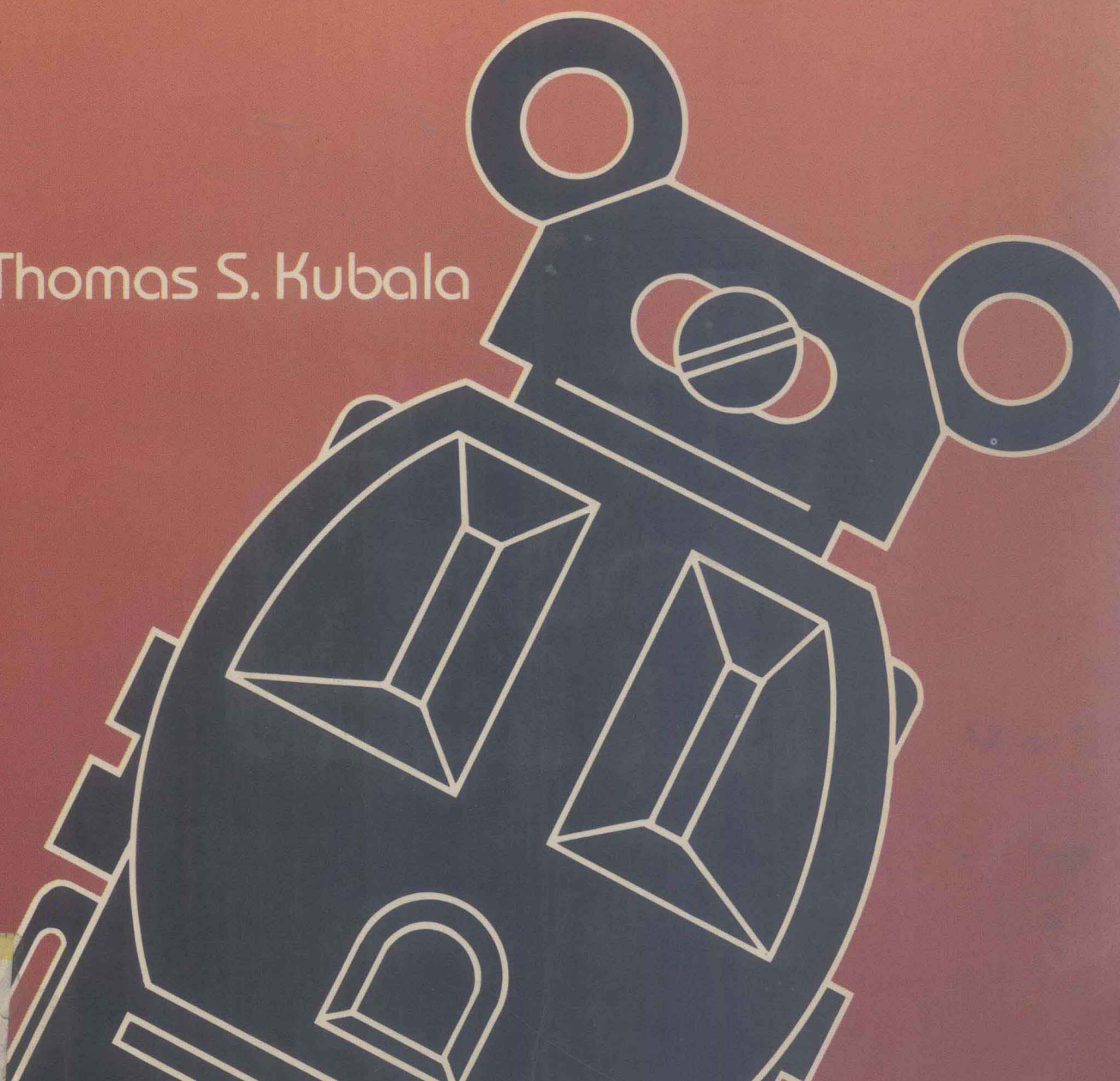
ELECTRICITY 1

Devices, Circuits, and Materials

4th Edition

Thomas S. Kubala



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FOURTH EDITION

THOMAS S. KUBALA

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ELECTRICITY 1

PREFACE

The fourth edition of *ELECTRICITY 1* has been updated to reflect current materials and techniques in electrical applications, while maintaining the features that have made the text so popular through previous editions.

ELECTRICITY 1 helps the student achieve a basic understanding of electrical theory and its application to devices, circuits, and materials. The knowledge obtained by a study of this text permits the student to progress to further study. It should be realized that both the development of the subject of electricity and the study of the subject are continuing processes. The electrical industry constantly introduces new and improved devices and materials, which in turn often lead to changes in installation techniques. Electrical codes undergo periodic revisions to upgrade safety and quality in electrical installations.

The text is easy to read and the topics are presented in a logical sequence. The problems provided in the text require the use of simple algebra only for their solution. The student is advised that electron movement (from negative to positive) is used in this text to define current direction.

Each unit begins with objectives to alert students to the learning that is expected as a result of studying the unit. An Achievement Review at the end of each unit tests student understanding to determine if the objectives have been met. Following selected groups of units, a summary review unit contains additional questions and problems to test student comprehension of a block of information. This combination of reviews is essential to the learning process required by this text.

All students of electricity will find this text useful, especially those in electrical apprenticeship programs, trade and technical schools, and various occupational programs.

It is recommended that the most recent edition of the National Electrical Code (published by the National Fire Protection Association) be available for reference as the student uses *ELECTRICITY 1*. Applicable state and local regulations should also be consulted when making actual installations.

Features of the fourth edition include:

- Updating of photos to reflect modern equipment and devices.
- Modification of selected circuit diagrams to include solid-state devices.
- References to the National Electrical Code (NEC) were updated to the requirements of the 1984 Code.
- New solved problems in selected units.
- Additional problems in the Achievement Reviews for student practice.
- Revised unit on wiring materials.
- Revised unit on batteries to include maintenance-free batteries.
- Revised material on low-voltage control wiring.
- New appendix of electrical wiring symbols.
- New glossary.

A combined Instructor's Guide for *ELECTRICITY 1* through *ELECTRICITY 4* is available. The guide includes the answers to the Achievement Reviews and Summary Reviews for each text and additional test questions covering the content of the four texts. Instructors may use these questions to devise additional tests to evaluate student learning. Student Study Guides to accompany each text will give students additional opportunities for classroom and laboratory practice.

ABOUT THE AUTHOR

Dr. Thomas S. Kubala is the President of Thomas Nelson Community College in Hampton, Virginia. Prior to this, he was Dean of the College at Anne Arundel Community College in Arnold, Maryland. Previous positions held at that college included Dean of Career Programs, Associate Professor of Engineering, and Director of Electrical Technology.

Dr. Kubala received an AAS degree in Electrical Technology from Broome Community College, Binghamton, New York; a BS degree in Electrical Engineering from the Rochester Institute of Technology, Rochester, New York; and an MS degree in Vocational-Technical Education from the State University of New York at Oswego, New York. He earned his doctoral degree from the University of Maryland, College Park, Maryland.

In addition to his extensive background in technological education, Dr. Kubala has had industrial experience with responsibilities in the fields of aerodynamics, electrical drafting, and electronic design.

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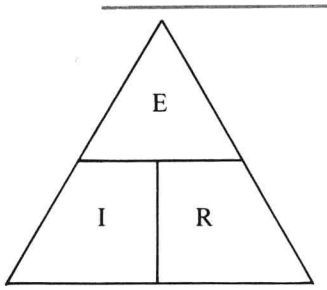
ELECTRICAL TRADES

The Delmar series of instructional material for electrical trades includes the texts, text-workbooks, and related information workbooks listed below. Each text features basic theory with practical applications and student involvement in hands-on activities.

ELECTRICITY 1
ELECTRICITY 2
ELECTRICITY 3
ELECTRICITY 4
ELECTRIC MOTOR CONTROL
ELECTRIC MOTOR CONTROL LABORATORY MANUAL
INDUSTRIAL MOTOR CONTROL
ALTERNATING CURRENT FUNDAMENTALS
DIRECT CURRENT FUNDAMENTALS
ELECTRICAL WIRING – RESIDENTIAL
ELECTRICAL WIRING – COMMERCIAL
ELECTRICAL WIRING – INDUSTRIAL
PRACTICAL PROBLEMS IN MATHEMATICS FOR ELECTRICIANS

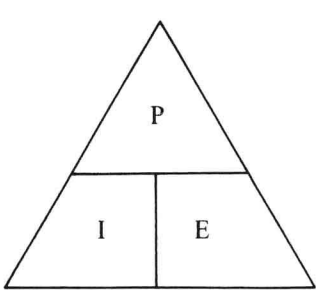
EQUATIONS BASED ON OHM'S LAW



$E = IR$

$I = \frac{E}{R}$

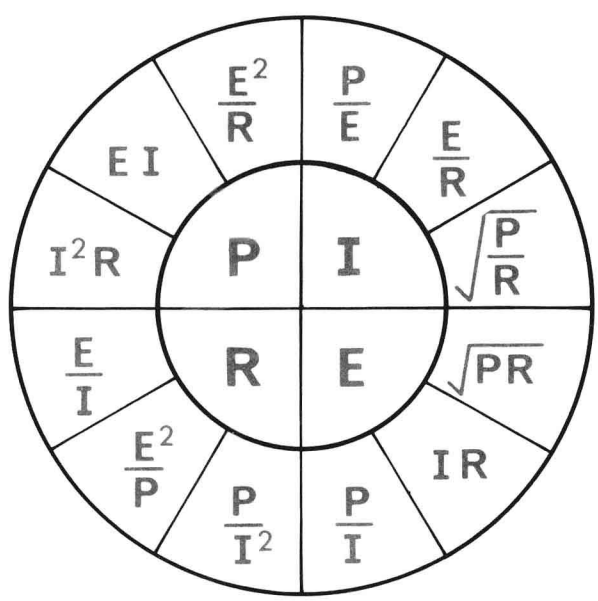
$R = \frac{E}{I}$



$P = IE$

$I = \frac{P}{E}$

$E = \frac{P}{I}$



CONTENTS

UNIT 1

INTRODUCTION

OBJECTIVES

After studying this unit, the student will be able to

- list the areas of work in which the apprentice electrician becomes involved.
- discuss the ethics of the electrical trade.
- describe the apprentice program as it applies locally, and discuss the values of any apprentice program.

When beginning a new program of study, an individual should be thoroughly familiar with the nature of the program, and its values and requirements. This is especially important when the program involves training for a lifelong occupation.

DESCRIPTION OF THE TRADE

The electrical trade is one of the basic trades in the construction industry. It is a trade in which individual ability and skill is recognized and rewarded. The trade involves the following areas: electrical installation in new buildings, rewiring of old buildings, electrical maintenance and repair, and troubleshooting of electrical equipment and installations. Many of these areas are also basic to the power and electronics fields.

The work involved in all fields often is so closely related to the technical and theoretical concepts of electricity that only a trained person can do the job. This is especially true in the field of electronics. Since more and more electronic equipment is being used, it is expected that the electrician can install and maintain this equipment. Therefore, it is necessary for the electrical apprentice to acquire the related technical information.

WORKING CONDITIONS IN THE TRADE

The surroundings and working conditions of the electrical trade are favorable to the worker. The trade offers opportunities for indoor and outdoor work. Working hours and conditions of the trade permit the electrical worker to find pleasure in doing a first-class job. The journeymen on many jobs have the opportunity to deal with customers; therefore, personal conduct of the experienced worker affects future advancement of the trade and industry. The electrical trade requires a high degree of responsibility on the part of the trained technician since this person has the responsibility for the interconnection and construction of complex electrical systems. These

systems are controlled by state and local building codes, and the National Electrical Code. As a result, the work requires skilled technicians.

OPPORTUNITIES IN THE TRADE

The general public's interest in building construction at the present time demands a greater number of more highly-trained electricians. The modern home, office, and factory require a higher degree of proficiency in electrical work. The constant increase in new types of construction, new electrical equipment, and new uses for electrical equipment offers increasing employment opportunities for qualified electricians. The ever-increasing use of electronic equipment in the power field has shown the need for advanced training of electricians.

Technological advances have created new improvements, new ideas, and new processes. It is necessary for the apprentice to be familiar with these developments in order to advance in the electrical profession. The increased use of this information by the electrician makes the electrical trade more interesting and desirable. The opportunity is open for the apprentice to become a first-class journeyman by understanding new phases of the electrical field. A first-class journeyman can advance to the position of foreman or contractor. The electrical trade is in need of individuals with a complete knowledge of the practical and technical phases of the trade including those who can supervise workers on the job.

Some of the fields which offer opportunities are: electrical construction, line construction, cable installation, signaling systems, light and power systems, electrical motor maintenance and repair, equipment and appliance servicing, and industrial electronics. Due to the increased needs of our society, new opportunities are developing very rapidly.

ETHICS OF THE TRADE

Electricians are judged by the quality of their work and by their attitude toward fellow workers, employers and the public. A good electrician takes pride in doing high-quality work and gives an honest day's work for an honest day's pay. An accurate and complete job is expected in every activity. Much work is done alone and unsupervised.

QUALIFICATIONS FOR EMPLOYMENT

Educational

The apprentice should be a high school graduate or equivalent. A trainee should be eager to learn the skills and technical information necessary for success in the electrical trade. The apprentice is expected to have a working knowledge of mathematics since this aids in the understanding of the important and necessary electrical formulas.

Physical

The apprentice must meet the requirements of a physical examination. A person must be strong enough to perform certain duties since the trade requires a considerable

amount of moving about, climbing, and working under conditions which require muscular action. The general health of the apprentice should be good.

General

The apprentice must like to work with electrical equipment and should be interested in the general theory of electricity. The trainee must like to work with others in a cooperative manner. Often, it is necessary for electricians to work in pairs and also with individuals in other trades. Electrical apprenticeship requires a liking for indoor as well as outdoor work, and a willingness to do a fair share of manual labor.

VALUES OF THE APPRENTICE PROGRAM

- Apprenticeship is an educational experience for the apprentice.
- The apprentice training program provides for training on an organized basis.
- A controlled apprenticeship brings together the fundamental factors which are necessary to produce a skilled technician.
- Apprenticeship is the most practical and efficient means of training a skilled technician.
- An apprenticeship program is of benefit to the trainee, the employer, the union, and society because all benefit from better workmanship.
- The successful electrician profits according to his or her knowledge and skill. It is an advantage to have the highest qualities possible.

THE RESPONSIBILITIES OF THE APPRENTICE

Educational programs and the work experience provide the apprentice with the opportunity to acquire the knowledge and skill necessary to become a skilled technician. It is the trainee's responsibility to make the most of these opportunities.

The apprentice is expected to take an interest in his or her work, to have a desire to learn, to fit into the employer's organization, to know the correct relationship of the apprentice to the journeyman, to plan and organize his or her work efficiently, to be resourceful, and to know how to conserve materials.

The trainee is further expected to be punctual, to maintain good health, to develop initiative and leadership, to cooperate in every way, to be neat in personal appearance, and to practice safe working procedures at all times.

The apprentice is expected to keep informed regarding new facts, new ideas, and new procedures of the trade. Because an apprentice is also expected to continue learning while earning, the trainee must be prepared to attend school to obtain the necessary technical and related instruction.

THE PROGRAM OF RELATED INSTRUCTION

Generally, the apprenticeship agreement requires the apprentice to attend classes in related subjects for a minimum number of hours. The length of the apprenticeship period in the electrical trade is normally five years. In certain localities, time spent in

related instruction is not classified as work time and is not paid for, while in other localities, school attendance is considered work time so that the apprentice receives pay at the prevailing wage rate.

The program of instruction consists of courses based on divisions of work within the trade such as residential wiring, commercial wiring, industrial plant wiring, and maintenance and repair. Each course includes such information as trade science, trade mathematics, and trade theory and practice.

If the apprentice enters a related instruction program at the time the course is being taught, he or she will obtain instruction in the normal manner by attending classes. If the related instruction course is not being given at the time the apprentice enters the program, this information must be acquired through self-study, under the supervision and with the assistance of the instructor. Apprentices are expected to provide their own necessary materials, such as textbooks, notebooks and workbooks, as advised by the instructor.

UNIT 2 ELECTRON THEORY AND OHM'S LAW

OBJECTIVES

After studying this unit, the student will be able to

- list the fundamental properties of matter.
- describe the structure of an atom.
- explain the basic electrical concepts of current, voltage, resistance, and electrical polarity.
- define Ohm's Law.

MATTER

Anything which occupies space and has weight is called *matter.* All liquids, gases, and solids are examples of matter in different forms. Matter itself is made up of smaller units called atoms.

ATOMS

An *atom* resembles the solar system with the sun as the center around which a series of planets revolve, figure 2-1. In the atom there is a relatively large mass at the center called the *nucleus. Electrons* revolve in orbital patterns around the nucleus.

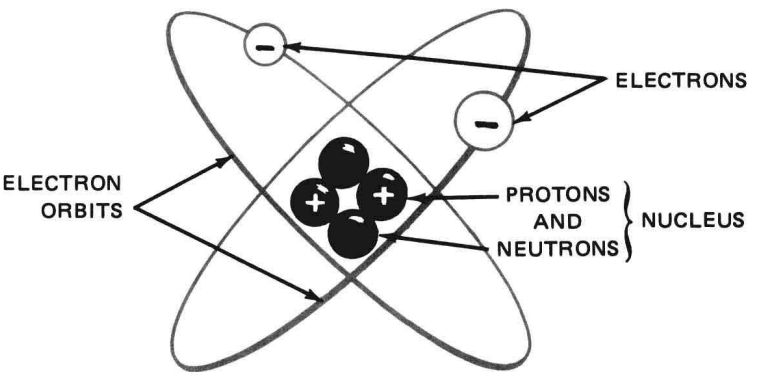


Fig. 2-1 Atomic structure.

ELECTRICAL CHARGE

A material is said to have an *electrical charge* when it attracts or repels another charged material. A material may have either a positive or a negative electrical charge.

Two objects with positive charges repel each other. Two objects with negative charges also repel each other. Two objects with unlike charges attract each other.

PROTONS AND NEUTRONS

Part of the nucleus of an atom is made up of protons. Each *proton* has a positive electrical charge and attracts electrons; neutrons form the remainder of the nucleus. *Neutrons* are electrically neutral. They can neither attract nor repel other electrical charges.

ELECTRON

One or more electrons revolve continuously about the nucleus of an atom (just as the planets revolve about the sun). *Electrons* possess a negative electrical charge and are very much lighter in weight than protons. All electrons are alike regardless of the atoms of which they are a part. An atom contains the same number of electrons as there are protons. For example, the aluminum atom has 13 electrons and 13 protons.

CURRENT

Electrons in motion result in an electrical current. Copper wire often is used to carry electrical current (moving electrons). For each atom of copper in the wire, electrons are revolving about the nucleus. When electrical pressure (voltage) from a battery or generator is applied, it is possible to force these electrons out of their circular paths and cause them to pass from atom to atom along the length of the wire (conductor).

The greater the number of electrons passing a given point in a circuit the greater the intensity of the current. The intensity of an electrical current is measured in *amperes* (A). The instrument used to measure current is called an *ammeter.* An ammeter must be connected in series with other devices in a circuit. The letter (I) is used to represent the amount of current in a circuit.

Current Types

Direct current (dc) is the movement of electrons in one direction in a conductor.

Pulsating direct current is a current in one direction which varies in intensity at a regular interval of time.

Alternating current (ac) is a current which changes in direction and intensity at a regular interval of time.

The three types of current are shown in figure 2-2.

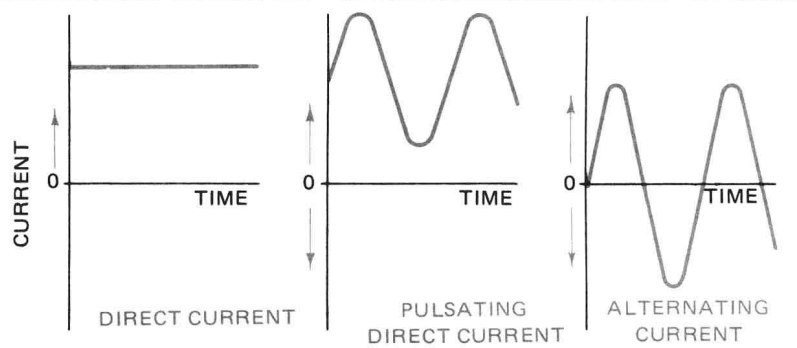


Fig. 2-2 Types of electrical current.

VOLTAGE

A closed circuit and a source of electrical pressure are necessary to produce an electrical current. Electrical pressure, known as *voltage,* or *potential difference,* is obtained from many sources. Generators are widely used for high-powered ac and dc installations. Storage batteries are used extensively for dc power in automobiles and aircraft. Photoelectric cells convert light energy into electrical energy. These cells are used as voltage sources in light-operated devices. A *thermocouple,* which consists of a junction of two unlike metals, generates a low voltage when heated. Of all the voltage sources mentioned, the generator is most important because of the magnitude of its commercial applications.

The letter (E) is used to represent a voltage. The *volt* (V) is the unit used to express the quantity of electrical pressure. The instrument used to measure voltage is the *voltmeter.* The voltmeter must be connected in parallel with other devices in a circuit.

ELECTRICAL POLARITY

All dc sources of electrical pressure have two terminals to which electrical devices are connected. These terminals have what is known as *electrical polarity.* One terminal is the positive terminal, while the other is called the negative terminal. Electrons flow through the device from the negative terminal of the source to the positive terminal of the source. The source maintains a supply of electrons on its negative terminal.

RESISTANCE

The property of a material which causes it to oppose the movement of electrons is called *resistance.* All materials have some resistance. Materials which offer little resistance to electron movement are called *conductors.* Those which offer high resistance are called *nonconductors* or *insulators.*

Resistance is measured in *ohms.* The symbol for ohms is the Greek letter omega (Ω). This symbol, representing ohms, and the letter (R), representing resistance, are used in formulas. The instrument used to measure resistance is called an *ohmmeter.* Electrical power must be disconnected in a circuit when using an ohmmeter.

OHM'S LAW

It is extremely important to understand the methods used to control the amount of current in a circuit. A simple formula, Ohm's Law, is used to show the relationship of current, voltage, and resistance. *Ohm's Law* states that in any electrical circuit the current is directly proportional to the voltage applied to the circuit and is inversely proportional to the resistance in the circuit. Note that both resistance and voltage affect the current.

According to Ohm's Law, when the resistance of a circuit is constant, the current can be changed by changing the voltage: current will increase when the voltage is increased, and current will decrease when the voltage is decreased. Similarly, when the voltage is constant, current will increase when the resistance is decreased, and current will decrease when resistance is increased.

The exact relationship of voltage, current, and resistance is expressed by the equation for Ohm's Law:

$$I = \frac{E}{R}$$

Where I = intensity of current in amperes
E = quantity of electrical pressure in volts
R = amount of resistance in ohms

Two other forms of Ohm's Law are:

$$E = IR \text{ and } R = \frac{E}{I}$$

ACHIEVEMENT REVIEW

1. Explain the meaning of voltage, current, and resistance.

2. State Ohm's Law and write three forms of Ohm's Law using equations.

3. What instruments are used to measure voltage, current, and resistance?

4. What units of measure are used for voltage, current, and resistance?

5. A trouble light has a resistance of 12 ohms and is rated at 1/2 ampere. What voltage must be applied to obtain the rated current?