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A PHYSICS COURSE AND TEXTBOOK

FOR

GENERAL-LEVEL STUDENTS

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By

ROBERT MACLENNAN SMYTHE, B.Sc., B.Ed.

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AUTHOR: Robert Maclennan Smythe, B.Sc. (University of Toronto)
B.Ed. (University of Toronto)

SUPERVISORS: Dr. David Brown
Dr. S. M. Najm

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Introduction

This project is an investigation of the need for a physics course and textbook for the general (four-year) level secondary school student, the designing of such a course, and the preparations for the writing of a suitable textbook.

Research for the project has involved communication with the Halton Board of Education, Ontario Ministry of Education, representatives from other provincial Departments of Education across Canada, advisers from community colleges, teachers, and principals.

In this report, I will summarize the need for such a course. I will describe the characteristics of the target population and outline how the course and text will be tailored to the students' needs. This will include discussions of the philosophy and design of the book. Then a proposed list of topics will be presented, along with specific objectives for the course. Finally, a sample unit from the textbook will be given.

Identification of the Target Population

Normally there are two major groups of students who enroll in general level courses. These are the underachievers and the students of low ability.

The underachievers are students who have the ability to handle the advanced (five-year) courses but are "turned off" school. The reason for this is often that they do not see a relevance of school to their daily lives or to their intended occupations. Of course, frequently they do not have much idea at all of their future lines of work, but they still do not feel that school is in any way providing them with useful skills. Thus they have less motivation to achieve than the advanced students of comparable abilities.

Far outnumbering those in the first category are the students of so-called "low ability". Here there is a wide range both in interest and in ability. Generally, these students have less competence in mathematical techniques, smaller vocabularies, slower reading rates, and greater interest in practical rather than abstract topics. According to the learning theory of Piaget, many of our high school students are operating at the formal operational stage of intellectual development. It is during this stage that they develop a greater sophistication with handling abstractions. Piaget suggests that development occurs in a series of stages: the intellectually maturing child uses a succession of methods to process data.* Every child passes through the stages of intellectual development in the same order but not at the same rate.** Since grade level at school closely correlates with age, in the senior school individual students at the same grade level may be operating at different levels of mental development. To account for the differences in mental abilities between general and advanced level students, Piaget proposes that many of the low ability students are proceeding at lower levels of abstraction. These students very often have to resort to direct or analagous concrete experiences in order to "see" the solution of a problem.

Gagne's hierarchy of learning also can serve as a theoretical model for instruction by using it to set up a series of learning experiences ranging from simple to complex. It is useful in explaining the difficulty experienced by general level students. Physics (and chemistry) deal with problem solving, principle learning, and concept learning. Other courses more easily handled by general students involve verbal associations and multiple discriminations, and less problem solving. A general level course must be

*Piaget, Jean. Science of Education and the Psychology of the Child. New York: Orion Press, 1970, p.33, p.159.
**Ibid., pp. 36, 37.

designed with this in mind.

Finally, Bloom's Taxonomy of Educational Objectives, Handbook I: Cognitive Domain also sheds some light on the capabilities of general level students. Whereas the higher levels of analysis and synthesis can be encouraged with advanced students in the senior grades, thought processes involving knowledge, comprehension, and application would be stressed in a course developed for general students. Many concrete experiences, real-life examples, and applications to their environment could be provided to help tempt them into higher thought levels.

Thus in terms of cognitive development or mental maturity the low achiever is operating at a level at which he or she still needs concrete materials and representational concrete experiences in order to take any steps into the realm of the abstract.

The low ability student is not by definition one who has little interest in learning in the school environment as is the case with the underachiever. But it must be recognized that if such a student has continually been placed in courses that require higher levels of cognitive ability than the student possesses, he or she may have lost interest in the classroom instruction out of sheer frustration.

It should be noted that because the target population consists of these two very different groups, there is a very wide range of abilities, interests, and motivation. For example, a general level student having his or her heart set on becoming a pilot may detest history, but will be extremely diligent in studying anything having to do with flight. Also it may be argued that these students are just as highly motivated to learn as are any others, but that they have been traditionally examined on topics more of interest to the university-bound students. Certainly, some may even be good readers and some might be capable in mathematics. However, I will take the position that, on average, the characteristics of the target population that I have listed above are valid. Even if the point can be made that the difference between general and advanced level students is smaller than I have maintained, the fact remains that there is a need for an alternative course and textbook in physics for such students, as I will demonstrate in this report.

Another characteristic of the general level student has to do with his or her future education. Very few will proceed to university. In fact, most will not complete grade thirteen. Many will pass straight from secondary school to the work force, and a number will attend community colleges. Thus the need to provide learning experiences that are required by the university-bound student does not apply. A general level physics course, however, should be of use to the student entering a science-oriented program at community college. In the main, though, such a secondary school course must provide the skills required by any adult member of our society. What these skills are will be treated later when the philosophy of the course and textbook is discussed.

To summarize, we can state that the target population is that group of students not necessarily proceeding to further institutional learning, of low reading and mathematical abilities, operating at or below the application level of Bloom's taxonomy, and of widely varying academic interest but mostly tending toward interest in the directly practical. The course and textbook will be tailored to appeal to and provide appropriate learning experiences for students with these characteristics.

Needs assessment

There is a need for a textbook for the grade eleven general level student. Mr. Truman M. Layton, Science Consultant for the Nova Scotia Department of Education, replying to an enquiry regarding the reference material used by his province's equivalent course, wrote "I would be very interested in a textbook which you may write since, to the best of my knowledge, there are no textbooks available which are Canadian or SI Metric." In Ontario, we find that many schools do not have separate courses for the general level student for precisely this reason. At a number of schools such students sit in on the regular advanced level classes, with the understanding that if they obtain over forty percent they will receive a general level credit in grade eleven physics. Usually these students attempt to use the same textbook as the advanced level students.

In other Ontario schools that have separate general level classes in grade eleven physics, often no textbook is used. There the students usually receive sheets prepared by the teacher on each topic.

Concerning the need for a general level course itself, it can be said that there is increasing interest in Ontario and some other provinces in the development of such a program. As attendance at community colleges continues to increase relative to attendance at universities, many students find that they need some background in the physical sciences if they wish to enter the job-oriented programs such as laboratory technician, media studies (audio-visual), or electrician. These students might be better served if there were a course for them that stressed the more practical aspects of physics than the theoretical knowledge required by the university entrants.

Nova Scotia is not the only province interested in new courses at this grade and level. British Columbia is in the process of revising their Physics 11 and 12 courses and selecting new texts, according to Mr. M. McKee, Curriculum Consultant for the Ministry of Education. The Yukon follows the B. C. guidelines and so are interested also. Mr. W. Oakley, Science Consultant for Newfoundland's Department of Education wrote "We do not have a curriculum bulletin for this program at this time. This area was under review last year by a committee, in an attempt to find suitable materials for the general student. Currently students use a text entitled Modern Physical Science. We are in the process of finding a replacement for this text."

It can be seen that there is interest across Canada in the development of a general level senior physics course, and a need for an appropriate textbook.

Philosophy of the course and textbook

The grade eleven general level physics course that is being proposed in this report has three main goals. They are: providing the background required by students who will be entering science-oriented programs at community colleges, building those skills useful to any adult in our increasingly technical world, and increasing the students' scientific literacy.

The first goal is the lowest priority. Not all the general level students will be proceeding to community colleges, or even entering an occupation that requires scientific knowledge. Although some community college programs cite a grade eleven physics course as a prerequisite, most will accept any student to any program as long as the student (from Ontario) is a grade twelve graduate and can demonstrate the ability to pick up the background knowledge necessary to keep up with the course. Discussions with Sheridan, Mohawk, and Seneca colleges, which surround the Oakville area, have revealed that the main requirement is that the student entering the sciences be proficient with the metric system, have adequate mathematical abilities, and be able to handle laboratory equipment (read meters, follow setup instructions, be familiar enough with basic techniques that the student is not a safely hazard). When asked what academic background knowledge was required by entrants, many college representatives began by saying "It would be nice if the student had studied...", but ended with the position that the specific knowledge was not an important requirement, that college courses generally start with basic information, and that only the fundamental skills mentioned above were necessary prerequisites.

Consequently, this grade eleven general course and textbook being proposed has been designed to provide the student with the general skills desired by the community colleges. When practical, academic knowledge consistent with that requested by the science departments at the colleges has been incorporated into the course.

The second goal is the accumulation of practical knowledge and skills. These may include wiring an electrical switch, understanding the dangers of replacing a fuse with a larger one, insulating a home, using a pulley to move a load, cooking with a microwave oven (with some understanding of what is going on in there), calculating times of trips or rates of fuel consumption. These are not specialized skills. They do not require great academic knowledge. It is not intended that the student, after completing this course, know how the family F.M. radio works, but if the dial light should go out, that he or she have enough scientific experience and confidence to undo the screws in the back, remove the bulb, and replace it, perhaps by solderring in a new one. (As the minimum repair charge at many small appliance shops is thirty dollars or more, this skill is surely "valuable".)

The course will provide students with opportunity for hands-on work with the practical scientific-technological tasks that an intelligent adult should be able to do.

The third goal is the encouragement of scientific literacy. One common feature of underachievers and low ability students, as has already been mentioned, is the fact that the majority will not participate in further science training. Therefore, whatever level of scientific literacy is developed in high school will have to be sufficient for the rest of their lives. Their secondary school background will be the basis for real life decisions which may have far-reaching social implications.

Scientific literacy implies a basic core of cognitive learning in the field of science--a core which will help the student in his or her adolescent years to relate to a world based on scientific thought extended and applied to technology. A high school science course for the general student should deal not only with relevant science-related experiences, but also with the social implications of scientific endeavour. To be scientifically literate means to be able to read an article pertaining to science in the newspaper or in a popular magazine and know enough about the general scientific principles to understand the point raised. Of course this does not mean that the student should be able to read Scientific American with comprehension. But when the daily newspaper discusses the problem of acid rain polluting our lakes, of the need to develop alternative energy sources such as solar energy, of the difficulties astronauts might be experiencing as they build a space station in earth orbit, the student should be able to say "I know something about that." Our society is a very technological one, and every citizen should have enough scientific literacy that he or she can participate in, or at least follow and learn from, general conversations dealing with the concepts of science and technology met in the everyday world.

Format of the textbook

For each topic in the book there are at least two different sections. As one reads the text one first finds a short, concise discussion of the concept being developed. The reading level is at or below grade nine. The basic information is displayed very obviously--the student does not have to wade through a great volume of words to find the important material. Following this reference section on each topic are reading articles that amplify the information that the student has just received or provide examples of how the material is applied in the everyday world. The reading level of these articles is slightly higher than in the first section. Whereas the core material is contained in the reference section for each topic, supplementary information appears in the subsequent articles. Some teachers may select one or more as compulsory reading and leave the others as optional.

Some concepts have, following these two sections, a third section containing laboratory investigations. These have been chosen to enable the student to have practice with equipment, experience with taking measurements, and visual confirmation of the concepts mentioned in the reference section.

Finally, at selected intervals throughout the text, a fourth section containing practice problems appears. In general, the mathematical content of the course has been kept to a minimum. But where basic competence in some concept requires familiarity with a certain mathematical technique or physical formula, there are a few straightforward problems for reinforcement of the concept.

In the sample unit included in this report, the different sections have been colour-coded. The basic information reference pages are white; the reading articles appear on pink paper; laboratory investigations are on yellow; and the problems are on blue background.

Rationale for the textbook format and style

This textbook has been designed for the student who is not a strong reader. In the planning of it two goals were kept in mind: first, that the text be written at a level the student could follow easily; and second, that the text help the student to improve his or her reading ability. These goals have been fulfilled by the format used to develop topics. Of the four different sections that have been used throughout the text, two provide information. The first reference section presents material using a minimum of words. Over the past fifteen years, with the admirable attempt to humanize science, the volume of text devoted to a specific topic has increased drastically in science books. From a human interest point of view, adding information about the history of the development of a theory or the life of a contributing scientist was a good idea. But for the slow reader, who was not much motivated to read science, this trend was damaging. This student, being unable to read through an assigned section in a reasonable time, did not read the textbook at all. To combat this, the individual presentation of a topic in this proposed textbook looks somewhat like a throwback to the old days, where a concept was merely defined, and little elaboration was presented.

The inquiry learning method has not been used. It is my opinion that the characteristics and requirements of the target population are such that the information should be presented to these students directly, that time should not be spent providing them with enough hints that they will be able to develop the concept for themselves. In this book a topic might be introduced with little more than definitions. It is hoped that the student will very easily see what he or she is to learn and study. This should accomplish the goal of providing information quickly at the student's level.

To progress toward the second aim of improving the student's reading ability, the second of the information sections for each topic contains reading articles. Written at a somewhat higher reading level than the first reference section, they usually provide applications of the concept under study. For example, after the brief introduction to static electricity there is an article on lightning, a newspaper account of a survivor of a lightning strike, and a report on St. Elmo's fire. It is hoped that the student will be encouraged to read one or more of these articles not because there is information that the student has to know for testing purposes, but out of general interest. The topics of these articles have for that reason been specially chosen to appeal to the student's interests, to answer some often asked question, to provide examples of common familiar applications of the principles just mentioned in the reference section, and to inform the student on areas of general concern of which an informed citizen should be aware. This is in keeping with the general goal of scientific literacy.

The laboratory investigations have also been selected carefully. In a textbook for advanced level students, the experiment is often used to introduce a topic. This is consistent with the generally universal appeal of inquiry learning. As mentioned earlier in this report, the inquiry method has not been chosen for this textbook. Consequently, the laboratory investigations are placed after the concept with which they are concerned. They amplify and illustrate rather than introduce the topic. Teachers wishing to use the inquiry method can of course have the students do the investigation early in the development of the concept. The tasks required of the students in the investigations have been chosen to fulfill the needs of the community colleges, and the manual skills useful for an adult in our society. They involve meter reading, equipment assembling, measuring, and following instructions. Some probably warrant the title of activity rather than investigation: examples of these are the making of an extension cord and the wiring of a switch for a light. These examples also illustrate the practical nature of the investigations chosen for the textbook.

Finally, a word should be said regarding the use of mathematics in the text. The approach is not physics minus mathematics. It is true that there is much less emphasis on mathematics than would appear in an advanced level physics course. But arithmetic is still required. However, the mathematical sophistication of the advanced student is not needed. Formulae have been presented as given facts rather than derived from first principles or induced from experimental results. It is also assumed that students will have access to calculators. Reasonable (but not necessarily difficult) numbers are used in the problem examples. In a worked example on the application of the formula for resistors in parallel, there is no resort to common factors to simplify the summation of fractions. I feel that the student at this level should be shown how to work out each step on the calculator. (Not very often in real life would the resistances be such that simple common factors would appear.) The sample solution shows what the student would find at each step if this were done. As in the case of the investigations, the problems provide practice in those skills which an entrant to community college requires, and which would prove useful to any adult in our society.

Course objectives

If the course being proposed here is to be taught in Ontario or elsewhere in Canada, then the topics covered must be consistent with the curriculum guidelines of the Ontario Ministry of Education and the other departments of education across Canada. Contact was made with those in charge of curriculum in all the provinces and territories. From the information that they provided, especially Ontario <u>Curriculum RP 17</u> and <u>S.17 A Guidelines</u>, content was chosen for this course. However, I have chosen to eliminate some topics and add others to fulfill the goals I have set for the grade eleven general level physics course being proposed in this report.

Measurement

The student should be able to

1. Name the three fundamental measurements, namely length, mass, and time.
2. Use simple instruments to measure length, mass, and time
3. Name the fundamental units of the Systeme International D'Unites (SI Metric) and give their correct abbreviations.
4. Use the prefixes kilo, centi, and milli, and their abbreviations.
5. Calculate areas of circles and rectangles, and volumes of boxes, cylinders, and spheres using the correct SI units.
6. Estimate distances, masses, times, areas, and volumes in SI units.
7. Given a formula of the form $a = bc$, rewrite it in the forms $b = a/c$ and $c = a/b$. Note: It is hoped that the student will be able to transform simple formulae in this way with understanding of the mathematical principles involved. However, these objectives are presented as a set of tasks that the student should be able to do to demonstrate competence: hence the use of the word "rewrite" which in itself does not guarantee understanding.
8. Solve simple problems involving formulae of the form $a = bc$ and $d = e/f$.

Kinematics

The student should be able to

1. Define average velocity as the total distance travelled divided by the time taken; use the formula $v_{av} = \frac{d}{t}$ to solve simple problems.
2. Obtain distances and times in an experiment, using odometer and stop watch, ticker-tape timer, or other

suitable equipment.

3. From data, plot a distance-time graph of an object's motion, and identify from the shape of the graph periods of rest, constant speed, acceleration, and deceleration.
4. Define acceleration in words as change in speed (or velocity) divided by the time taken; and use the formula $a = (v_2 - v_1)/t$ to solve simple problems.
5. Express speeds in km/h and m/s, and convert between the two.
6. Express accelerations in km/h/s and m/s^2.
7. From a distance-time graph (by drawing the tangent to the curve) estimate the actual velocity of the object at any given time.

Dynamics

The student should be able to

1. Represent forces as arrows on a scale diagram, and sum them vectorially to find the net force.
2. State Newton's First Law of Motion, define inertia, and give simple examples of the law.
3. State Newton's Second Law of Motion in words, and as $F = ma$, and use the formula to solve simple problems.
4. Define the unit newton as $kg\text{-}m/s^2$.
5. Identify the force of friction as the force that prevents objects from maintaining constant velocity when all applied forces are removed.
6. Recognize that, in the absence of air resistance, all falling bodies, regardless of mass, (a) accelerate, (b) have the same constant acceleration, and (c) hit the ground at the same time when dropped from rest from equal heights. Note: there is redundancy in these three skills, but experience shows that students can quote that $a = 9.8\ m/s^2$ for all bodies yet not appre-

ciate that objects do not fall at uniform speed.

7. Distinguish between weight and mass.
8. Express his or her own mass in kilograms and weight in newtons.
9. Recognize that gravitational force is a property of all matter.
10. Describe the factors that affect the magnitude of the gravitational attraction between two objects.
11. Assemble pulleys and use levers to obtain a greater net force than applied force.
12. Describe pressure as force per unit area, and recognize that air pressure is the weight of all the air above a surface of area one square metre.
13. Describe the relationship of water pressure to depth.
14. State, and recognize examples of, Bernouli's Principle.
15. Calculate the density of an object given its linear dimensions, for those objects in Measurement Objective number five, or its volume, and its mass.
16. State Archimedes' Principle.
17. Define work or energy in words, and as $E = Fd$.
18. Describe different types of energy (kinetic energy, chemical energy, electrical energy, etc.) Note: at this level it is more valuable that the student recognize that energy can be transformed from one type to another, rather than classify all types of energy as either kinetic or potential, as is taught in the advanced level course.
19. Express energy in joules. Note: although the calorie is not an SI unit, it is useful to mention this unit here too.
20. Recognize that energy can be transformed from one type to another, and describe examples of the law of conservation of energy.

21. Recognize the loss of energy to friction, and so producing heat, as the reason coasting objects stop in the everyday world (see objective number five).
22. Define power in words, and as $P = E/t$, and use the formula to solve simple problems.
23. Define and use the units watt and kilowatt.

Waves

The student should be able to

1. Define the terms periodic motion, period, frequency, amplitude, wavelength, vibration, oscillation, medium.
2. Define the unit hertz, and express frequencies in hertz.
3. Relate the concepts period and frequency and from one calculate the other.
4. Describe with and without diagrams the features of transverse and longitudinal waves, using the terms crest, trough, compression (condensation), and rarefaction, and cite examples of each.
5. Describe what happens when waves travelling in opposite directions meet, recognizing that while one influences the other while they occupy the same space, that after the interaction each one resumes its original characteristics.
6. Define and cite examples of standing waves, and state the conditions necessary for their occurrence.
7. Distinguish between movement of the medium and the movement of the wave itself.

Sound

The student should be able to

1. Define the terms pitch, intensity, quality.
2. Describe sound waves in terms applicable to longitudinal vibrations, and describe the events that occur from the

beginning of the movement of an object to the time we hear the sound.

3. Describe what is meant by ultra and infra sonic, and state the approximate frequency range to which the human ear responds.
4. Identify on an oscilloscope the features corresponding to pitch, intensity, and quality, relating them to the terms frequency, amplitude, and overtone pattern.
5. Relate "dead spots" in an auditorium to the nodes produced in a standing wave. Note: a detailed discussion of interference is not required. The point is just that the student should recognize that sound is a wave phenomenon.
6. Explain the production of beats in terms of interference.
7. Cite examples of, and conditions for, resonance.
8. State the speed of sound in air and its dependence on air temperature.
9. Recognize examples of the Doppler effect. Note: complete understanding of the cause is not needed, but the student should be able to state what the Doppler effect is.

Light

The student should be able to

1. State the speed of light in air (vacuum).
2. Define and use the terms: luminous, incandescent, fluorescent, absorption, reflection, opaque, translucent, refraction, dispersion, transparent.
3. State the laws of reflection, using the terms incident ray, reflected ray, angles of incidence and reflection, and the normal (perpendicular) to the surface.
4. Determine by experiment and by geometry the location of the image of an object in a plane mirror, in a concave mirror, and in a convex lens.

5. Draw diagrams to show the paths of light rays passing from a less dense medium to a more dense medium, from a more dense to less dense medium at a small angle of incidence, and from more to less dense medium at a large angle of incidence (total internal reflection).
6. Compare the eye with the camera.
7. Draw diagrams and show the paths of light rays in refracting and reflecting telescopes.
8. Use the results of objective 4 to demonstrate in a diagram how a magnifying glass works.
9. Describe the phenomenon of dispersion, and describe what is meant by the terms colour, white, black, in terms of frequency and wavelength of light.
10. Define and locate on (to the outsides of) a spectrum the "colours" infrared and ultraviolet.
11. Recognize the terms X-rays, microwaves, cosmic rays, gamma rays, and radiowaves as describing light to which our eyes are not sensitive, and locate on the (electromagnetic) spectrum these forms of radiation with respect to visible light, labelling the ends as low or high frequency and wavelength.
12. Recognize the speed of light as the fastest speed in the universe for material and information transport, and that the time for light travel becomes significant in space travel to distant stars, communication over astronomical distances, and operation times of high-speed computers.

Electricity

The student should be able to

1. Name or identify the three main subatomic particles, namely proton, electron, and neutron, as to their masses, charges, and locations in the atom.

2. Define a positively charged object as having a deficit of electrons and a negatively charged object as having a surplus of electrons.
3. State the rules of electrostatic attraction and repulsion.
4. Distinguish between the terms conductor and insulator, and give examples of each.
5. Define the terms charge, current, and voltage, and state the units used to measure each, and their abbreviations.
6. Use the formulae $I = Qt$ and $V = E/Q$ to solve simple problems.
7. State Ohm's law, define the term resistance, and solve simple problems involving R, I, V, Q, and t.
8. State the factors affecting the resistance of a conductor.
9. Draw simple circuits showing batteries and resistors in series or parallel.
10. Locate voltmeters and ammeters correctly on a circuit diagram, and use them to measure voltages and currents in a given circuit.
11. Use the equations for resistances in series and parallel to calculate the total resistance of a circuit.
12. Describe a battery as an electron pump or as a source of voltage.
13. Recognize and apply Kirchhof's Laws to simple circuits.
14. Define the terms energy and power, the units joules and watts, and use the formulae $E = VIt$, $P = VI$, and $P = I^2R$ in simple practical problems.
15. Wire an extension cord, replace a receptacle, install a switch, and design and draw simple circuits (e.g. show two electrical receptacle outlets in parallel with each other and a lamp which is controlled by a switch.)

16. State the purpose of a fuse or circuit breaker, and calculate how many appliances of given power ratings can be plugged into a fused circuit.
17. Distinguish between the ground, neutral, and live wires, and explain the use of each.
18. Read a hydro meter, calculate the costs of running certain appliances, and identify the locations of maximum electrical energy usage and waste in the home.
19. Describe the basic differences between AC and DC (but not the principles of their production), and recognize wall receptacles as a source of AC and batteries as a source of DC.

Electromagnetism

The student should be able to

1. Describe the shapes of the magnetic fields about bar magnets, horse-shoe magnets, and the earth.
2. Demonstrate induced magnetism and define the concept of permeability.
3. Define the north pole of a magnet as the end that points approximately towards geographic north on earth, so that the north magnetic pole of the earth is a magnetic south pole.
4. State and use the rules for attraction and repulsion of the poles of a magnet.
5. Describe the magnetic field about conductors where electrons are moving (a) in a straight conductor, (b) in a single loop, and (c) in a helix or coil, including the use of the left hand rule.
6. Describe the factors that affect the strength of the magnetic field in a coil.

7. Describe the use of electromagnets for lifting, relays, bells and buzzers, and telegraph sounders.
8. State the motor principle.
9. Describe the effect of moving a magnet in an electric field (electromagnetic induction) and relate the magnitude of the induced potential to the strength of the magnet and the rapidity of the changing magnetic field.
10. Describe the structure and explain the operation of (a) the AC generator with slip rings, (b) the DC generator with a two-segment commutator, (c) the simple DC motor, and (d) transformers.
11. Distinguish between alternating current and direct current, and state the advantages of each.
12. Discuss the use of transformers in the distribution of electrical energy.

Modern Physics

The student should be able to

1. Describe electromagnetic radiation in terms of a succession of changing magnetic and electric fields.
2. Describe an experiment which demonstrates the existence of electromagnetic waves (Hertz' spark gap, for example).
3. Describe the equipment required to produce cathode rays, and discuss how it can be demonstrated that cathode rays are streams of negatively charged particles.
4. Discuss the use of cathode rays in fluorescent lights and television tubes.
5. Explain the production of X-rays in a cathode ray tube in terms of the nature of electromagnetic radiation.
6. Discuss the uses and dangers of X-rays.
7. List the four types of electronic emission.
8. Cite uses for the photoelectric effect (e.g. burglar alarms, door openers, solar electrical energy generators).

9. List and contrast the properties of the three types of radioactive emission.
10. Define and cite two examples of transmutation.
11. Describe some uses of radioactivity (e.g. biological tracers, radiocarbon dating), and the dangers of radioactivity.
12. Define what is meant by the half-life of a radioactive substance.
13. Define isotope, fission, and fusion.
14. Define chain-reaction and critical mass, and use the concepts to discuss the atomic bomb and atomic energy.
15. Describe the basic design of the CANDU nuclear reactor, and discuss the advantages and disadvantages of nuclear energy.

Space Science

The student should be able to

1. Distinguish among the terms planet, star, comet, meteor, meteorite, asteriod, and galaxy.
2. Recognize that our sun is a star.
3. Describe orbitting bodies as falling objects that just happen to have a suitable sideways velocity so that they do not get any closer to the central object as they fall.
4. Recognize that the force of gravity holds the universe together and keeps the moons in orbit about their planets, the planets about the sun, and the sun about the stars toward the centre of our galaxy.
5. Describe the conditions for weightlessness.
6. Explain how to place a satellite in earth orbit, how to bring it out of orbit, and why satellites sometimes fall out of orbit themselves.

7. Describe how rocket propulsion works, and how an astronaut might use it to move in space.
8. Discuss some future uses of space (exploration, asteriod mining, solar energy collection, etc.).
9. Describe the difficulties of long distance space travel and communication.
10. Discuss the chances that there is intelligent life elsewhere in the universe, and how we might discover and communicate with it.

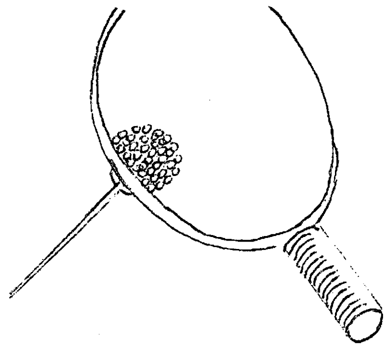
The textbook

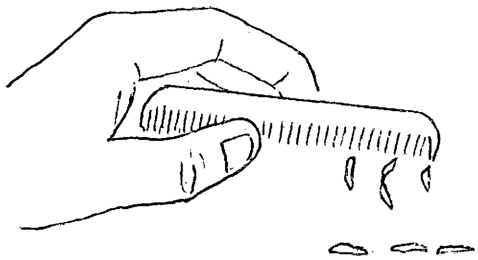
The remainder of this report is a sample chapter of a suitable textbook for the proposed grade eleven general level physics course. It will deal with the objectives on electricity, and has been presented in the format described earlier in this report: reference sections appear printed on white background; reading articles on pink; investigations on yellow; and problems on blue paper.

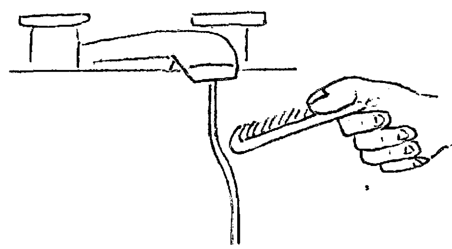
ELECTRICITY

A. Static Electricity

There is a theory in science which states that all matter (all substances: solids, liquids, gases) is made up of tiny particles called atoms. These atoms are so small that they cannot even be seen in a large microscope, much less in the magnifying glass shown just for fun at the right. They are so minute that a million million of them could sit on the head of a pin. The atom is not solid throughout, but has a heavy central core, the nucleus, surrounded by a number of much more tiny particles called electrons. The electrons have a property called electric charge, and are said to be negatively charged. When you run a comb through your hair on a cold dry day your comb picks up electrons from your hair. The charged comb will then attract small bits of paper or deflect a thin stream of running water.

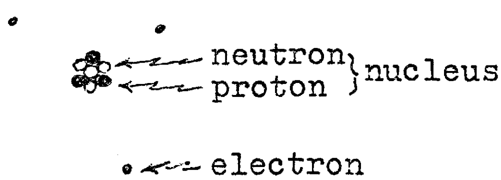






Any object with extra electrons is negatively charged and will attract uncharged, neutral objects.

There are other particles inside atoms besides the electrons. Two of the most important of these are the protons and the neutrons. Both of these particles are much heavier and larger than the electron, and are packed together in the nucleus. The neutron has no electric charge on it and so is neutral. The proton, however, has a charge equal in size to the electronic charge but of opposite sign: the proton is positively charged. An atom usually has equal numbers of negative electrons and positive protons, and

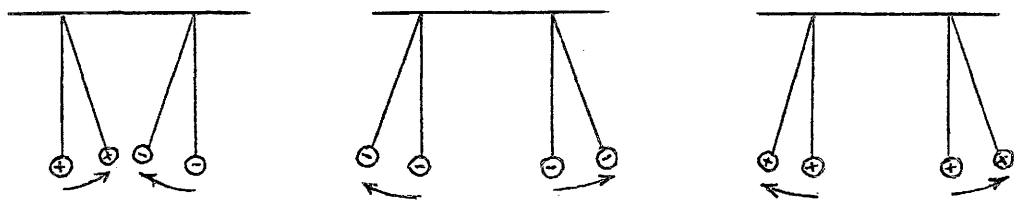


so is neutral. The number of neutrons can vary, but does not much affect the atom.

The atom does not have an outer wall, just a nucleus in the centre and electrons here and there around the nucleus. The diagram on the previous page shows an atom containing three protons, four neutrons, and three electrons.

When you combed your hair, some electrons were removed from the atoms of your hair and were left on the comb, making the comb negatively charged. The atoms that lost electrons used to be neutral but now are positively charged. This is because although electrons were taken from the atoms, the protons are still there, being locked in the nucleus. So since there are now more protons than electrons in these atoms of your hair, the hair got positively charged.

The example of the negative comb attracting a piece of uncharged paper shows that charged objects exert forces of attraction on uncharged objects. You can demonstrate forces beteen charged objects by hanging objects with a surplus of electrons (negative) or a deficit of electrons (positive) near each other on strings. The diagrams show what happens.



From these experiments we see that

1. like charges repel
2. unlike charges attract

and from before 3. charged objects attract uncharged objects

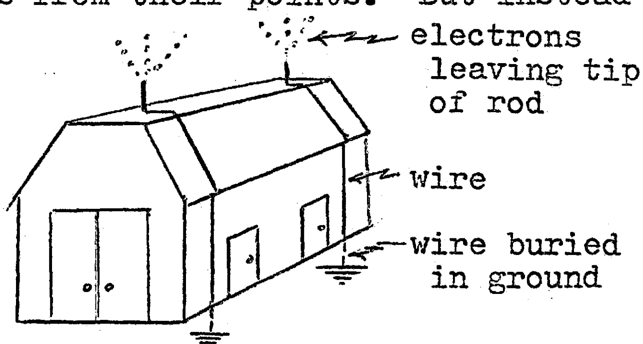
If there is a great surplus of electrons on an object, the negative charges will be repelling each other so much that if an uncharged object comes near, some electrons could jump to it from the negative object. You have probably noticed this as you reach to touch something after walking across a rug. The shock you got was the result of a spark, a leaping of electrons from you to the object. Your shoes picked up electrons from the rug as you walked across it, just as the comb takes electrons from your hair.

Lightning

During a thunderstorm, clouds can become charged. It is thought that in the violent updrafts that occur in the thunderclouds, raindrops might be separated into positive and negative particles, with the negative droplets rising up to the greatest heights. This leaves the lower clouds negatively charged. As the charge builds up, electrons from the ground are drawn to the tops of trees, buildings, and posts. If the charge becomes great enough a discharge may occur. The lightning bolt is a tremendous spark, forming a current of up to 200 000 A. (See the next topic in the text on currents to find out how much this is.) When electricity flows through the air, depending on the air's density, a glow occurs and you can see the lightning. As you should be able to figure out, since the spark is a flow of electrons, the lightning jumps upward from the ground to the cloud.

What makes the lightning bolts so dangerous? Damage is not caused when objects are first hit by electricity, but by the terrific electric current travelling through them. It makes no difference which way the electrons flow. Just as the filament in a light bulb heats up and glows when an electric current passes through it, so the huge current of electrons from lightning flowing upward through a tree trunk could produce such a severe heating that the tree cracks or catches fire.

You might think that to safeguard buildings we should try to shield them from "being hit" by lightning. Actually we do the opposite: we encourage electrons to leave the roof into the air. We provide lightning rods which continually discharge electrons from their points. But instead of flowing through the building, the electrons come up a wire stretched between the lightning rod and the ground. By providing a better pathway than the house for the electric current to flow from ground to cloud, the house is protected.



Some people have been hit by lightning. Probably, if you were about to be struck, you would notice your hair standing on end as the electrons collected on your head, ready to leap toward the clouds. Perhaps crouching down might help, but do not stand under the highest tree in the field! (Some people have survived a lightning attack. To find out what happened to one person, read the next article.)

The Globe and Mail, October 13, 1978.

'DEAD' LIGHTNING VICTIM SURVIVED

GREENSBORO,N.C.(AP)--The urgent scream--"Run!"--was the last sound to reach Maria Brown before the lightning bolt crackled through her body.

It flattened her on the beach, stopped her breathing and her heartbeat and plunged her into a coma.

Today, more than six weeks after that moment of terror at Atlantic Beach, the 25-year-old bookkeeper from Greensboro has recovered so rapidly--and inexplicably--that the doctors who treated her say she may be a marvel in the medical world.

"I think everybody is surprised that, with a direct strike, she could survive," said Dr. Richard Bloomfield, the physician who was called to the emergency room at Carteret General Hospital in Morehead City shortly after the accident.

Maria wears a ring of raw flesh around her neck where the lightning struck her necklace and fried her skin. It also scorched a spot on the right side of her skull and left long, jagged burns where the electricity travelled down her stomach and leg and out between the toes of her right foot.

Because her heart muscle was burned by the electricity, Dr. Gilmore, a heart specialist, ordered her to take it easy until the muscle mends itself, a process that could take another month or longer. Like the other physicians involved in the case he admits certain aspects bewilder him: "Why didn't it fry the brain? Or fry the heart? I just don't know."

For someone who was near death and now appears likely to become the stuff of medical history, Maria Brown is remarkably chipper--and down to earth--when talking about her ordeal.

"I felt like a train had run over me. But other than that, I didn't feel too bad," she said recently.

After the lightning struck, her heart stopped beating for about five minutes--roughly the maximum before the brain begins to suffer permanent damage--and she lay in a coma for 18 hours.

With the help of her 10-year-old sister Sally, who was with her at the time, Maria is able to reconstruct the events of Aug. 26. With a violent storm brewing, Maria and Sally and a male companion went onto the beach to retrieve a raft and a backpack. Suddenly the girls' companion screamed--"Run!" and the lightning struck. Though the bolt struck Maria, all three of them and another man standing nearby were knocked unconscious. Their companion regained consciousness first, though his legs were temporarily paralyzed. He shook Sally, and she recalled running--shakily--to a nearby structure where some men had taken refuge.

"I ran into the arcade and I said, 'I've been struck by lightning and my sister's dead. Will you help us?'"

The men dragged Maria, whose skin and hair had been darkened by the flash, off the beach and onto the boardwalk.

Sammy Piner, an off-duty Atlantic Beach policeman and member of the rescue squad, was three blocks away when the radio call came. When he arrived, he helped move Maria from the boardwalk under a nearby building that roosts on stilts, a saloon called the Jolly Knave.

"When we arrived," Mr Piner recalled, "she had the dark look and her necklace was burned. I'd never seen anyone struck by lightning before, and I had my doubts we could revive her."

Mr. Piner administered mouth-to-mouth resuscitation and another man helped in the effort to revive the young woman. By the time the ambulance arrived, Maria was breathing and her heart was beating.

Today Maria Brown hobbles slightly from the burn between her toes where the lightning bolt exited. With a jack knife she cuts pieces off an aloe plant and applies them to the charred flesh. She said the ring of scorched flesh around her neck and the jagged burn, where the electric charge travelled through her body have both healed markedly since she left the hospital on Sept. 3.

St. Elmo's Fire

Lightning, with the accompanying crashes of thunder, has traditionally been a fearful thing. But there is another electrical phenomenon that has been welcomed by those who have seen it often.

During unsettled weather, sailors on the high seas would sometimes notice a blue, green, or violet glow around the tops of the ship's masts, often accompanied by a crackling sound. As no harm ever came to the ship from this phenomenon, it came to be known as St. Elmo's fire, and was taken by the sailors to be a sign that their patron saint was protecting the ship.

St. Elmo's fire is a type of coronal discharge. It indicates the presence of a high-intensity electric field. If your school has a tesla coil, turn it on in the dark. (DO NOT TOUCH THE TIP...better still, let your teacher operate it!) You can see the bluish haze around the end, formed as electrons gather there. Hold it near some plumbing and the electrons leap to the pipes and travel down them into the ground. You can see the "lightning" and hear the "thunder".

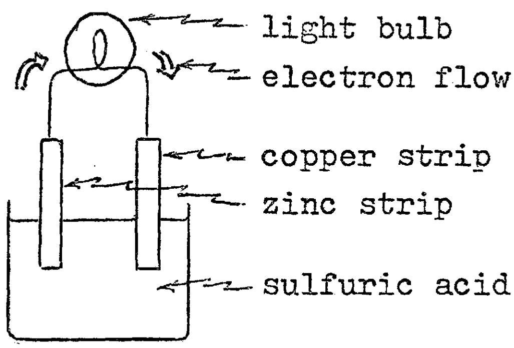
St. Elmo's fire has also been seen around the wing tips of airplanes and the metal ice-axes held by mountain climbers. A mountain guide can often put on an impressive display by pointing a finger toward the heavens. When the air is thoroughly charged, sparks will sizzle from the fingertip, making a noise like frying bacon.

B. Batteries

An electric current is a flow of electrons. To provide the pressure that keeps the electrons moving we use a battery.*

Think of a battery as an electron pump. Imagine pumping water from a lake up to a water tower. Suppose there were a tap on the bottom of the tower with a hose leading back to the lake. If you open the tap, the water will flow back through the hose to the lake. The same thing happens with batteries. Electrons are pumped from one side of the battery to the other. The negative side has a surplus of electrons that will return to the positive side when you provide a wire through which they can travel. As long as the battery can keep pumping electrons to the negative side, electrons will keep returning through your wire to the positive side.

There are various types of batteries. One is the voltaic cell. This consists of a container of dilute sulfuric acid with two different metal strips, such as zinc and copper, set into it. Effectively, electrons are carried from the copper side to the zinc side. Thus the zinc strip becomes negatively charged. If wires are attached between the zinc terminal or electrode and a lamp, then from the lamp to the copper electrode, as shown in the diagram, electrons will flow from the negative zinc plate through the light bulb to the positive copper side. The light bulb glows.



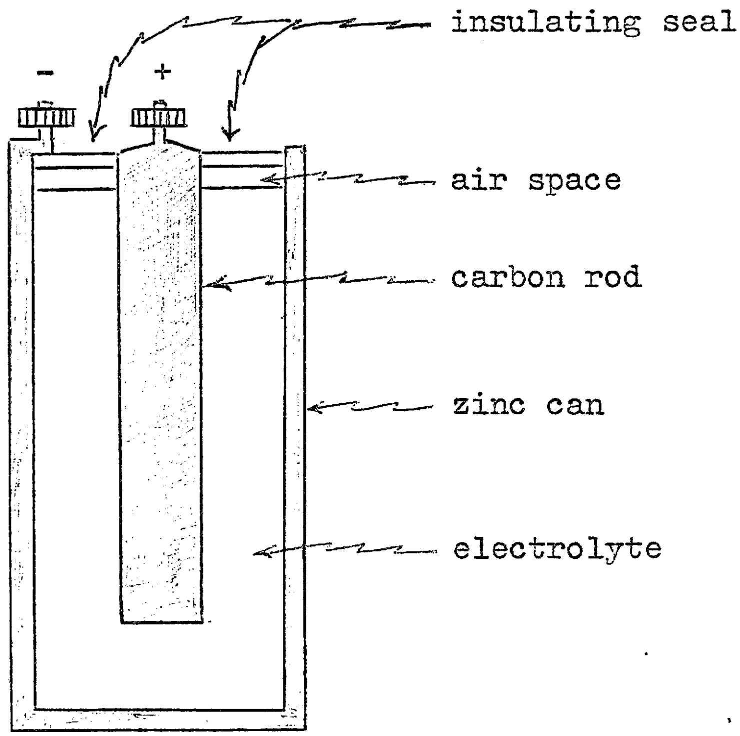
A VOLTAIC CELL

Another type of battery is the dry cell, shown on the diagram on the next page. Instead of two plates side by side as in the voltaic cell, there is a carbon rod in the centre, and the zinc metal container acts as the other plate. The carbon rod is positive and the outside negative. As the dry cell is used, the zinc gets "eaten away". After a while it gets very thin, develops holes, and leaks. The cell becomes dead and useless.

A third type of battery is the lead-storage battery, which is found in cars and trucks. If you wish to see how that works, you may study the next reading article.

*More precisely, the term battery refers to a set of cells hooked together. Here we use it to describe any supplier of voltage (electrons under pressure).

There is much research going on now to develop and perfect better batteries. Some new types can deliver a greater current, others last longer. But the basic principles behind these new types are the same as you have learned here.



A DRY CELL

(In flashlight batteries, the negative terminal is on the bottom.)

The lead-storage battery

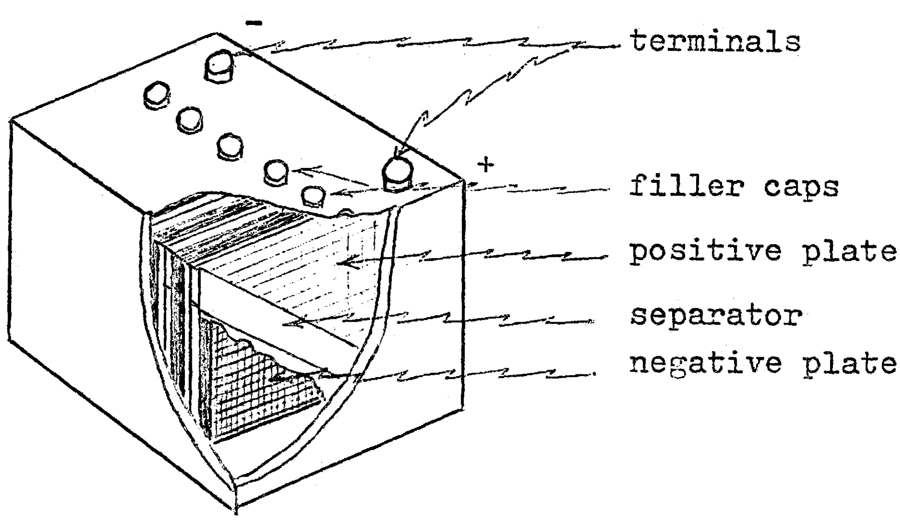
On the preceding pages you learned about batteries. You saw examples of two kinds: the voltaic cell and the dry cell. Both are electrochemical cells. Although people often look at a flashlight and say that there are two batteries inside, the term "battery" actually refers to a number of cells hooked together. What people should say is that the flashlight is powered by two cells in series (placed one after another).

A car, although it runs on gasoline, requires electricity to start it. One cell does not provide enough voltage to do the job. In the usual 12 V automotive battery there are six cells packed together in series.

Each cell is similar to the simple voltaic cell in that it is made up of two plates with a liquid, called the electrolyte, between them. The negative plate is lead or lead oxide and the positive plate is lead peroxide (lead dioxide). Sulfuric acid is the electrolyte. The plates are very large, and are separated from each other by some insulating material like wood. The cells are enclosed in a hard rubber case.

When the battery is providing electric current, the sulfuric acid combines with the material of each plate. The plates get coated by lead sulfate, and the electrolyte gets diluted (more water, less sulfuric acid in it).

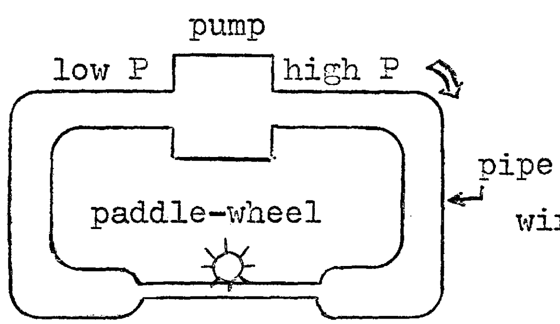
The important feature of the lead-storage battery, unlike the dry cell, is that it can be recharged. Electricity is forced through the battery in the opposite direction. This results in a cleaning of the plates, and a returning to the electrolyte of the sulfate which can combine with the water to provide the sulfuric acid, ready to produce electricity once again.



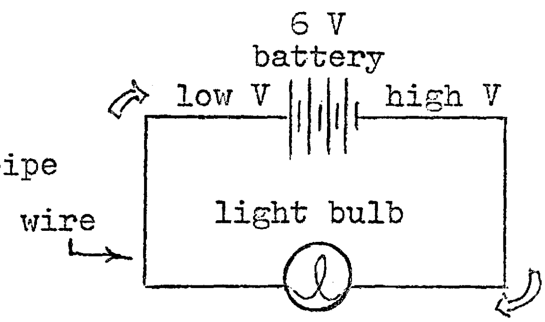
C. Circuits

Currents and voltages

We have seen that the battery is a kind of electron pump. If you had to move water around a circuit of pipes, your source of water pressure would be a water pump. When you buy a water pump, the information with it usually states how much water can be moved in a certain time, and at what pressure the pump operates. Similarly, when a battery is connected up to a lamp as shown in the diagram, we can speak of how many electrons flow per second, the current, and the pressure behind the electricity, the voltage, (or potential difference on each side of the battery).



A WATER CIRCUIT



AN ELECTRICAL CIRCUIT

We could measure the size of the electric current in electrons per second, but electrons are so small that instead we measure current in coulombs per second. A coulomb is a certain number of electrons, so coulombs is a measure of electric charge. (To find out how the charge on one single electron was discovered, you can read one of the articles following this section.) We do the same with water flowing through pipes: instead of measuring the current in water molecules per second, we measure it in litres per second. A litre is a more convenient unit than a water molecule, and even if we do not remember how many water molecules there are in a litre, we can still measure the current.

We say, then, that electric charge is measured in coulombs, and current is measured in coulombs per second. To save us saying "coulombs per second" we say "amperes". One ampere, the unit of electric current, is one coulomb per second.

Current can be expressed in a mathematical formula as

$I = \frac{Q}{t}$, where I equals current in amperes (A), Q is the charge in coulombs (C), and t is the time in seconds (s).

If a wire is provided through which electrons can flow from the negative side of a battery to the positive side, a current will be set up in the wire. This is just like the water supply to your house: the water represents the electricity, the pipes are the wires, and the flow of water molecules the current of electrons. Have you ever put your finger over the opening of the tap in your sink and tried to hold back the water? Even if the tap is turned on just a tiny amount, eventually you find that you cannot stop the water from squirting out. This is because the water pressure is strong. The pressure does not depend on how much water is flowing: it is a measure of the force behind the water (like the strength of the pump or the height of the water tower). There is a similar situation with electricity. The "pressure" behind the flow of electricity is called the <u>voltage</u>. Just as operating pressures are marked on water pumps, the voltages are marked on batteries.

The voltage does not tell you how much electricity there is in the battery. It tells you what pressure is available to force electrons to flow through a circuit of wires, lamps, and appliances. It also tells you what <u>energy</u> each electron carries: high voltage electricity means a great amount of energy per coulomb of charge. This gives us another useful electrical formula:

$V = \frac{E}{Q}$, where V is the voltage in volts (V), E is the energy in joules (J), and Q is the charge in coulombs (C).

Often this formula is memorized in the form $E = VQ$.

Potential Difference

You will see soon that it is often useful for us to study how the voltage (pressure) drops throughout an electrical circuit. Imagine that in your circuit of water pipes, high pressure water is coming out of the pump. As it flows through the pipes the pressure drops. Perhaps the water has to turn a paddle-wheel: it loses energy to the wheel, so each water molecule carries less energy than before. There is less pressure available for the water to do work farther down the line.

Similarly, when electricity comes out of a battery and flows through a circuit of wires, the voltage drops. If the electrons flow through a light bulb they lose energy (which is turned into light), and the voltage decreases. Sometimes we wish to measure precisely how much the voltage drops as the electricity flows through a lamp or other appliance. We just compare the voltage on each side of the lamp. The difference is "pressure" on each side is the voltage drop, or potential difference across the appliance.

You must memorize these two expressions, because voltage drop and potential difference are both used. Of course, since they mean the same thing, they both have the same symbol, V, and the formula at the bottom of the previous page holds for both. For example, if the potential difference across a light is 1 V, then each coulomb of charge will lose 1 J of energy while flowing through the light.

Resistance

If you are watering your garden with a hose, and you wish to cut down the flow of water, sometimes you bend the hose in the middle. The kink in the hose is a narrow place that offers resistance to the flow of water. The current drops. (To keep the current the same you would need higher water pressure.) The paddle-wheel mentioned earlier is another example of a resistor in a water circuit.

In an electric circuit, a very thin wire offers more resistance to the flow of electricity than does a thick wire. The thin filament in a light bulb offers such high resistance that the electrons have to expend a lot of energy getting by: the filament heats up and glows. Any appliance, or load, in a circuit is a source of resistance. Voltages drop across resistances, and increased resistance in a circuit usually means less current flows from the battery.

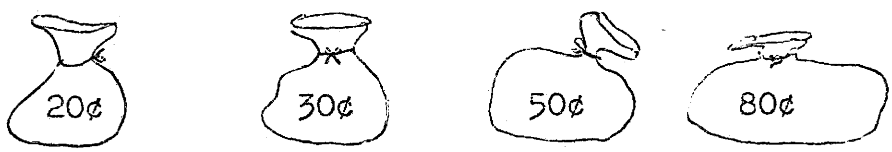
A Comparison of Water and Electric Circuits

Concept	Water	Electricity
What flows?	water molecules	electrons
Quantity	volume in litres	charge in coulombs
Circuit	water flows through pipes	electricity flows through wires
Pressure: source	pump or water tower	battery
units	pressure in pascals	voltage in volts
Current: units	litres per second	amperes (1 A = 1 C/s)
Resistance	friction in pipe or when water is put to work turning a wheel	friction in wire or when electricity is put to work providing energy (heat, light, movement)

How the Charge on the Electron was Discovered

We measure charge in coulombs. But the basic unit of charge is the charge on an electron.* When it was discovered that the tiny electrons carry the fundamental charge the big question was to find out how many coulombs of charge an electron possessed. R. A. Millikin in 1906 began a series of ingenius experiments which enabled him to find out the charge on an electron, even though the electron is so small that no one can see it. The method was very clever, but the reasoning was so simple that, if you were given his data, you could determine the charge on the electron yourself. Try the following puzzle: it is identical with Millikin's experiment in the logic he used to solve his problem.

Imagine that you are buying apples. The diagrams below show four bags of apples. You do not know how many apples are in each bag, but only the price of each bunch. Make a guess as to the price of a single apple, assuming that all apples have the same price.

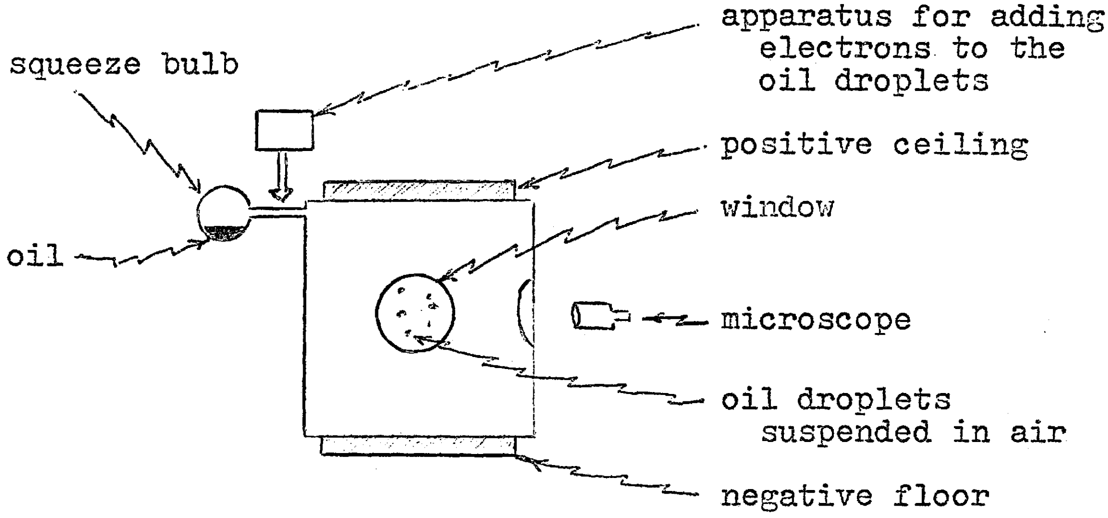


If you guessed that the price per apple was 10 ¢ then you have shown good thinking. If that were the case then the first bag would have contained two apples, the next one three, the third five, and the last one six apples. Of course each bag could have had twice as many apples. That would have made the price per apple 5 ¢. But then you would have expected to see a bag marked 25 ¢ or 65 ¢ or some other price ending in five. If you checked a thousand different bags of apples, and they all cost some multiple of 10 ¢, then you could be pretty sure that apples were a dime apiece.

If you can see this logic, then you can understand Millikin's experiment. He used an apparatus like the one drawn at the top of the next page. By squeezing a bulb full of oil, Millikin could spray into a chamber some oil droplets. These droplets picked up some electrons, but Millikin did not know how many electrons there were per droplet. But by putting a negative charge on the floor of the chamber,

*A more recent theory suggests that particles with one third the electron's charge exist.

which by repelling the negative droplets balanced gravity and caused them to float, he could calculate the total number of coulombs of charge on each droplet. Can you see how he could use this to guess the number of coulombs per electron?



MILLIKIN'S APPARATUS

It is just like the apples puzzle. The bag is the oil droplet. The unknown number of apples in the bag is the number of electrons on each droplet. The total cost of each bag is the total charge on each drop. By examining a large number of drops (bags), Millikin could make a reasonable guess as to the charge per electron (the price per apple).

Problems

1. Starting with $I = Q/t$, rewrite the formula to begin with
   a. $Q =$
   b. $t =$

2. a. If a charge of 10 C flows in a time of 2 s, the current will be...
   b. If the current is 50 A for a time of 10 s, the charge that flows will be...
   c. If a charge of 2 C flows in a current of 5 A, the time will be...

3. If 120 C of charge flow past a point in a wire in one minute, what will the current be? Watch your units.

4. A 2 A current flows for the very short time of 4 ms. How much charge moved?

5. How long would it take a battery to supply 500 C of charge at a rate of 2.5 A ?

6. Starting with $V = E/Q$, rewrite the formula to begin with
   a. $E =$
   b. $Q =$

7. a. If the energy is 20 J and a charge of 4 C flows, the voltage will be...
   b. If a charge of 5 C flowed when the voltage was 1.5 V the energy used was...
   c. If the energy used is 100 J when the voltage is 6 V, the charge that moves is...

8. How much voltage is a battery supplying if 20 C of charge flow through a wire carrying a total of 200 J of energy?

9. If 50 C moved under a voltage of 6 V, what would be the total energy delivered?

10. How much charge would flow from a 1.5 V cell through a heater that delivered a total of 300 J of heat energy during the period it was turned on? If the current to the heater was 2 A during that time, for how long was the heater working?

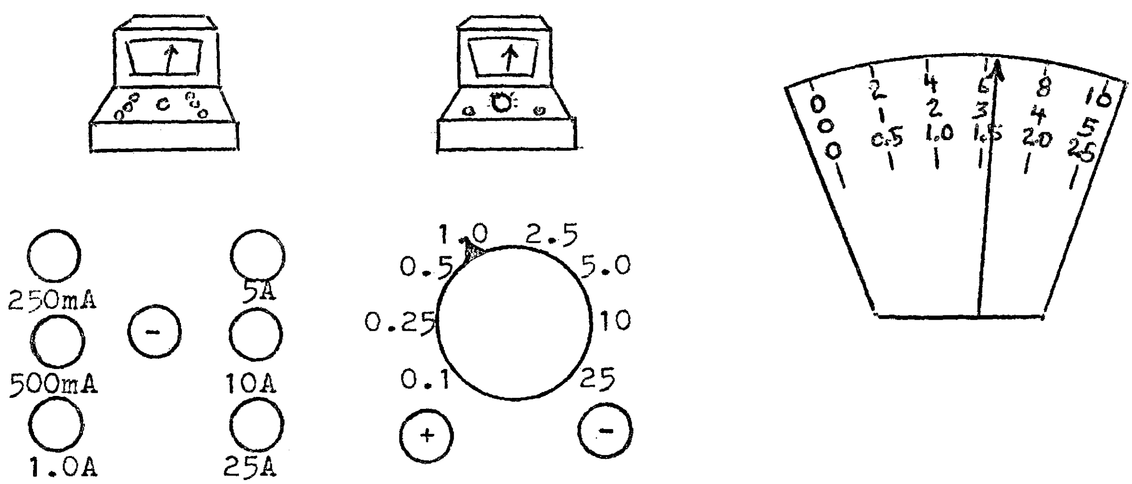
D. Circuit Instruments

Reading the scales

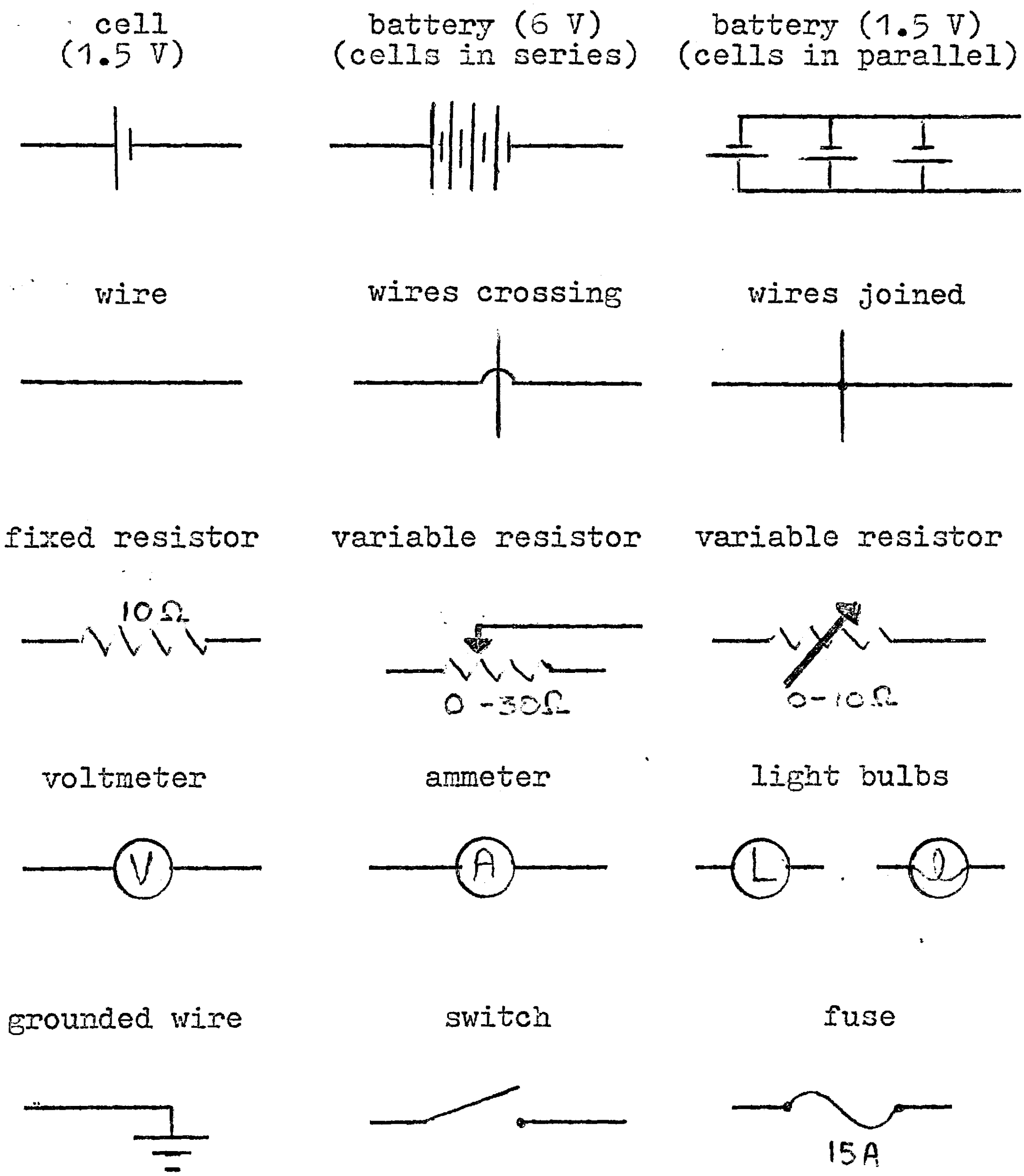
There are two simple instruments which you will have to use when you measure currents and voltages in circuits. Before we look at each one in detail, let us see how to read a meter. Most of the meters you will use have several scales, and several terminals onto which you can connect a wire. The terminals will be marked with a value. This tells you to take your reading off the scale that has this value as its maximum reading.

Study the meters shown in the diagram below. A close-up view of the face of the meter is on the right, and below each meter you can see what the terminals look like. Let's see how to use the meter on the left. Suppose you bring your wire into the terminal marked 10 A. Then you will take your reading from the scale with 10 as its maximum value. The reading is 6.2 A. If the wire is connected to the 5 A terminal, you read off the middle scale, the one with 5 at the top end. The reading is 3.1 A. If the wire is connected to the 250 mA terminal then use the lower scale. The 2.5 at the right end of the scale becomes 250 mA, and the reading would be 160 mA.

Some meters do not have alternate positive terminals. They will have a knob that you rotate until you get a convenient reading. The knob will then point to the value that, in the same way as with the first type of meter, tells you what scale to use and the maximum value that the scale can read. The second of the little meters in the diagram is of this kind. With the knob pointing to 1.0 A, what would be the reading?



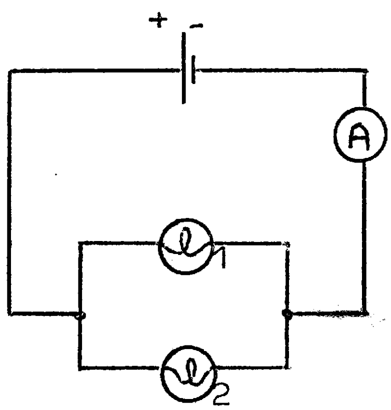
The reading would be 0.62 A .

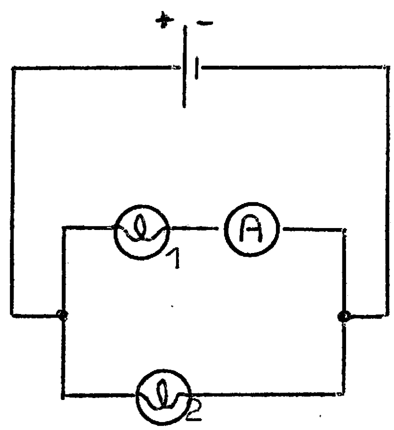


CIRCUIT SYMBOLS

The ammeter

This instrument measures the current in the circuit. You want to count every electron that flows through the circuit, or through the part of the circuit that you are studying, so you put the ammeter in series with the circuit. The diagram on the left shows the ammeter measuring the entire current in the circuit. The diagram on the right shows where to put the ammeter to determine the current flowing through lamp number one only.



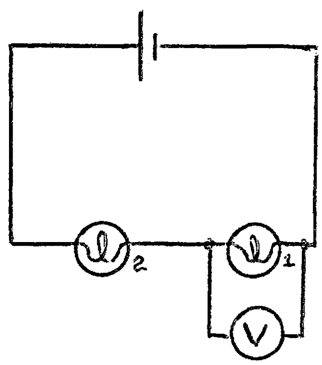


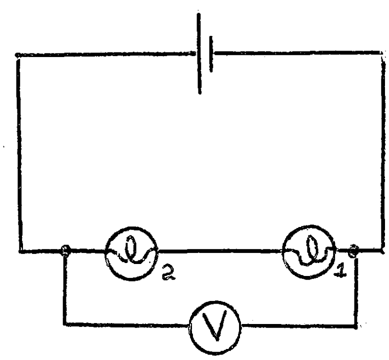
When you hook up the ammeter, always bring the wire coming from the negative side of the battery into the negative or black terminal of the meter. The wire coming out of the red terminal of the ammeter should eventually make it back to the positive side of the battery. Always watch the dial as you make the last connection. If you see the needle start to go backward disconnect immediately: you have got your positive and negative wires reversed.

It is good practice to bring the wire into the terminal that corresponds to the highest current reading, if you are using a meter that has alternate terminals. Or if your meter is the kind that has the knob to turn to make use of different scales, set it to the highest scale. If you do this then your meter expects a large current. If upon hooking it up you do not see much movement of the needle, then try the lower scales. This way the meter should never receive a current too large for it to handle, if you have set up the rest of the circuit correctly, and the needle will never jump off the scale.

The voltmeter

This instrument measures the voltage drop across a portion of the circuit, or the potential difference between any two points. It is never connected in series, but is placed in parallel with the light, appliance, or load, across which you are studying the voltage drop. If you remember that you are measuring a pressure difference between two points, then you will be reminded to connect the voltmeter up to two different places in the circuit, one wire on each side of the region you are studying. The diagram on the left shows the voltmeter placed to measure the potential difference across lamp number one, and in the second diagram the voltage drop across both of the lamps.



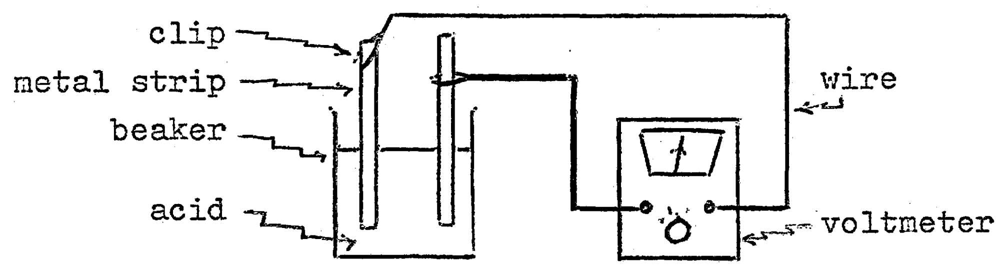


You may find it easier to set up the main circuit without the voltmeter first. The current should flow with the voltmeter absent. Then pick up the two leads from the meter and touch them on opposite sides of the resistor you are measuring.

As with the ammeter, keep the red side of the voltmeter pointing toward the positive side of the battery, and watch your needle carefully to see that it does not go backward or off the scale.

Investigation Electrochemical Cells

Obtain the following equipment:
- voltmeter
- two wires with alligator clips on one end
- strips of zinc, lead, copper, and iron
- beaker full of dilute sulphuric acid

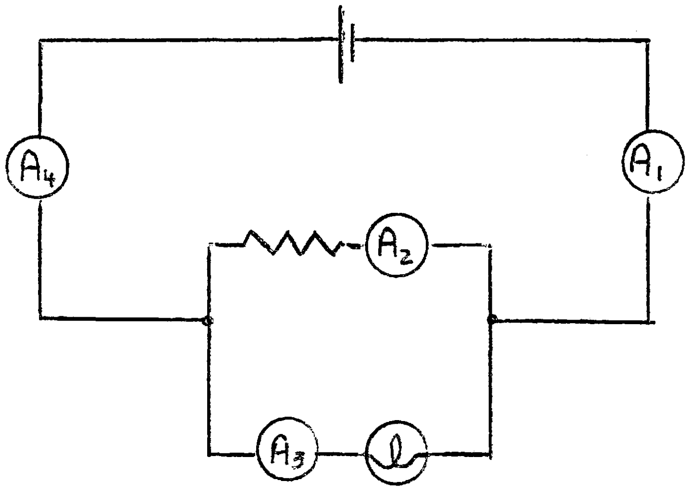


Set up the equipment as shown in the diagram. Connect one of the wires to the positive terminal of the voltmeter and the other lead to the negative terminal. You are to measure the voltage produced by the cell with each pair of different metal strips. There are six possible pairings of metals. As you make the last connection, watch the meter closely. If the needle starts to go backward disconnect immediately and reverse the leads (switch the clips from one metal to the other).
In the chart below, record the voltage in the circuit and which metal was connected to the positive terminal in each cell.

Setup	Electrodes	Positive electrode	Voltage (V)
1			
2			
3			
4			
5			
6			

E. Circuit properties

Here is a circuit with four ammeters in it.



The electrons come out of the negative side of the battery, flow through meter 1, and reach a fork in the road. Some take the high road through the resistor and meter 2, and the rest travel down through the light and meter 3. The two streams of electrons come together again, pass through meter 4 and make in back to the battery. How would the readings on the ammeters compare?

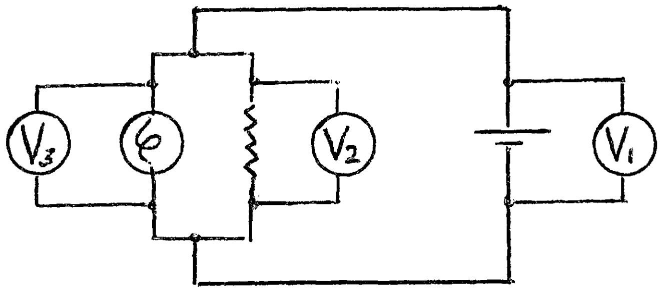
Sometimes people expect meter 4 to read lower than meter 1. But this is not the case. No electrons get lost in a circuit, they just lose energy. The current will be the same before and after the load. <u>Meter 1 reads the same as meter 4</u>.

What about meters 2 and 3? Each of these will read less than meter 1, but they will not necessarily show the same value. That depends on which path the electrons find harder to travel. But if you add the currents registered on ammeters 2 and 3 together, you will get the current through meter 1. <u>Reading on meter 2 plus reading on meter 3 equals the reading on meter 1</u>.

This gives us two properties of circuits:

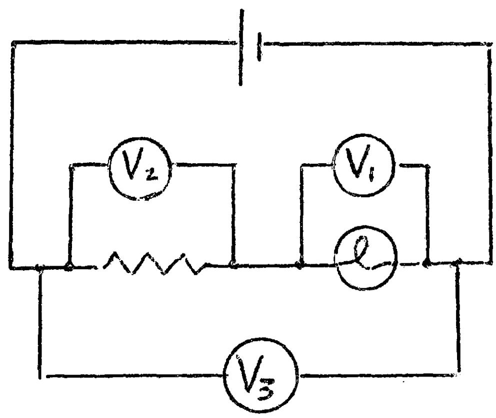
1. The current past any point in a <u>simple</u> circuit (no branches) is the same.
2. The currents in parallel pathways add up to the total current before the branching.

Here is another circuit. Now we have voltmeters checking the potential difference across the battery (meter 1) and each of the resistances (meters 2 and 3). How will the meter readings compare?



You may be surprised to find that all meters read the same, if we are using good large wires of low resistance. Think of pressure. High pressure electrons come out of the battery and are still at high pressure as they reach the fork, and still at the same high pressure as they are about to enter each appliance. They lose their pressure in the appliances, and are at low pressure all the way back to the battery. The battery then steps up the pressure again. All the voltmeters are comparing the difference in voltage between a place of high voltage and a place of low voltage. They all measure the same potential difference. The readings are identical.

If the appliances in the circuit are placed in series, and voltmeters measure the voltage drop across each one individually, the sum of the readings on the meters will equal the total voltage drop in the circuit, which will equal the voltage of the battery. In the diagram below, the readings on voltmeters 1 and 2 add up to the reading on voltmeter number three.



So we have three more properties of circuits dealing with voltage.

3. The voltage drop across the entire load equals the voltage of the battery.
4. The successive voltage drops across elements placed in series add up to the total voltage drop from the beginning to the end of the chain of elements.
5. The voltage drop across elements in parallel is the same, even if the resistances of the elements are different.

F. Resistance

Factors Affecting resistance, Ohm's Law

When a load (e.g. lamp, appliance, heater, motor) is placed in an electric circuit, it provides resistance to the flow of electricity. Less current can flow. So if we wish to restrict the current in our circuit, we can put in a resistor.

A wire itself resists the flow of electricity somewhat. The longer the wire is, the more resistance it has. In the usual circuits which we build, this resistance is not very great. But it becomes important in long distance transmission of electricity.

The thinner the wire is, the harder it is for electricity to travel through it. Resistance is governed by the cross-sectional area of the wire.

Temperature affects the resistance. In most metals, as temperature increases the resistance increases, but in other substances (e.g. glass, carbon) the reverse is true. At extremely cold temperatures (near absolute zero) some metals become superconducting: their resistance drops to zero.

Materials whose resistance to the flow of electricity is high are called <u>insulators</u>. Examples are wood, glass, rubber, and porcelain. Substances with low resistance such as metals are good <u>conductors</u>.

Thus we have four factors that affect the resistance of a wire: its length, its cross-section, the temperature, and the type of material of which it is made.

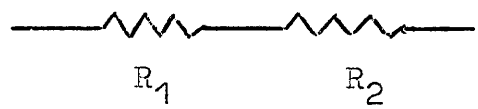
In many substances there is a relationship between the resistance of the substance, the voltage in the circuit, and the current that flows through the circuit. In 1826 the scientist Georg Simon Ohm announced that he had found a formula combining these three quantities, known now as Ohm's Law:

$R = \frac{V}{I}$, where R is the resistance in ohms, (Ω),
V is the voltage in volts, (V),
and I is the current in amperes, (A).

This relationship holds for certain substances as long as the temperature remains constant. It means that if the resistance of the circuit were 1 Ω, then a 1 V battery could supply 1 A of current, and a 2 V battery would deliver 2 A, and so on. Thus for a given battery, we can control the amount of current flowing by using a resistor of just the right value.

Resistances in series

If resistors are placed end to end, then the electricity will encounter resistance due to the first one, and then some more from the second one. The total resistance will be the sum of the two resistances.



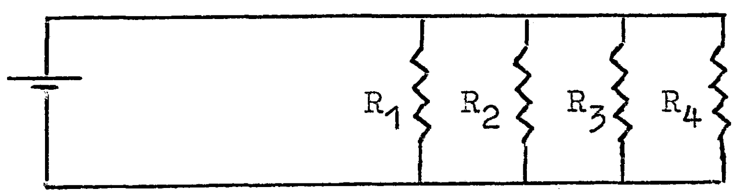
$$R_{total} = R_1 + R_2$$

For resistors R_1, R_2, R_3, and so on <u>in series</u>:

$$R_{total} = R_1 + R_2 + R_3 + \ldots$$

Resistances in parallel

If a circuit is designed so that resistors are placed <u>in parallel</u>, as shown in the diagram below, then the total resistance is <u>less</u> than the resistance the circuit would have if there were <u>just</u> one resistor there. This may seem strange until you realize that when you place resistors in parallel you are providing alternative pathways through which the electricity can flow. So more current can come out of the battery. The formula that works for resistors in parallel is more complicated than the formula for resistors in series.



For resistors R_1, R_2, R_3, and so on <u>in parallel</u>:

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

Examples of the use of the formulae:

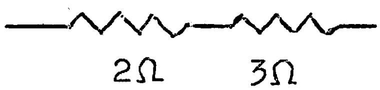
a. Ohm's Law: Calculate the resistance of a light bulb that carries a current of 2 A when it is plugged in to a 6 V supply.

$R = ?$
$V = 6\ V$
$I = 2\ A$

$$\begin{aligned} R &= \frac{V}{I} \\ &= \frac{6\ V}{2\ A} \\ &= 3 \end{aligned}$$

The resistance is 3Ω.

b. Series resistors: Calculate the total resistance when a 2Ω resistor is connected in series with a 3Ω resistor.

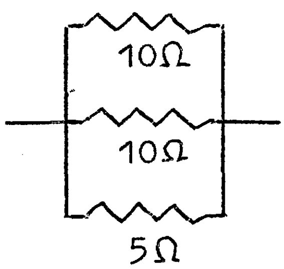


$R_1 = 2\ \Omega$
$R_2 = 3\ \Omega$
$R_{total} = ?$

$$\begin{aligned} R_{total} &= R_1 + R_2 \\ &= 2\Omega + 3\Omega \\ &= 5\Omega \end{aligned}$$

The total resistance is 5Ω.

c. Parallel resistors: Calculate the total resistance when two 10Ω resistors and one 5Ω resistor are connected in parallel.



$R_1 = 10\ \Omega$
$R_2 = 10\ \Omega$
$R_3 = 5\ \Omega$
$R_t = ?$

$$\begin{aligned} \frac{1}{R_t} &= \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \\ &= \frac{1}{10} + \frac{1}{10} + \frac{1}{5} \\ &= 0.1 + 0.1 + 0.2 \\ &= 0.4 \\ R_t &= \frac{1}{0.4} = 2.5\ \Omega \end{aligned}$$

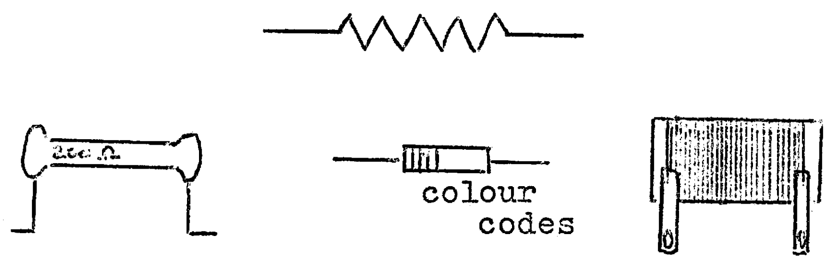
The total resistance is $2.5\ \Omega$

Types of Resistors

Resistors are used to control the amount of current in a circuit, and to cut down the voltage before the electricity passes through a circuit element requiring less voltage than the battery supplies.

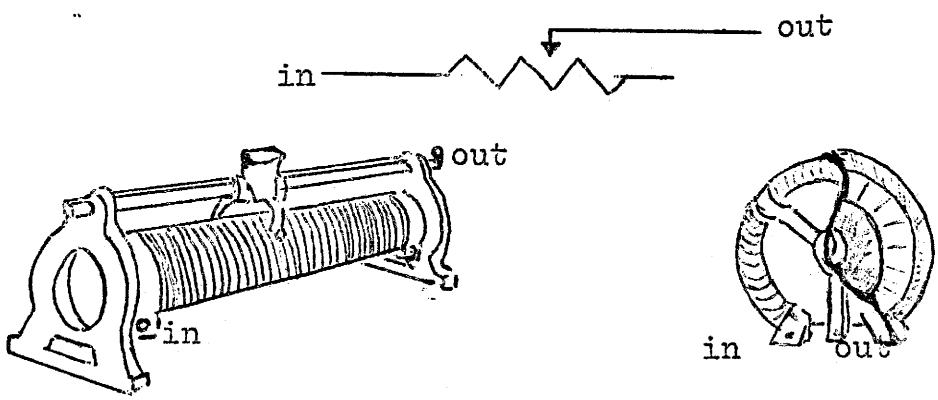
a. Fixed resistors

Fixed resistors may be made of wire, of molded carbon, or of ceramics. The most accurate is a thin wire. The length of the wire is carefully calculated to give the desired resistance. The easiest to make in industry is the tiny resistor you can see in the insides of transistor radios or pocket calculators. These are colour coded so one can read the value of the resistance in ohms.



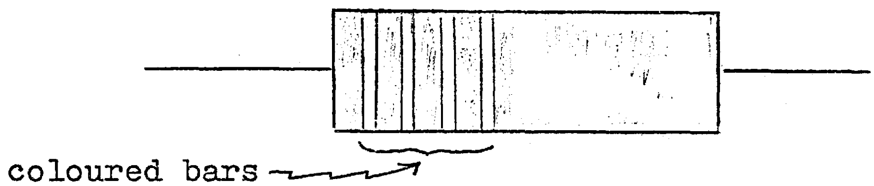
b. Variable resistors.

If you have a long wire for your resistor, and can vary the length of the wire, then you have a variable resistor--a resistor of varying value. A rheostat is one such device. A contact slides along the coil. Depending on where you place this contact, more or less of the coil is in the circuit. Variable resistors such as this come in many sizes and shaped and are used in radio volume controls and light dimmers.



Colour-Coding of Resistors

If you open the back of a pocket calculator or transistor radio, you will see many different kinds of components. The colour-coded resistors are easy to identify, and if you know the code you can figure out their resistance values.



The first three coloured bars on a resistor tell the value of the resistance according to the following formula. Each colour represents a number. The resistance is

$$\text{first number} \quad \text{second number} \quad \times \quad 10^{\text{third number}}$$

For example, if the numbers are 1, 2, and 3 then the resistance is

$$1\ 2 \quad \times 10^{3} \quad = \quad 12000$$

(You put the first two numbers together to get a two digit number, then use the third number to tell you how many zeros to put after it. Note that there is no decimal point between the first two digits.)

The colours and their corresponding numbers are:

Black	0	Green	5	Gold	5%
Brown	1	Blue	6	Silver	10%
Red	2	Violet	7		
Orange	3	Gray	8		
Yellow	4	White	9		

The fourth colour bar is gold or silver and tells you how accurate the value stated is. For example, gold means 5%: the value is accurate to plus or minus 5%--it can be 5% lower or 5% higher, for a total range of values of 10%.

Investigation: Circuits and Ohm's Law

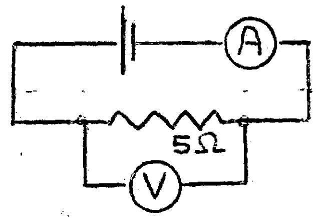
Obtain the following equipment: 5Ω resistor, 10Ω resistor, 1.5 V dry cell, ammeter, voltmeter, wires.

Study each of these circuits. Make any necessary calculations so that you can fill in the predicted resistances before you set up the equipment. Then connect the wires, take the readings, and determine the resistance in each circuit.

1. Predicted resistance ______

   I = ________ V = __________

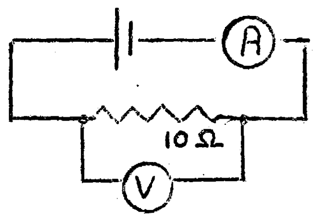
   $R = \frac{V}{I} =$ ____________



2. Predicted resistance ______

   I = ________ V = __________

   $R = \frac{V}{I} =$ ____________

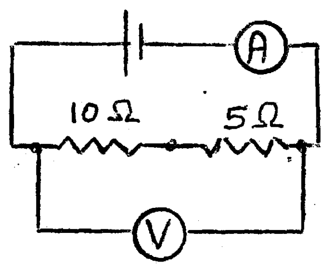


3. Resistance formula ________

   Predicted resistance ______

   I = ________ V = __________

   R =

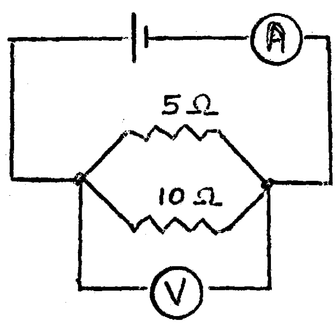


4. Resistance formula ________

   Predicted resistance ______

   I = ________ V = __________

   R =

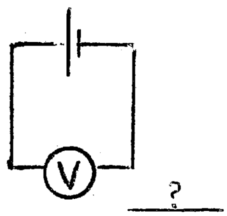


Investigation   Circuit Instruments

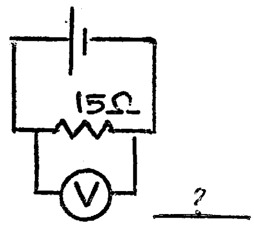
Obtain the following equipment: battery, wire,
four resistors: 10Ω, 20Ω, 15Ω, 15Ω;
ammeter, voltmeter.

Set up the following circuits and obtain the readings indicated by the question marks. Then answer the questions that follow the diagrams.

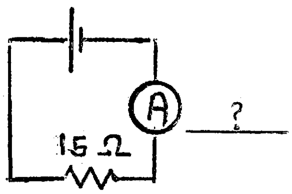
1.



2.



3.



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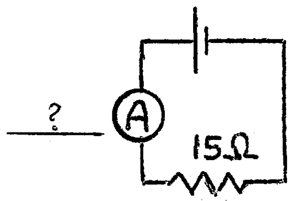

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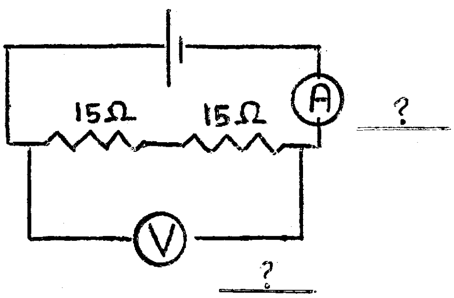
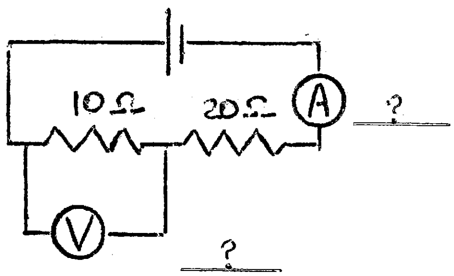
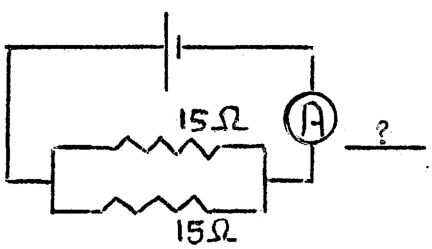


6.



7.



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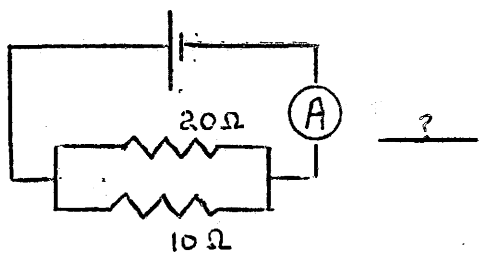


Answer the questions on the next page.

Questions

1. Compare the voltmeter readings in setups one and two. Look at the writing on the battery. How could you have predicted the readings?

2. Compare the ammeter readings in setups three and four. Does it matter where in a simple circuit, before or after the load, you put the ammeter?

3. In setups five and six, compare the readings on the voltmeter to the voltage of the battery. As long as the voltmeter measures the potential difference across the entire resistance in the circuit, how will the value compare to the voltage of the battery?

4. How do the ammeter readings in setups five and six compare? What do you know about the total resistance in each circuit?

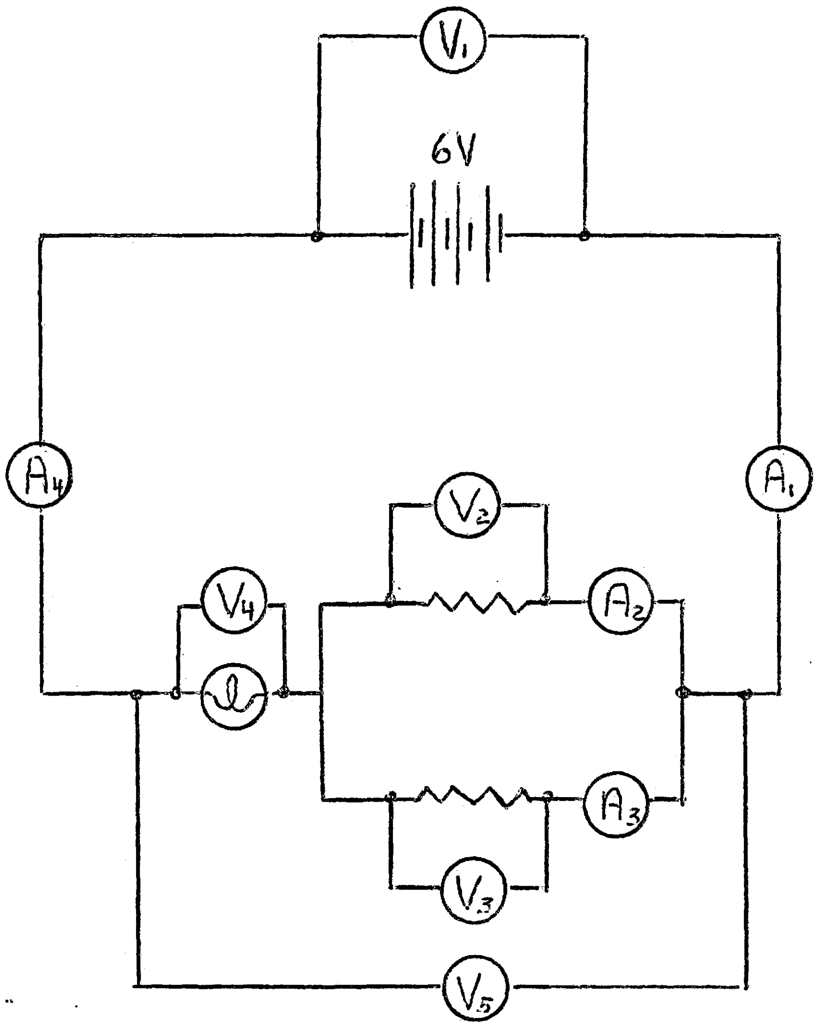
5. Compare the ammeter readings in setups seven and eight. Are the total resistances the same when resistors are connected in parallel?

6. Compare the currents in setups three and five. Can you see a relation between the amount of resistance and the current?

7. Compare the currents in setups five and seven, and also in setups six and eight. If resistors are connected in series, how will their resistance compare to that if they are connected in parallel?

Problem

Predict the readings on the meters in this circuit. Some readings have been provided for you to get you started.



A_1 reads	12 A	A_2 reads	2 A	A_3 reads	
A_4 reads		V_1 reads		V_2 reads	
V_3 reads	5 V	V_4 reads		V_5 reads	

G. Electrical Energy and Power

Have you ever heard people say that the cost of electric power is too high, or that you must pay for the power you use? When someone talks of "using power", the person is misusing the word "power". We use energy, not power. The electric companies supply us with electrical energy.

You already have a formula for energy. You learned that when one coulomb of charge carries an energy of one joule, the voltage is one volt. The formula is shown at the right. Rewriting the formula gives us an expression for energy. If we also juggle around the formula for current, we can substitute for the charge in our energy formula and get a new formula for electrical energy:

$$V = \frac{E}{Q} \qquad I = \frac{Q}{t}$$

$$\text{So} \quad E = VQ \quad \text{and} \quad Q = It$$

$$\text{Therefore} \quad E = VIt$$

$E = VIt$, where E is the energy in joules (J),
V is the voltage in volts (V),
I is the current in amperes (A),
and t is the time in seconds (s).

With this formula we can determine how much energy a certain electrical appliance uses if we leave it turned on for a period of time. For example, suppose a light bulb runs on a current of 2.0 A for 1.0 h, when connected to a 1.5 V dry cell. Finding the energy supplied by the battery is easy:

$I = 2.0$ A
$V = 1.5$ V
$t = 1.0$ h $= 3600$ s
$E = ?$

$$\begin{aligned} E &= VIt \\ &= (1.5\ \text{V})(2\ \text{A})(3600\ \text{s}) \\ &= 10\ 800\ \text{J} \\ &= 1.1 \times 10^4\ \text{J} \end{aligned}$$

You may not be able to use this method for calculating the energy used by light bulbs in your lamps at home because you may not know the current drawn by the bulbs. If you look at the markings on the top of a light bulb you will not see the number of amperes. Instead there is printed a number of watts. This is the power of the bulb. Power tells us how much energy the bulb uses per second. A powerful man is not just one who uses a lot of energy: he uses a lot of energy in a short period of time. Power is the rate of energy usage:

$$P = \frac{E}{t}, \quad \text{where } P \text{ is the power in watts (W),}$$
$$E \text{ is the energy in joules (J),}$$
$$\text{and } t \text{ is the time in seconds (s).}$$

One watt, the unit of power, is one joule per second.

Let us once again consider the light bulb in your lamp at home. Suppose it is a hundred watt bulb that you have left on for two hours. Instead of worrying about currents and voltages, we can find the energy the lamp uses with this power formula. First we rewrite the formula and then we substitute the data:

$P = 100\ \text{W}$
$t = 2.0\ \text{h} = 7200\ \text{s}$
$E = ?$

$$P = \frac{E}{t}$$
$$\text{So } E = Pt$$
$$= (100\ \text{W})(7200\ \text{s})$$
$$= 720\ 000\ \text{J}$$
$$= 7.2 \times 10^5\ \text{J}$$

You can see that leaving a light on for a short time uses a large number of joules. When we are dealing with the great amounts of energy used in the home we usually use a more convenient unit of energy, the <u>kilowatt-hour</u>. If you look at the above example, you will see that the units of energy worked out to watt-seconds, which we wrote as joules. If the power had been given in kilowatts instead of watts, and the time had been left in hours, then the units of the answer would have been kilowatt-hours. Let's do the problem again in these units:

$P = 100\ \text{W} = 0.100\ \text{kW}$
$t = 2.0\ \text{h}$
$E = ?$

$$P = \frac{E}{t}$$
$$\text{So } E = Pt$$
$$= (0.100\ \text{kW})(2.0\ \text{h})$$
$$= 0.20\ \text{kW}\cdot\text{h}$$

The answer is two tenths of a kilowatt-hour, a more convenient unit than joule because with periods longer than a few hours, you get up into the millions of joules. For that reason, the electrical companies usually print their bills in kilowatt-hours, and work out the cost of electricity in ¢/kW•h rather than ¢/J. At 5¢ for each kilowatt-hour of electrical energy, running that 100 W bulb for two hours would have cost 1¢ :

$$\text{Cost} = 5\ \frac{¢}{\text{kW}\cdot\text{h}} \times 0.20\ \text{kW}\cdot\text{h}$$

$$= 1.0\ ¢$$

Of course, if you are required to work out electrical costs, and the price of energy is given in cents per kilowatt-hour, then you must use kilowatts and hours instead of joules and seconds.

There is one more formula worth knowing. If we start with $E = VIt$ and use the power formula $P = E/t$, we can combine them to obtain:

$P = VI$, where P is the power in watts (W),
V is the voltage in volts (V),
and I is the current in amperes (A).

Problems: Electrical Energy and Power

1. Starting with $E = VIt$, rewrite the formula to begin with

   a. $V =$
   b. $I =$
   c. $t =$

2. a. If the voltage is 12 V, and a current of 2 A flows for 5 s, the energy used will be ...
   b. If a current of 10 A flows for 30 s, bringing an energy of 200 J, the voltage would be ...
   c. To provide an energy of 20 J for a time of 10 s under a voltage of 1.5 V, the current must be ...
   d. If a battery with voltage of 6 V supplies a current of 10 A, 200 J of energy would be delivered in a time of ...

3. How much energy is provided by a 120 V power source delivering a current of 15 A for 10 minutes? Watch your units.

4. This question uses two formulae. First use Ohm's law to find the current. How much energy is used by a 10 motor connected to a 6 V battery for 30 s ?

5. A 10 V power source supplies 20 A . For how long must it be turned on if it must provide 500 J of energy?

6. Starting with $P = E/t$, rewrite the formula to begin with

   a. $E =$
   b. $t =$

7. a. If 100 J of energy is used in a time of 20 s, the power is ...
   b. If an appliance with power rating of 10 W is run for 30 s, the amount of energy used is ...
   c. If a heater with power rating of 50 W is to provide 2000 J of heat energy, it must be turned on for a time of ...

8. Suppose an appliance uses 4000 J of energy in 10 minutes. What would be the power of the appliance?

9. An appliance uses energy at a rate of 4000 W. It is run for 20 min. Calculate the energy used in

   a. joules
   b. kilowatt-hours

MORE PROBLEMS ARE ON THE NEXT PAGE!

10. A 1 kW appliance is used for 2 d (days). If electricity costs 5 ¢/kW•h, find the cost of operating this appliance.

11. Starting with P = VI , rewrite the formula to begin with a. V =

    b. I =

12. What is the power of an appliance that draws 12 A when plugged into a 120 V circuit?

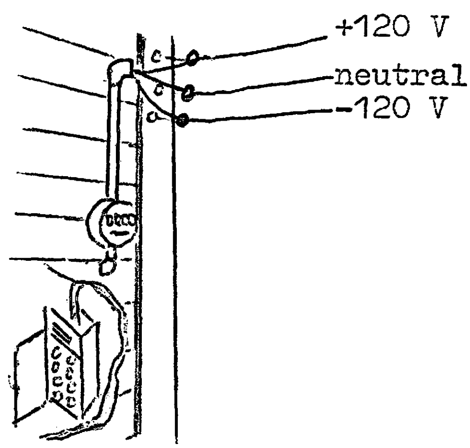
13. What current will a 1 kW appliance draw when plugged into a 120 V circuit.

14. Find the cost of operating an electric toaster for 3 hours if it draws 5 A on a 120 V circuit. The energy cost is 5 ¢/kW•h .

15. With the same energy cost as in question fourteen, find the cost of running a 1500 W electric heater for two days. The heater is connected to a 120 V line.

H. House wiring

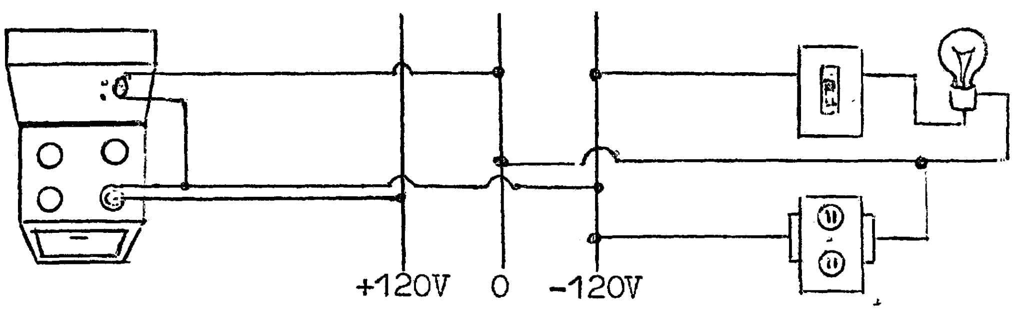
Most of the appliances in the place you live are designed to run on 120 V electricity. However, the stove, electric water heater, and many permanent electric baseboard heaters use 240 V. To meet these electrical requirements, three wires from the electric company enter your home. One wire is negative compared to the ground, at a potential difference of 120 V. Another wire is at positive 120 V with respect to the ground. The potential difference between these two wires, the red and the black wires, is 240 V. The neutral wire, at ground potential, is white.



If you wish to supply a receptacle with 120 V electricity, you can connect it to the black and white wires or to the red and white wires. If you need 240 V electricity, however, you hook up to the red and black wires.

The diagram above shows the three wires from the electric company coming to your electrical service entrance. From there they pass through the meter which measures the amount of energy you use. Then the wires enter the electrcal panel, where the electricity is distributed to individual circuits. In most homes this panel is a fuse box. The fuses are little sensors that will "blow" if more current comes down the wires than is safe. Other homes have breakers instead of fuses. These are switches that automatically turn off the electricity when the circuit is overloaded. Instead of replacing a breaker, as one does with a fuse, one just resets the switch.

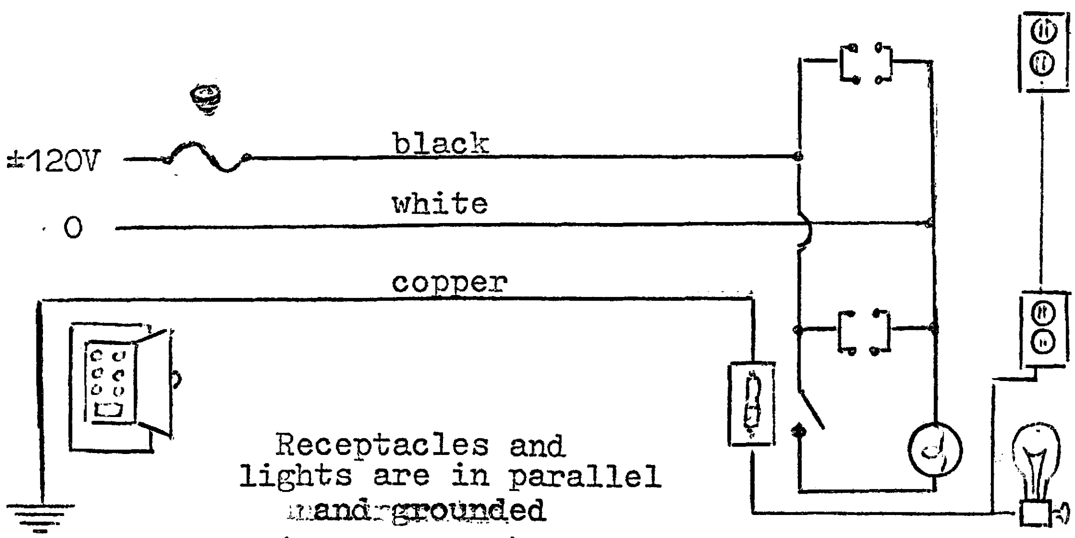
The diagram below shows how the wires then can be used to supply a receptacle, a light, and a timer with 120 V, and the cooking element of a stove with 240 V.



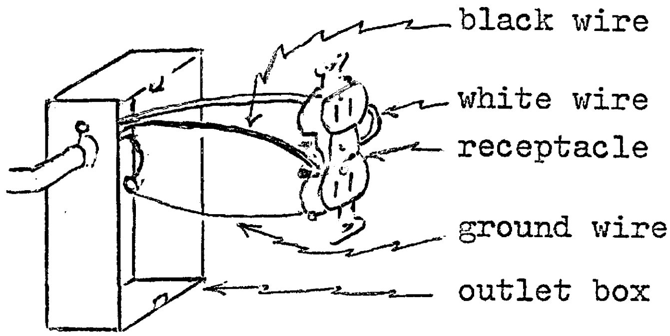
You must never replace a fuse with a larger one. If a 15 A fuse blows, that means that more than 15 A of current is trying to flow through that circuit. Most house wiring (not lamp cord, but the wire in your walls) is rated for 15 A but if you put in a larger fuse, say a 20 A fuse, then instead of the fuse blowing, the wiring may overheat. If it melts, you have a house fire. When fuses continue to blow on a certain circuit, check first the number of appliances on that circuit, and then the wiring.

You can calculate quite easily the number of appliances that can be plugged into the same circuit. All receptacles and lights controlled by a single fuse are in parallel. (You know this, because you know that unplugging one lamp does not cause all the other lights and appliances to turn off. This would happen if they were connected in series.) Every time you turn on another appliance you provide another pathway for current to flow in the circuit. If you know that power ratings of all the appliances you can check to see if, when all are switched on, they will draw over 15 A. Since P = VI, and V is 120 V for regular household wiring in most places, then the total wattage cannot exceed 1800 W. If a fuse blows in that case, you had better examine the wiring to look for short circuits (Hot wire able to touch ground or neutral wire without passing through the appliance).

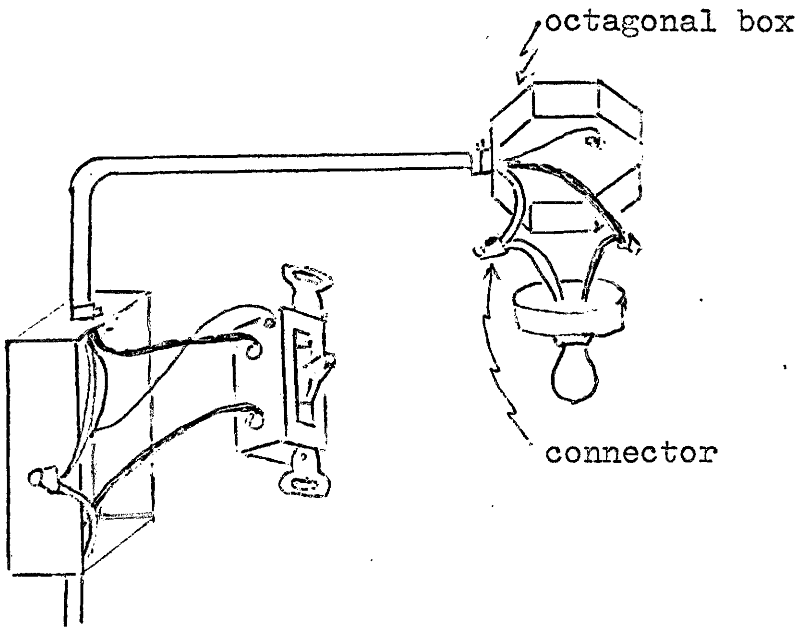
$$P = VI = (120\ \text{V})(15\ \text{A}) = 1800\ \text{W}$$



Receptacles and lights are in parallel and grounded (see page 72)



A DOUBLE ELECTRICAL RECEPTACLE
(at the end of a line)



A SWITCHED LIGHT
(at the end of a line)

The diagram on the bottom of page 69 showed only two wires entering a light or receptacle, yet if you study the diagrams on the previous page closely, you will see that the large cable feeding the lights and receptacles contains three wires: a black, a white, and an uninsulated copper wire (or aluminum in some homes). The black is the hot wire, carrying electricity at a potential difference of 120 V with respect to the ground (either +120V or −120V: the black wire originates at the panel connected to either the black or red service wires). If you were to touch this black wire and the ground (a tap, the metal outlet box), then a dangerous current could flow through you. This could be fatal. The white wire is neutral. The electricity flows through it back to the fuse box or breaker panel. The bare wire is the ground wire. All the metal surfaces of the light switches, receptacles, outlet boxes, and appliances that possess the three-pronged plugs are connected by this wire to the ground. If a receptacle box were not grounded in this way and the black wire happened to come loose and contact it, then the entire box would be "hot" or "live", posing a danger to anyone who might touch it. When the box is grounded, the current flows out of the black wire directly back to the ground via the bare wire, probably blowing the fuse to the circuit. A properly connected ground wire is like your life preserver in a boat or seat belt in a car: if something goes wrong with the electrical appliance, it can save your life. If ever you feel a tingle when you pick up an electric tool or turn on a lamp, check the ground connection, after first turning off the entire circuit by taking out the fuse.

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