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Signature Gerald E Evans

Date August 3, 1982

ANALOGIES AS AIDS TO LEARNING

by

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ABSTRACT

Two analogies of electricity were compared with a control condition to determine whether the use of an analogy affected performance on a quiz. The control condition, the analogy of water flowing in pipes, and the analogy of people moving in corridors were presented to an introductory psychology class in written texts about 1,100 words long. The 16-question, multiple-choice quiz had eight items which required only recall of read material and eight items which required subjects to make inferences to solve electrical circuits for volts and amperes. The results indicated that the subjects who were in the analogy groups did no better on the quiz than the control group subjects. No differences between the two analogies were reported either. Various reasons for the lack of differences were discussed.

INTRODUCTION

One of the first uses of analogies in psychology was by scientists interested in measuring individual differences, especially differences in intelligence. Both visual and verbal analogies which took the form A:B::C:D were used by such individuals as Spearman (1927), Thurstone (1938), Guilford (1967), and Cattell (1971). Use of analogies as a tool to measure individual differences raised the issue of how individuals solved these word or picture problems. This was an attempt to learn about the higher mental processes involved in problem solving (Spearman, 1923; Johnson, 1962; Shalom and Schlesinger, 1972; and Rumelhart and Abrehamson, 1973).

More recently, interest has grown in the study of analogies as a type of metaphor. Instead of the terms of an analogy being single words or pictures, longer statements of the analogical terms were used until they ceased being succinct analogies and began resembling extended metaphors. One of the chief concerns with these metaphorical analogies was their usefulness as aids to solve complex problems. For example, Schustack and Anderson (1979) provided subjects with biographies of fictional characters which were analogous to those of real, historic characters. The question was whether subjects would use the relationship with the real characters as an aid in remembering the facts about the fictional biographies. Their findings indicated that while the analogies were helpful in remembering the facts of the fictional biographies, subjects used the analogous relationship only when the idea to do so was suggested by the experimenter. Another conclusion drawn was that analogies are useful in retaining new knowledge because of the more elaborate encoding that takes place when new knowledge is related to prior knowledge by the analogy.

Gick and Holyoak (1980) made a similar use of analogies to solve problems. In their work, the "Radiation Problem" (Duncker, 1945) provided a task to be solved with the aid of another analogous story. Results indicated that although the analogy was helpful in the solution of the Radiation Problem, there was a significant decline in the use of the analogy by subjects who were not given the hint to use the analogous story as part of the solution. Their conclusion was similar to Schustack and Anderson's: analogies may be useful in problem-solving but few subjects use the analogies unless such a strategy is suggested to them.

Such studies suggest the following about analogies used in the acquisition of new knowledge: (a) drawing a relationship to prior knowledge through an analogy is helpful in acquiring or retaining information about the new topic; and (b) the strategy of using the analogous relationship as an aid in solving a problem must be suggested. Spontaneous use of analogies is employed by few subjects.

Tourangeau and Sternberg (1981) investigated the types of relationships within a metaphor that best facilitates understanding.

Their results indicate that two kinds of relationships within a metaphor are important to the metaphor being easily understood. The first is what they call _within-domains similarity_, which is the relative position within a domain that an object or concept occupies. Within-domains similarity is high when two objects or concepts being compared by a metaphor enjoy a high level of similarity in their relationship with other objects and concepts within their respective domains. If within-domains similarity is high, the metaphor proves to be more easily understood than if the within-domains similarity is low.

The second relationship that is important to understanding is what Tourangeau and Sternberg call _between-domains similarity_. This type of relationship is concerned with how closely the two domains are related that contain the objects or concepts being compared by the metaphor. The greater the similarity between the domains, the less of a metaphor the comparison becomes. This means that the best understood metaphors are ones that have high within-domains similarity and low between-domains similarity.

These findings have been expanded into a model of metaphorical reasoning by Tourangeau and Sternberg (1982) which they call _domains-interaction_. In the process of developing their model, they demonstrated that effective metaphors involved more than mere comparisons or anomalies between objects and concepts. The domains-interaction model of metaphor was essentially an elaboration and further experimental demonstration of the study in which they concluded that good metaphors have high within-domains similarity and low between-domains similarity (Tourangeau and Sternberg, 1981).

Additionally, Tourangeau and Sternberg suggested that a close similarity in cognitive processing exists between metaphors and analogies. Although the analogies they discussed were the A:B::C:D type, they concluded that analogies and metaphors are processed in a similar manner, except that domains interaction is less critical in the processing of simple analogies. However, as the terms of simple analogies become more elaborate and begin to resemble metaphors, the domain interaction becomes more critical.

Gentner (1982) proposed a model of scientific analogies which she calls structure-mapping that is closely related to Tourangeau and Sternberg's (1982) domains-interaction. Structure-mapping suggests that analogies have identical operations and relationships that are held among non-identical objects. This seems to be another way of saying that good metaphors have high within-domains similarity and low between-domains similarity. Further, Gentner's (1982) suggestion that scientific analogies were comparisons between systems and not mere comparisons between objects places scientific analogies and metaphors in the same experimental category.

Although there has been some agreement in what makes a good metaphor or scientific analogy, the question of whether these analogies are useful in learning and using new information is largely unanswered. Gentner (1981) investigated the use of analogies to convey knowledge of electrical circuits to students. She used the analogy of water flowing through pipes and people moving through corridors to explain batteries and resistors in electric circuits. Not only did this study solve the problem noted by Schustack and Anderson (1979) and Gick and Holyoak (1980) by introducing students to the strategy of using analogies to solve problems, it also introduced two new elements in analogical problem-solving.

First, the domain used represents a more complex academic discipline than the mere word or picture analogies used in previous studies. Second, the measure of success went beyond recognition or recall of previously studied information and included application of studied concepts in solving problems not previously encountered. Success on such a task would indicate that scientific analogies are useful in the acquisition of new knowledge and the application of newly-acquired information in solving novel problems.

The results of Gentner's (1981) study indicated that scientific analogies were indeed useful in producing deep, indirect inferences beyond mere surface associations. This was seen primarily in the differences in inferences made by subjects who were given the two different analogies. For example, it was predicted that the analogy of water flowing in pipes would be better in explaining the function of batteries and that the analogy of people moving in corridors would be better at explaining resistors. This prediction was supported by the results of the experiment.

The purpose of the present study was to further test Gentner's (1982) model of structure-mapping by testing the flowing-water and moving-people analogies of electricity against a control condition that explained the same electrical concepts without the aid of an analogy. Differences between the two analogies were also investigated to determine whether the results of Gentner's (1981) study could be replicated. Furthermore, both recall of studied information and solution of novel problems were assessed.

The primary concerns of this study were whether analogies are useful in solving the novel problems and whether the use of an analogy facilitated or interfered with the comprehension and recall of studied information. It was hypothesized that the analogies would produce superior results in the solving of novel problems without interfering with the comprehension or recall of studied material. It was also expected that some differences between the two analogies would be evident similar to the findings of Gentner (1981).

METHODS

Subjects

Subjects were 226 college students from an introductory psychology class at Montana State University. They were randomly assigned to one of three conditions: control, water analogy, and people analogy. Two subjects were dropped at random from each of the two experimental conditions so that there would be an equal number of subjects (74) in each of the three conditions. Students who participated in the experiment were given class credit for their participation.

Materials

A reading text of about 1,100 words was prepared. It explained some of the basic concepts of electricity, batteries, resistors, and electrical circuits. The material was taken for the most part from introductory electronics textbooks. The text for the control condition presented the electrical concepts without the use of analogies. The texts for the two experimental conditions presented identical concepts but used analogies. The text for the first experimental condition used the analogy of water flowing in pipes and the text for the second experimental condition used the analogy of people moving in corridors. The text for each of the experimental conditions were only about 100 words longer than the control condition text.

In addition to the reading text, there was a 16-question, multiple-choice quiz. The first eight questions on the quiz--the recall items--required subjects to recall information that was directly presented in the reading text. The last eight questions--the inference items--required subjects to solve a set of eight electrical circuits which had not been presented in the reading text. These eight circuits consisted of various combinations of batteries and resistors in parallel and series. The first four inference items consisted of circuits that had only batteries in series or in parallel, or resistors in series or in parallel, but not both. The last four inference items consisted of circuits that had both batteries and resistors in series or in parallel. The quiz was identical for all three conditions. It carefully avoided language from either of the analogies.

The reading text and the quiz were assembled together in a booklet which also included a consent form, an information form, and general instructions. A computerized answer form on which the subjects recorded their answers to the quiz questions was placed into each booklet.

Procedure

The experiment was conducted on a regular class day, in the normal room, during the regular class period. The class was notified of the experiment and its general nature several days in advance. After all of the subjects had gathered in the classroom, general instructions were given concerning the consent form and the information form. The booklets were then randomly distributed to the entire class. The reading period began after everyone had read and signed the consent form, filled out the information form, and read the general instructions.

Subjects were given 20 min. to read the text. A start command was given along with time reminders every 5 min. At the end of the reading period, a stop command was given. After the reading period, subjects were given 15 min. to complete the quiz. Time reminders were given every 5 min. One minute before the end of the time allowed for the quiz, everyone had finished writing.

As the booklets were being collected, subjects were told the full nature of the experiment and the various hypotheses and expectations were explained. At a later class period, the results of the experiment were presented to the class as part of a lecture.

RESULTS

Table 1 presents the means and standard deviations for the recall and inference questions for each of the three groups. The means represent the total number right out of eight for both question types.

Table 1

Group Means for Recall and Inference Questions

Question Type	Control Group	Water Analogy	People Analogy
Recall Questions	6.12 SD = 1.461	6.14 SD = 1.443	6.19 SD = 1.527
Inference Questions	2.76 SD = 1.985	2.66 SD = 1.973	2.77 SD = 1.999

Note. N = 222.

In order to determine whether the analogies affected performance on the quiz, a split-plot or nested analysis of variance design is used (McNemar, 1969). This analysis of variance consists of one between-subjects variable (control group vs. water analogy vs. people analogy) and one within-subjects variable (recall-type questions vs. inference-type questions). There is no significant differences between the treatment groups: F (2, 219) = .062, $p < .94$. The interaction between the treatment group and the question type is also not significant: F (2, 219) = .048, $p < .95$. Significant differences do not result when the level of background in electronics is included as a covariate in the analysis of variance model: recall questions, F (2, 219) = .077, $p < .93$; inference questions, F (2, 219) = .11, $p < .90$.

This experience covariate is a discrete variable from 0 to 5. A further test for differences between treatment groups is made using a multivariate analysis of variance. This analysis treats the two question types as a single vector. There are no significant differences between the treatment groups when compared with the two question types. Both Fs are less than one.

A split-plot or nested analysis of variance design (McNemar, 1969) with one between-subjects variable (control group vs. water analogy vs. people analogy) and one within-subjects variable (questions concerning batteries vs. questions concerning resistors) is used. This analysis is an attempt to replicate the interaction Gentner (1981) reported between analogy type and questions dealing with only batteries and resistors. No significant differences emerge from this analysis: treatment groups, F (2, 219) = .221, $p < .80$; interaction between treatment groups and question type, F (2, 219) = .433, $p < .65$.

Correlation coefficients between the scores on recall questions and the scores on inference questions are computed for each of the three groups. Each of the correlation coefficients is significant as seen in Table 2. Furthermore, there is no difference between the size of the correlation coefficients for the three groups as determined by Fisher's Z Transformation and a t-test.

Table 2

Correlations between Recall and Inference Questions

Experiment Group	Correlation Coefficient	*t* Value
Control Group	.3031	2.709**
Water Analogy	.2840	2.548**
People Analogy	.2406	2.132*

*p < .05
**p < .01

To determine whether there is any relationship between the three treatment groups and the answer selected on each quiz item, a χ^2 test of independence is used on each of the 16 quiz items. For each quiz item, a 4 x 3 contingency table is constructed using the four possible answer choices as one variable and the three treatment groups as the other variable. With one exception, there is no relationship between the treatment groups and the selected answer. The single exception (question 2) produces a significant relationship between treatment group and answer choice: χ^2 (6) = 14.69, $p < .05$. This result may be due to the fact that over 90% of the subjects in each of the treatment groups answered the item correctly. Consequently, several cells within the contingency table contained zero values. The one significant result out of 16 separate analyses could also be due to mere chance.

DISCUSSION

The results of this research show that the subjects in the two experimental conditions did not use the analogies in a way that produced significant improvement compared to the control group. Although many suggestions were given throughout the texts to use the analogies to solve circuits for volts and amperes, no differences emerged on the quiz.

This lack of difference is demonstrated first by the fact that the group means for both types of questions were virtually identical. If the analogies were used effectively, some differences should have been evident. Secondly, the χ^2 analysis supports this description. If the analogies were used, there should have been some relationship between the treatment groups and the answer chosen by subjects. However, with the exception of question 2, there was no significant relationship between the treatment groups and the answer selected. The relationship noted in question 2 could be due to the high percentage of subjects who answered the item correctly or to mere chance. Thus, it can be concluded that there is no difference between the treatment groups when either the number of correct choices or incorrect choices are used for comparison. These two facts seem to support the conclusions that the subjects did not use the analogies in any effective way to answer the questions on the quiz.

The correlation coefficients provide some additional support for this conclusion. Since all of the correlations between recall and inference questions were significant, it could be concluded that performance on the inference questions was closely related to performance on the recall questions. If the analogies were affecting subjects' performance on the inference items only, there would be less of a relationship between recall and inference items scores creating smaller correlation coefficients. However, if the analogies were being used effectively, they may have an equal effect on both recall and inference item scores. This would produce little change in the correlation coefficients. Given both of these possibilities, the similarity of the correlation coefficients merely emphasizes the lack of differences between the three groups. Little can be determined from these data about the problem solving strategies employed by the subjects.

Given this lack of differences between the treatment groups, it might be concluded that subjects did not use the analogies at all. Although this conclusion may have some merit, it is beyond the scope of this experiment to make such a determination. This study was concerned with how analogies presented in a written text affected performance on a quiz. Determination of the precise cognitive processes employed by subjects would require a much more elaborate methodology such as collection of protocols and interviews of subjects following the quiz. From the present study, it can only be concluded that analogies in written texts did not influence the results on a particular quiz.

Questions may arise as to the validity of the two models of electricity presented in the written texts. Although the results of this experiment may indicate some weaknesses in the analogies of flowing-water and moving-people, they seem to meet the criteria for analogies presented by Tourangeau and Sternberg (1982) and Gentner (1982). Furthermore, both analogies are used in electronics textbooks indicating that professionals in that field see some value in these analogies. However, the present study may indicate that the introduction of these analogies into written texts will have little impact on students' recall and problem solving ability as measured by the type of written test used here.

There are several possible reasons why there were no differences between the treatment groups. It is entirely possible that the subjects did not use the analogies effectively simply because a single, isolated presentation did not cause the subjects to adopt an unfamiliar analogical model of electricity. This explanation is supported experimentally by the work of Gick and Holyoak (1980) and Schustack and Anderson (1979) who found that presentation of the analogy without the experimentor's suggestion to use it did not lead to adoption of the analogical model. It seems possible that although when analogies are used in problem solving they are helpful, adopting an analogical model requires more than a brief presentation in written form. It was hoped in designing this experiment that presenting the two analogies in a text with numerous statements as to the application of the analogies to solving electrical circuits would have been sufficient to allow the subjects to adopt the analogies. The research presented here suggests that this may not have been the case.

Another possible explanation of why subjects did not use the analogies to any advantage is that subjects already were using some analogical model of electricity. These native analogies may have been similar to the flowing-water and moving-people models presented in the experimental condition texts or they may have been entirely different models. Gentner (1981) demonstrated that most people use some sort of analogical model when thinking about electricity. Although the protocols she collected indicate that most people use a flowing-water or crowding-objects model of electricity, others were also used natively by subjects.

If the subjects in this experiment were using native analogies, it could possibly mean that the control group subjects were using analogical models. Since the chances are slight that subjects in a particular analogy group were using a native analogy that corresponded to the analogy in the text, some confusion may have been introduced into the two analogy groups. For example, if a subject were using a water analogy natively and was assigned to the moving-people condition, he/she may have easily been confused. If this confusion due to the use of native analogies was taking place in the experimental groups, the control condition (which had no analogies presented in the text) may have had an advantage when taking the quiz. This may have statistically cancelled the effects of the analogies in the written texts presented to the two analogy groups which would explain the lack of difference noted between the control group and the analogy groups.

A third possible explanation of why subjects did not use the analogies effectively is that the subjects did not understand the base domain. Gentner (1981) found that subjects who did not understand the base domain in the analogy were unable to use the analogy effectively in subsequent problem-solving tasks. If understanding the characteristics of flowing water and moving people is critical to using the analogy effectively, failure in this understanding of the base domain could limit the successful use of the analogical model. Thus, an analogy is good or bad for a particular individual depending on their understanding of the base domain.

In addition to the failure of this experiment to yield significant differences between the control group and the analogy groups, there was also a failure to replicate Gentner's (1981) findings in regards to the differences between the two analogies. Her research demonstrated a significant interaction between the analogy type and circuits dealing with batteries and resistors. She found that the water analogy was superior in explaining batteries in series or in parallel. The present results reveal an absence of a significant interaction similar to Gentner's.

There are several differences between Gentner's study and the present study that provide tentative explanations for the failure of the present experiment to replicate her findings. First of all, she assigned subjects to the analogy condition according to the analogy of electricity they were using natively. This would prevent any of the cross-analogy confusion discussed earlier from cancelling out the effects of the analogies. In addition, Gentner also screened subjects for their understanding of the base domain insuring that they were reasonably adept in their use of the analogy. She also selected her subjects after they demonstrated some basic ability in solving simple circuits for volts and amperes. Since none of these conditions were matched in the present study, Gentner's findings are in no way questioned. Only a study that matched Gentner's procedures more closely could determine whether her findings could be reproduced.

These procedures were not used in the present study because Gentner's primary concern was with the differences in processing evident in subjects who used the two different analogies. The concern in the present study was with the possible advantage an analogy provides in solving novel problems. Her study revealed that subjects who use different analogies make different inferences when solving problems. One possible conclusion from this study is that subjects do not readily adopt an analogical model.

There are at least two general implications to be drawn from the present study. First, the lack of significant differences between groups does not invalidate the two models of analogical reasoning discussed in the introduction. Both domains-interaction and structure mapping concern themselves with the nature of analogical thinking, not with the conditions under which analogies will be used. The present study seems to indicate that inducing subjects to adopt an analogy requires more than a brief introduction to the analogy in a written text.

This failure of subjects to adopt an analogy after reading a text that introduced an analogical model points out that analogies cannot be used as short-cuts in the learning process. Merely giving students an analogy to aid in learning a complex topic will not insure that they will perform better on a subsequent test. However, it will take further research to determine whether repeated presentations of an analogical model will help students in gaining a grasp of a complex discipline.

The next logical experiment to follow the present study would be to provide subjects with longer or more in-depth or repeated presentations of the analogical models. This procedure would provide the subjects with a longer exposure to the model and insure that they understood the base domain. For now, however, it is clear that the addition of an analogy to a brief presentation of information does not significantly affect performance on either recall of studied material or solution of novel problems. Further research must be conducted to determine whether analogies presented under different conditions affect such performance.

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APPENDIX

STATEMENT OF CONFIDENTIALITY

Any information you write in this booklet will be kept completely confidential. Your name or ID number will not be matched up with your experiment book or with your answer sheet. We ask for your name only to insure that you understand the confidential nature of your participation and to insure that you receive extra credit points for your part in this research. The information requested on the next page is necessary for the scientific control of the data collected today.

My signature below, in return for the opportunity of participating as a subject in a scientific research investigation, hereby authorizes my cooperation in the procedure described above. This consent I give voluntarily and after the nature of the experimental procedure, any known dangers and the possible risks and complications have been fully explained to me. I knowingly assume the risks, if any, involved and I am aware that I may withdraw my consent and discontinue participation at any time without penalty or prejudice against myself.

____

Your signature

INFORMATION SHEET

Year in school_________________ Age__________ Sex____________

Major__________________________ Minor______________________

Please place an "X" beside each of the courses below you have taken or are taking presently.

____Introductory Physics

____Introductory Electronics/Electricity

____Introductory Electronic Circuits

____Other courses which include topics in electricity or electronics.

GENERAL INSTRUCTIONS

1. Following this page is a short passage which introduces electricity and simple electric circuits. When the signal is given, you will have the next 20 minutes to read and study the passage. At the end of the 20 minutes, you will be told to stop reading. Please do not refer to the passage after the stop command has been given.

2. After you have read the passage, a 16-question, multiple-choice quiz will be given on what you have read. Please mark your answers on the answer sheet provided. Do not begin the quiz until the command to do so is given. Do not refer to the text passage once you have begun the quiz. Please do as best as you can on the quiz and make every attempt to complete all the questions. You will be given 20 minutes to complete the quiz.

3. When the time is up for writing the quiz, please place your answer sheet back into the experiment booklet and pass the entire booklet to the nearest aisle.

4. After the test booklets have been collected, the full nature of the experiment will be explained. The results of the experiment will be given at a later time after the data collected today has been analyzed.

STOP! Do not turn the page until the start command has been given!

Control Condition Text

BASIC ELECTRICAL CIRCUITS

Electricity is the exchange of electrons through a conductor such as a copper wire. This exchange of electrons is from an area of negative charge to an area of positive charge since a negative charge is produced by an excess of negatively charged electrons and a positive charge is produced by a deficiency of electrons. The force which causes this electron exchange is called electromotive force (emf). The electromotive force is also known as voltage. Voltage then is the electrical force which produces an electron exchange that creates electricity. It is measured in VOLTS. The greater the force causing an exchange of electrons, the greater will be the voltage measured on the conductor. The volt was named after Alesandro Volta, an Italian scientist who discovered how to make batteries.

In addition to volts, there are several other measures of electricity. The simplest electrical unit is the COULOMB. One coulomb is 6,240,000,000,000,000,000 electrons. If that number of surplus electrons accumulated on a metal ball, we would say that the ball has a negative charge of one coulomb. If there are twice as many electrons, the charge is two coulombs. If 6,240,000,000,000,000,000 electrons are missing from an object, the object has a positive charge of one coulomb. The coulomb was named after a French scientist, Charles A. Coulomb, who experimented with electrical charges and discovered many of the principles and laws related to them.

Electron exchange rates are expressed as a quantity of electrons exchanged in a particular period of time. A quantity of electrons measured in coulombs measures the rate of electron exchange in coulombs per second. If 600 coulombs pass through an electric heater in 60 seconds, the rate of exchange is 10 coulombs per second. If 50 coulombs pass through a lamp in 100 seconds, the rate is 0.5 coul./sec. Read the slanting line / as "per," 0.5 coul./sec. is said as "0.5 coulomb per second." Measurement of exchange rate is one of the most often used electrical measurements. Measurement of exchange rate is so important that one word is now used to replace the longer term "coulombs per second." The word used is AMPERE (amp). For example, instead of saying 5 coulombs per second, the term 5 amperes, which means the same thing, is used. The ampere is named for Andre Ampere, a French mathematician and scientist who investigated magnetic forces due to electricity and set up the mathematical theory of electromagnetism.

The rate of exchange (amps) of electrons through a wire depends on the electromotive force (volts) and the resistance of the wire to the exchange of electrons. Electrical resistance is the name given to the internal friction involved in the exchange of electrons through a wire, or though any material. The unit of measure of resistance is named the OHM after the German scientist, G. S. Ohm, who discovered that the electron exchange rate (amps) in a wire is proportional to the electromotive force (volts). One OHM of resistance is defined as exactly enough resistance to allow one VOLT of applied electromotive force to cause electron exchange rate of one AMPERE.

When the emf (volts) applied to a device is increased, the electron exchange rate (amps) increases. When the resistance (ohms) is increased without changing the emf (volts), there is a smaller exchange rate (amps). These two facts can be combined into one statement written as a formula that explains the relationship between the three units of measure of electrical energy.

$$\text{Exchange rate in amperes} = \frac{\text{electromotive force in volts}}{\text{resistance in ohms}}$$

This formula is called "Ohm's Law." To shorten it further, it may be written either as $I = \frac{E}{R}$ or $E = IR$. E represents electromotive force (emf) measured in volts. I stands for intensity of the electron exchange rate, measured in amperes. R represents resistance, measured in ohms.

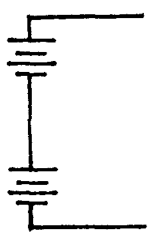
In review, we have seen that there are three measures critical to an understanding of electricity. The first is the electromotive force (emf) which causes electron exchange. Electromotive force (emf) is measured in VOLTS. The second measure of electricity is concerned with the rate of exchange electrons. The rate of exchange of electrons is measured in AMPERES where one ampere equals one coulomb per second. The final measure of importance in electricity is the OHM which measures resistance to electron exchange. One ohm of resistance is just enough to allow one volt of electromotive force to cause an exchange rate of one ampere.

One of the more familiar sources of electricity is the battery. The Italian scientist, Galvani, observed a strange phenomena during the dissection of a frog which was supported on copper wires. Each time he touched the frog with his steel scalpel, its leg would twitch. Galvani reasoned that the frog's leg contained electricity. As a result of related experiments, Alesandra Volta, another Italian scientist, invented the electric cell, named in his honor, called the Voltaic Cell. As you recall, the unit of electromotive force, the volt, is also named in his honor. Volta discovered that when two dissimilar elements were placed in a chemical which acted upon them, electricity was built up between them. Any device that creates electricity by a chemical reaction with two dissimilar metals is called a battery.

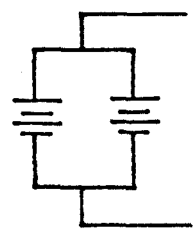
A battery will have two terminals corresponding to the two dissimilar metals upon which the chemical reaction is taking place. The terminal where an excess of electrons is building up is the negative terminal and the terminal where a deficiency of electrons is being created is the positive terminal. If a conductor is connected to the positive and negative terminals of a battery, an electron exchange occurs from the negative to the positive terminals creating electricity.

Battery cells can be arranged together in two different ways.

They can be connected in <u>series</u> where the positive terminal of one cell is connected to the negative terminal of the next cell. Battery cells can also be connected in <u>parallel</u> where all the positive terminals are connected together and all of the negative terminals are connected together. Each of these two arrangements of battery cells will produce different voltages and amperages.

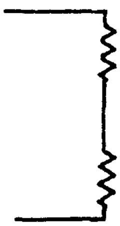


Batteries
in
Series

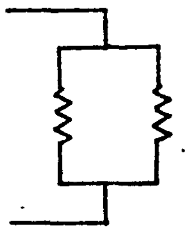


Batteries
in
Parallel

A resistor is any piece of material having a known electrical resistance which is used to control the electron exchange rate or produce heat. The heating element in toasters and irons is a wire or ribbon made of a nickel-chromium alloy. Such resistors have relatively few ohms of resistance so they can allow a relatively large amperage which produces plenty of heat. The resistor in an incandescent lamp is a coil of fine wolfram (tungsten) wire of a size that will become white-hot. Other resistors like those found in radios and televisions are used to control the exchange rate of electrons. Since the rate of electron exchange (amps) can be changed by changing the resistance (ohms) when electromotive force (volts) is kept constant, the addition of resistors in a conductor can regulate the rate of electron exchange. As with battery cells, resistors can be placed in either series or parallel to produce more or less resistance in a conductor.

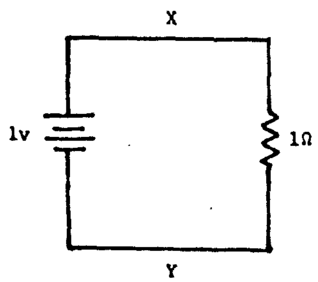


Resistors
in
Series



Resistors
in
Parallel

From what we have seen so far, a simple electrical circuit can be analyzed. A circuit is simply a set of batteries and resistors connected together by a conductor to form a closed loop from the negative terminal to the positive terminal of the battery. In the diagram below, Ohm's law is demonstrated in a simple circuit. Note that one ohm of resistance allows one volt of electromotive force to produce an electron exchange rate of one ampere.



Simple Circuit

More complex citcuits can easily be constructed using battery cells either in series or parallel and resistors either in series or parallel. These more complex circuits, however, can still be analyzed accordint to Ohm's Law so that the voltage and amperage can be computed as a function of resistance.

STOP! Do not turn the page until told to do so. You may go back and review the text passage.

Water Analogy Text

NOTE. Analogous words and phrases added to the text are underlined. They were not underlined when presented to subjects in the study.

BASIC ELECTRICAL CIRCUITS

Electricity is the exchange of electrons through a conductor such as copper wire. This exchange of electrons is from an area of negative charge to an area of positive charge since a negative charge is produced by an excess of negatively charged electrons and a positive charge is produced by a deficiency of electrons. The force which causes this electron exchange is called electromotive force (emf). It is often helpful to think of an electric current as the flow of water in pipes with the pressure causing the flow of water being similar to the electromotive force (emf) that causes electrons to flow. This electromotive force or "pressure" is also known as voltage. Voltage then is the electrical force or pressure which causes the flow of electrons. It is measured in VOLTS. The greater the pressure causing electrons to flow, the greater will be the voltage measured on the conductor. The volt was named after Alesandro Volta, an Italian scientist who discovered how to make batteries.

In addition to volts, there are several other measures of electricity. The simplest electrical unit is the COULOMB. One coulomb is 6,240,000,000,000,000,000 electrons. If that number of surplus electrons accumulated on a metal ball, we would say that the ball has a negative charge of one coulomb. Thinking again in our flowing water model, a coulomb would be a certain number of water molecules that collect in a reservoir creating a pressure to escape. A positive charge would be a reservoir where there was an absence of water molecules. The coulomb was named after French scientist, Charles A. Coulomb, who experimented with electrical charges and discovered many of the principles and laws related to them.

Electron flow rates are expressed as a quantity of electrons flowing in a particular unit of time. A quantity of electrons measured in coulombs measures the rate of electron flow in coulombs per second. If 600 coulombs pass through an electric heater in 60 seconds, the rate of flow is 10 coulombs each second. Coulombs per second in electricity is very similar to gallons per minute in the flow of water in pipes. Measure of flow rate is so important that one word is now used to replace the longer term "coulombs per second." The word used is ampere (amp). For example, instead of saying 5 coulombs per second, the term 5 amperes, which means the same thing is used. So, an ampere in electricity is similar to gallons per minute in water flow. The ampere is named for Andre Ampere, a French mathematician and scientist who investigated magnetic forces due to electricity and set up the mathematical theory of electromagnetism.

The rate of flow (amps) of electrons through a wire depends on the electromotive force (volts) and the resistance of the wire to the flow of electrons. Electrical resistance is the name given to the internal friction involved in the exchange of electrons through a wire, or through any material. Electrical resistance is very much like the resistance to the flow of water in pipes caused by the size of the pipe or by the obstructions in it. The unit of measure of resistance is named the OHM after the German scientist, G. S. Ohm, who discovered that the electric current (amps) in a wire is proportional to the electromotive force (volts). One OHM of resistance is defined as exactly enough resistance to allow one VOLT of applied electromotive force to produce an electron flow rate of one AMPERE.

When the emf (volts) applied to a device is increased, the electron flow rate (amps) increases. When the resistance (ohms) is increased without change the emf (volts), there is less electron flow (amps). These two facts can be combined into one statement written as a formula that explains the relationship between the three units of measure of electrical energy.

$$\text{Electron flow rate in amperes} = \frac{\text{electromotive force in volts}}{\text{resistance in ohms}}$$

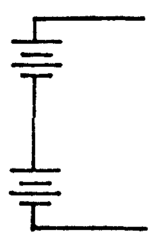
This formula is called "Ohm's Law." To shorten it further, it may be written either as $I = \frac{E}{R}$ or $E = IR$. E represents electromotive force (emf) measured in volts. I stands for intensity of electron flow, measured in amperes. R represents resistance, measured in ohms. Ohm's Law can be understood in our water model also. The gallons per minute of flow (amps) equals the water pressure (volts) divided by the constriction in the pipes (ohms). Or, the water pressure (volts) equals the gallons per minute of flow (amperes) times the constriction in the pipes (ohms).

In review, we have three measures of electricity, each of which has its counterpart in flowing water. Volts is the electromotive force or "pressure" causing the movement of electrons. Amperes is the flow rate of electrons similar to gallons per minute in water flow. Ohms is the measure of resistance to flow very similar to constrictions in pipes.

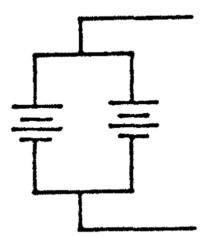
One of the more familiar sources of electricity is the battery. The Italian scientist, Galvani, discovered electricity in a frog he was dissecting which was caused by the copper wires supporting the frog and his steel scalpel. As a result of related experiments, Alesandra Volta, another Italian scientist, invented the electric cell, named in his honor, called the Voltaic Cell. As you recall, the unit of electromotive force, the volt, is also named in his honor. Volta discovered that when two dissimilar elements were placed in a chemical which acted upon them, electricity was built up between them. Any device that creates electricity by a chemical reaction with two dissimilar metals is called a battery. A battery is like a water reservoir where water under pressure is creating a potential for movement through pipes.

A battery will have two terminals corresponding to the two dissimilar metals upon which the chemical reaction is taking place. The terminal where an excess of electrons is building up is the negative terminal and terminal where a deficiency of electrons is being created is the positive terminal. If a conductor is connected to the positive and negative terminals of a battery, electrons will flow from the negative to the positive, creating electricity. In much the same way, a pipe connected between the outlet and inlet of a reservoir will allow water to flow through the system.

Battery cells can be arranged together in two different ways. They can be connected in series where the positive terminal of one cell is connected to the negative terminal of the next cell. Battery cells can also be connected in parallel where all the positive terminals are connected together. These arrangements can be seen in water reservoirs also. Reservoirs can be connected end-to-end (series) or side-by-side (parallel). Just as the two arrangement of reservoirs will produce different water pressures (volts) and different flow rates (amps), the two different arrangements of batteries produce different voltages and amperages.

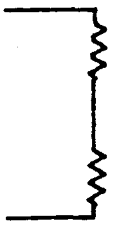


Batteries
in
Series

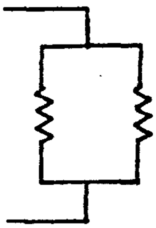


Batteries
in
Parallel

A resistor is any piece of material having a known electrical resistance which is used to control electron flow rates or produce heat. The heating element in a toaster or iron and the coil of wire in an incandescent lamp are examples of resistors. Other resistors found in radio and television circuits are used to control the flow of electrons. Resistors are like valves or constricted places in pipes that reduce the flow of water. The narrower the pipe, the less will be the flow. Since the rate of electron flow (amps) can be changed by changing the resistance (ohms) when the electromotive force (volts) is kept constant, the addition of resistors in a conductor can regulate the rate of electron flow. As with battery cells, resistors can be placed in either series or parallel to produce more or less resistance in a conductor. This is similar to valves in water pipes that can be placed either along side each other or one after the other in a system.

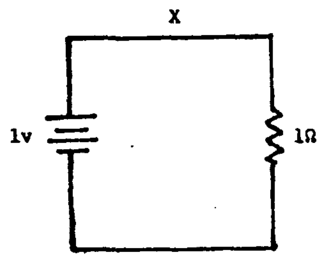


Resistors
in
Series

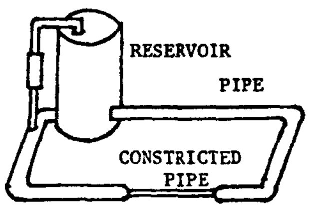


Resistors
in
Parallel

From what we have seen so far, a simple electrical circuit can be analyzed. A circuit is simply a set of batteries and resistors connected together by a conductor to form a loop from the negative terminal to the positive terminal of the battery. In the diagram below, Ohm's Law is demonstrated in a simple circuit. Note that one ohm of resistance allows one volt of electromotive force to produce an electron flow rate of one amp. The corresponding water system diagram is also shown to give you a better idea of simple circuits.



Simple Circuit



WATER SYSTEM

More complex circuits can easily be constructed using battery cells either in series or parallel and resistors either in series or parallel. These more complex circuits, however, can still be analyzed according to Ohm's Law so that the voltage and amperage can be computed as a function of resistance. Also, corresponding water systems can be developed for each electrical circuit to make the analysis easier.

STOP! Do not turn the page until told to do so. You may go back and review the text passage.

People Analogy Text

NOTE. Analogous words and phrases added to the text are underlined. They were not underlined when presented to subjects in the study.

BASIC ELECTRICAL CIRCUITS

Electricity is the exchange of electrons through a conductor such as a copper wire. This exchange of electrons is from an area of negative charge to an area of positive chanrge since a negative charge is produced by an excess of negatively charged electrons and a positive charge is produced by a deficiency of electrons. The force which causes this electron exchange is called electromotive force (emf). It is often helpful to think of electricity as the movement of people through corridors with the crowding of people which causes them to move out of a room and down a corridor being similar to the electromotive force (emf). This electromotive force or crowding motion is also known as voltage. Vòltage then is the electrical force or "crowding motion" which causes the movement of electrons. It is measured in VOLTS. The greater the force causing electrons to move, the greater will be the voltage measured on the conductor. The volt was named after Alesandro Volta, an Italian scientist who discovered how to make batteries.

In addition to volts, there are several other measures of electricity. The simplest electrical unit is the COULOMB. One coulomb is 6,240,000,000,000,000,000 electrons. If that number of surplus electrons accumulated on a metal ball, we would say that the ball has a negative charge of one coulomb. Thinking again in our moving people model, a coulomb would be a certain number of people gathered in a room creating a crowding pressure to escape down a corridor. A positive charge would be a room where there was an absence of people. The coulomb was named after French scientist, Charles A. Coulomb, who experimented with electrical charges and discovered many of the principles and laws related to them.

Electron movement rates are expressed as a quantity of electrons moving in a particular period of time. A quantity of electrons measured in coulombs measures the rate of electron flow in coulombs per second. If 600 coulombs pass through an electric heater in 60 seconds, the rate of flow is 10 coulombs each second. Coulombs per second in electricity is similar to people per minute in our moving people model. Measurement of movement rate is so important that one word is now used to replace the longer term "coulomb per second." The word used is AMPERE (amp). For example, instead of saying 5 coulombs per second, the term 5 amperes, which means the same thing, is used. So, an ampere in electricity is similar to people per minute in the movement of people in corridors. The ampere is named for Andre Ampere, a French mathematician and scientist who investigated magnetic forces due to electricity and set up the mathematical theory of electromagnetism.

The rate of movement (amps) of electrons through a wire depends on the electromotive force (volts) and the resistance of the wire to the movement of electrons. Electrical resistance is the name given to the internal friction involved in the exchange of electrons through a wire, or through any material. Electrical resistance is very much like the resistance to the movement of people in corridors caused by narrow doorways or obstructions in the corridors. The unit of measure of resistance is named the OHM after the German scientist, G. S. Ohm, who discovered that the electron movement rate (amps) in a wire is proportional to the electromotive force (volts). One OHM of resistance is defined as exactly enough resistance to allow one volt of applied electromotive force to produce an electron movement rate of one AMPERE.

When the emf (volts) applied to a device is increased, the rate of electron movement (amps) increases. When the resistance (ohms) is increased without changing the emf (volts), there is less electron movement (amps). There two facts can be conbined into one statement written as a formula that explains the relationship between the three units of measure of electrical energy.

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This formula is called "Ohm's Law." To shorten it further, it may be written either as $I = \frac{E}{R}$ or $E = IR$. E represents electromotive force (emf) measured in volts. I stands for rate of electron movement measured in amperes. R represents resistance, measured in ohms. Ohm's Law can be understood in our moving people model also. The people per minute of movement (amps) equals the crowding pressure (volts) divided by the number of doorways or obstacles in the corridors (ohms). Or, the crowding pressure (volts) equals the people per minute of movement (amps) times the number of obstacles or doorways (ohms).

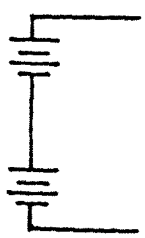
In review, we have three measures of electricity, each of which has its counterpart in the movement of people. Volts is the electromotive force or crowding pressure causing the movement of electrons. Amperes is the movement rate of electrons similar to people per minute. Ohms is the measure of resistance to movement very similar to the obstacles like furniture in corridors.

One of the more familiar sources of electricity is the battery. The Italian scientist, Galvani, discovered electricity in a frog he was dissecting which was caused by the copper wires supporting the frog and his steel scalpel. As a result of related experiments, Alesandra Volta, another Italian scientist, invented the electric cell, named in his honor, called the Voltaic Cell. As you recall, the unit of electromotive force, the volt, is also named in his honor. Volta discovered that when two dissimilar elements were placed in a chemical which acted upon them, electricity was built up between them. Any device that creates electricity by a chemical reaction with two dissimilar metals is called a battery. A battery is like a crowded room where the bumping of people into each other creates a potential for movement down a corridor.

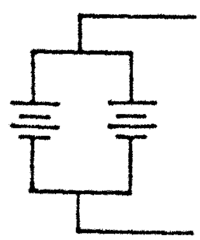
A battery will have two terminals corresponding to the two dissimilar metals upon which the chemical reaction is taking place.

The terminal where an excess of electrons is building up is the negative terminal and the terminal where a deficiency of electrons is being created is the positive terminal. If a conductor is connected to the positive and negative terminals of a battery, electrons will move from the negative to the positive terminal creating electricity. In much the same way, a corridor connected between the exit and entrance of a room will allow people to move through the system.

Battery cells can be arranged together in two different ways. They can be connected in series where the positive terminal of one cell is connected to the negative terminal of the next cell. Battery cells can also be connected in parallel where all the positive terminals are connected together and all the negative terminals are connected together. These arrangements can be seen in rooms also. Rooms can be connected end-to-end (series) or side-by-side (parallel). Just as the two arrangements of rooms will produce different crowding pressure (volts) and different movement rates (amps), the two different arrangements of batteries will produce different voltages and amperages.



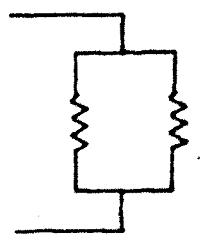
Batteries in Series



Batteries in Parallel

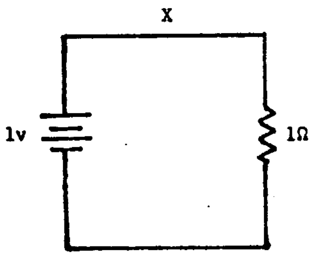
A resistor is any piece of material having a known electrical resistance which is used to control the rate of electron movement or produce heat. The heating element in a toaster or iron and the coil of wire in an incandescent lamp are examples of resistors. Other resistors found in radio and television circuits are used to control the rate of electron mobement. Resistors are like doorways or furniture in corridors that reduce the movement of people. The narrower the corridor, the less will be the movement. Since the rate of electron movement (amps) can be changed by changing the resistance (ohms) when the electromotive force (volts) is kept constant, the addition of resistors in a conductor can regulate the rate of electron movement. As with battery cells, resistors can be placed in either series or parallel to produce more or less resistance in a conductor. This is similar to doorways in corridors that can be placed either along side each other or one after the other in the hallway system.

Resistors
in
Series

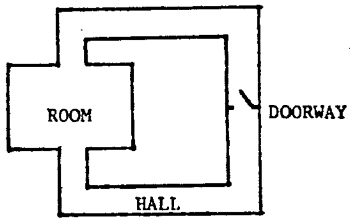


Resistors
in
Parallel

From what we have seen so far, a simple electrical circuit can be analyzed. A circuit is simply a set of batteries and resistors connected together by a conductor to form a loop from the negative terminal to the positive terminal of the battery. In the diagram below, Ohm's Law is demonstrated in a simple circuit. Note that one ohm of resistance allows one volt of electromotive force to produce electron movement rate of one ampere. <u>The corresponding corridor system diagram is also shown to give you a better idea of simple circuits.</u>



Simple Circuit



CORRIDOR SYSTEM

More complex circuits can easily be constructed using battery cells either in series or parallel and resistors either in series or parallel. These more complex citcuits, however, can still be analyzed according to Ohm's Law so that the voltage and amperage can be computed as a function of resistance. <u>Also, corresponding corridor systems can be developed for each electrical circuit to make the analysis easier.</u>

STOP! Do not turn the page until told to do so. You may go back and review the text passage.

QUIZ

Questions 1-8: Select the best answer and mark your selection on the answer sheet.

1. The exchange of electrons in electricity takes place from an area of __________ change to an area of __________ change.
   a. positive; negative
   *b. negative; positive
   c. positive; neutral
   d. negative; neutral

2. The force which produces the exchange of electrons leading to electrical energy is called:
   a. the electric potential force
   b. the electric current force
   *c. the electromotive force
   d. the current induction force

3. The force which produces the exchange of electrons is measured in:
   *a. volts
   b. amperes
   c. coulombs
   d. ohms

4. The measure of electricity that is the same as coulombs per second is the:
   a. volt
   *b. ampere
   c. ohm
   d. emf

5. The name given to the internal friction involved in the exchange of electrons through any material is called:
   a. electrical conductance
   *b. electrical resistance
   c. electromotive resistance
   d. electromagnetism

6. One ohm is defined as exactly enough internal friction to allow one ____________________ to produce ____________________.
   *a. volt of emf; ampere of electron exchange
   b. ampere of electron exchange; volt of emf
   c. volt of emf; coulomb of electron exchange
   d. coulomb of electron exchange; volt of emf

7. Any device that produced electricity by a chemical reaction with two dissimilar metals is called a:
   a. Voltaic Cell
   b. resistor
   *c. battery
   d. generator

8. A device used to control the amperage in a circuit when voltage remains constant is called a:
   a. voltaic cell
   *b. resistor
   c. battery
   d. current regulator

Continued on the following page!

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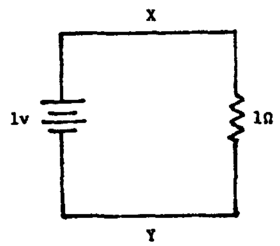
*Denotes correct answer.

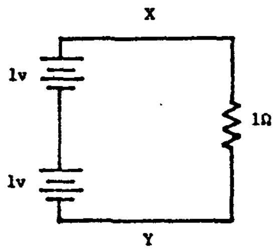
Questions 9-16: Given the simple circuit below and Ohm's Law ($I = \frac{E}{R}$ or $E=IR$) where I is the electron exchange rate in amperes, E is emf in volts and R is resistance in ohms; solve each of the Complex Circuits below for volts and amperes. Each battery cell has one volt of emf (1v) and each resistor has one ohm resistance (1Ω). Mark your answers on the answer sheet.



Simple Circuit

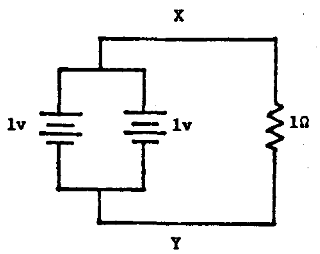
Volts = 1
Amperes = 1

9. In the complex circuit below using batteries in series and a single resistor; what is the voltage and the amperage between X and Y?



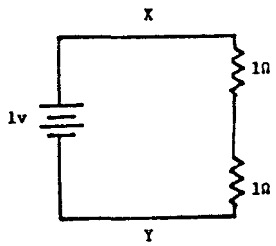
a. 1 volt; 1 ampere
b. 2 volts; 1 ampere
c. 1 volt; ½ ampere = ½
*d. 2 volts; 2 amperes

10. In the Complex Circuit below using batteries in parallel and a single resistor; what is the voltage and amperage between X and Y?



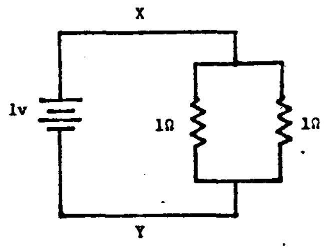
*a. 1 volt; 1 ampere
b. 2 volts; 2 amperes
c. 1 volt; ½ ampere
d. 2 volts; ½ ampere

11. In the complex circuit below using a single battery and resistors in series, what is the voltage and amperage between X and Y?



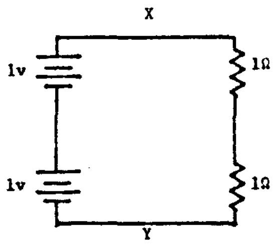
a. 1 volt; 1 ampere
b. 1 volt; 2 amperes
*c. 1 volt; ½ ampere
d. 2 volts; ½ ampere

12. In the Complex Circuit below using a single battery and resistors in parallel, what is the voltage and amperage between X and Y?



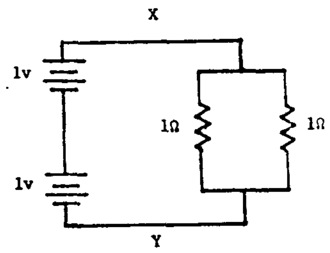
a. 1 volt; 1 ampere
b. 1 volt; ½ ampere
*c. 1 volt; 2 amperes
d. 2 volts; 2 amperes

13. In the Complex Circuit below using batteries in series and resistors in series; what is the voltage and amperage between X and Y?



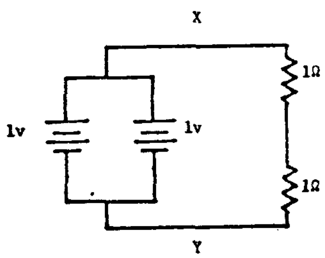
a. 1 volt; 1 ampere
b. ½ volt; ½ ampere
*c. 2 volts; 1 ampere
d. 2 volts; ½ ampere

14. In the Complex Circuit below using batteries in series and resistors in parallel, what is the voltage and amperage between X and Y?



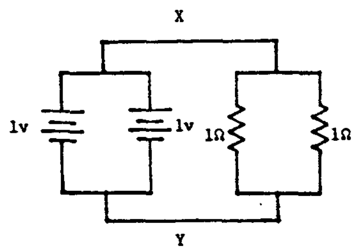
a. 1 volt; 1 ampere
b. ½ volt; ½ ampere
c. 2 volts; 2 amperes
*d. 2 volts; 4 amperes

15. In the Complex Circuit below using batteries in parallel and resistors in series, what is the voltage and amperage between X and Y?



a. 1 volt; 1 ampere
*b. 1 volt; ½ ampere
c. 2 volts; 1 ampere
d. 2 volts; 2 amperes

16. In the Complex Circuit below using batteries in parrallel and resistors in parallel, what is the voltage and amperage between X and Y?



a. 1 volt; 1 ampere
*b. 1 volt; 2 amperes
c. ½ volt; 1 ampere
d. ½ volt; ½ ampere