PROGRAMED INSTRUCTION FOR REMEDIAL ELECTRONICS STUDENTS

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Herbert Paul Froehlich

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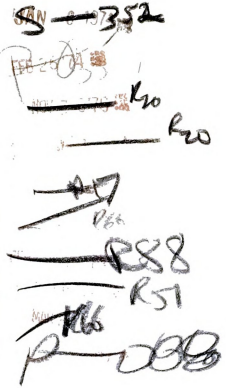

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ABSTRACT

PROGRAMED INSTRUCTION FOR
REMEDIAL ELECTRONICS STUDENTS

by Herbert Paul Froehlich

Programed instruction began as an application of principles from the laboratory to the technology of education. The two major forms of programed instruction are the linear and non-linear, introduced by Skinner and Crowder, respectively. While linear programs are designed to elicit correct learner responses by means of a fixed sequence of small instructional steps, non-linear programs provide a flexible sequence of large instructional steps. Because of these and other differences between linear and non-linear programs, related to their degree of organization and readability, it was hypothesized that the relative effectiveness of these two types of programs in teaching electronics would depend on the academic, intellectual, and reading abilities of the students who used them.

Furthermore, since the results of previous investigations suggested that the sequencing of instructional steps provided an organization of subject matter for the low-achieving student which he was not able to provide for himself, it was hypothesized that the two forms of programed instruction would assist a group of slow learners undertaking remedial training to achieve at a higher level than a conventional lecture. This hypothesis was tested against criteria which were designed to measure (a) achievement

on electronics subject matter specifically taught in lecture, linear, and non-linear presentations, and (b) later academic performance on electronics concepts which depended on an understanding of the more elementary principles developed in the remedial presentations.

The fact that responses are constructed in a linear program rather than selected from among several alternatives, as they are in a non-linear program, suggested the hypothesis that there was an interaction between the form of response required by the program and the form of response required by a criterion test (multiple choice and construction), the criterion test measuring electronics ability. A second hypothesis stemming from the difference in program response form was that the student would need more time to complete the linear program than the non-linear. Obviously, then, linear programs would provide less efficient learning than non-linear programs, from a time point of view only, everything else being equal.

The subjects of this study were 494 naval trainees undertaking remedial instruction. These students had failed an examination given at the end of the second week of a 19-week basic electronics course and were required to repeat the second week of instruction at night while continuing the third week of instruction during the day.

Remedial classes, with students repeating the second week of instruction, met for two hours each of three nights. Each class received comparable lecture, linear, or non-linear instructional presentations using the second week subject matter. These three instructional treatments were randomly assigned to classes.

There were two studies due to the fact that the two forms of the criterion test (S1 and S2), used alternately as pre-treatment and post-treatment measures of electronics ability, were not parallel. One study was concerned with the analysis of data from classes provided with the S1-S2 order of presentation, while the second study considered classes given the S2-S1 order. Each form of the criterion test contained 15 multiple choice and 15 construction items.

Because of unequal treatment sample sizes, and for greater precision, regression analyses were conducted. These analyses were, in effect, analyses of covariance using two control variables within each of two regression models. One regression model included scores on intelligence and prior academic achievement as independent variables, and the other used reading comprehension and pretest scores. Each of several regression equations provided an error sum of squares which was used in an F-statistic designed to test hypotheses concerning interactions between learner and method variables, and treatment main effects. Intercorrelation matrices included all the variables for each treatment group.

The results from one set of data showed that the linear program was best for students with low prior achievement scores, and that the lecture was best for students with high scores. An examination of the mean and the distribution of the posttest criterion scores suggested that this interaction, and the lack of a significant treatment main effect, was due to criterion tests which were too difficult. High ability individuals were

academically superior to those of low ability, although neither form of programed instruction, nor the lecture, permitted the high ability students to reach the academic level usually attained by non-remedial students. Although it took students using the linear program on the average 10 percent longer to complete instruction than students using the non-linear program, based on the total number of minutes to complete instruction, the average student using either form of programed instruction completed remedial training better than 30 percent sooner than those in the lecture.

It was concluded that either the principles of learning developed in the laboratory were not directly applicable to human verbal learning as represented by programed instruction, or designers of programed learning were far from providing faithful implementation of these principles of learning.

PROGRAMED INSTRUCTION FOR REMEDIAL ELECTRONICS STUDENTS

By

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CHAPTER I

INTRODUCTION

While learning theorists have agreed upon certain principles established in the psychological laboratory, they have not, in the past, always been able to institute such principles in the classroom. Glaser (32) has pointed out the unfortunate lack of influence which education and the developing science of learning have had on each other. Major obstacles to the fruitful interaction between laboratory findings and learning in the classroom may be attributed to differences between the experimental laboratory and the classroom, namely, differences in species of the subject, conditions of learning, and subject matter. Skinner (63, 64) and Crowder (16), however, have sought to close the gap between the laboratory and the classroom, assisted by recent advances in educational technology.

Kendler (40) cautioned against making an automatic connection between theory and its successful application to a practical problem, while Glaser (32) argued that applied research was the meeting ground of applied and basic endeavors. It was at the applied level that solutions to both theoretical and practical issues were attempted, often in the same experimental program. Indeed, the work of Skinner and Crowder, on verbal learning by means of self-instructional devices, stimulated both theoretical and practical aspects of research in learning. Through the use of self-instructional devices - those concerned with the presentation, activity,

and feedback phases of the teaching cycle (23) - researchers functioning in an educational context were able to manipulate and study parameters of learning previously confined to laboratory analysis. Thus, "schedules of reinforcement (42, 57)," "contingencies of reinforcement (65)," and "shaping" became terms applied to human as well as non-human learning.

On the practical side, educational specialists gave more attention to an examination of instruction, putting aside for a time attempts at patching up activities which supported instruction, such as the manipulation of teacher-student ratios, the lengthening of courses, or the introduction of training aids to instruction. Because self-instructional devices provided frequent and immediate reinforcement, allowed for active student response, and took into account the fact and the nature of individual differences, psychologists felt that such learning devices were often more efficient sources of communication and control of the learning process than were classroom instructors (65). Those concerned with education attempted to capitalize on this potential. They saw in programed instruction a way to relieve shortages of teachers and educational facilities (66), a means of providing students with "individualized instruction (65)," and an approach to assisting those with limited intellectual capabilities (11).

Thus, learning principles, translated by an educational technology, allowed theoretical and practical research to blossom within a few short years (25, 31).

Purpose

The present research, conducted in a military training environment, had both theoretical and practical implications. The theoretical implications stemmed from characteristics of Skinnerian and Crowderian approaches to programing. These characteristics, outlined in Table 1, suggested to the present investigator that differences in a learner's intellectual, reading, and academic abilities might condition the degree to which different approaches to implementing knowledge of results, active responding, and program step size affect student performance. The chief purpose of the present study, therefore, was to investigate the relationship between learner and instructional variables.

Table 1 shows that responses are constructed in a linear program rather than selected from among several alternatives as they are in a non-linear program. Hedberg (34) pointed out that a criterion test of only multiple choice items would favor Crowder's non-linear method of programing if the criterion test was for that kind of program. The present study, therefore, investigated the possible interaction between the response form of the criterion (multiple choice and fill-in) and the form of programed instruction.

Practical implications were based on several empirically supported assumptions: first, that students using programed instruction could attain a common, but high level, of academic achievement. Skinner (64), for example, has pointed out that low ability students were capable of substantial, even extraordinary, achievement if permitted to move at their own

TABLE 1

DIFFERENCES BETWEEN SKINNERIAN AND CROWDERIAN APPROACHES TO PROGRAMING INSTRUCTION

Skinnerian		Crowderian
Laboratory Principle	Programing Principle	Programing Principle
The relation between behavior and the consequences of behavior is brought about by "contingencies" of reinforcement	Immediate and frequent reinforcement of behavior appropriate to the desired goal	Teaching is a communication process. Feedback to the student determines whether the communication was successful or not
Complex performance is shaped by changing contingencies of reinforcement progressively in the direction of the required behavior	Gradual progression from simple to complex concepts in successive steps. Instruction is presented in a fixed "logical" sequence of small steps	If communication is not effective the student may be shifted to subject matter not mastered (branching). Steps are large and allow flexibility of instruction
Behavior is brought under control of the environment by reinforcing only when particular stimuli are present	The stimuli to be discriminated are present and reinforced in a variety of stimulus contexts	
Before behavior is reinforced the response must be omitted	Students respond by constructing the response before receiving confirmation	Students respond by selecting a response from among alternatives
Appropriate stimulus-response connections must be made	Correct responses are assured through prompting and cueing. Errors leave traces of erroneous responses	Error is used to guide the student who is learning
	Students proceed at their own rate through the sequence	Individual differences are accounted for through branching

pace, if frequently and immediately reinforced, and if allowed to follow a coherent sequence of instructional frames. Porter (53), using a linear spelling program showed that there was almost no correlation between aptitude and achievement following learning by programed instruction. Such a finding was predictable if, in fact, programed instruction allowed students, progressing at their own pace, to attain a common level of performance, since achievement test scores following programed instruction would then show little variation. Second, it was assumed that the time devoted to conventional training could be shortened, even when training low ability or remedial students, as in the present study. Previous studies showed a savings of 13 percent for a high ability group using an electronics program (10) and almost a 50 percent savings in training time for a program in German (24).

There were, thus, two other major purposes to the present study. Since programed instruction provided the organization which low ability or "remedial" students could not independently develop from texts and lectures, the present research investigated the extent to which programed instruction could actually assist a group of slow learners to achieve at a high level. The present study considered as well whether programed instruction reduced conventional training time, and whether the Skinnerian or the Crowderian program was more effective in such reduction.

Table 2 presents the instructional and learner variables used in the present study for making tests related to the interactions between ability

and method, and method main effects. The following section examines in greater detail the theoretical and practical foundations on which the present study was based.

TABLE 2

INDEPENDENT AND DEPENDENT VARIABLES USED IN TESTING HYPOTHESES OF INTERACTIONS BETWEEN ABILITY AND METHOD VARIABLES, AND METHOD MAIN EFFECTS

Class of Variable	Variables in Class
Independent Variable	
Instructional (method)	Lecture Skinner Crowder
Learner (ability)	Intelligence (IQ) Reading Comprehension (RC) Week 1 grade (WK 1)
Dependent Variable	
Immediate test of retention	Total posttest score (PTT tot) Multiple choice posttest score (PTT mc) Fill-in posttest score (PTT fi)
Delayed test of retention	Total retest score (RT tot) Multiple choice retest score (RT mc) Fill-in retest score (RT fi)
Related subject matter	Week 3 grade (WK 3) Week 5 grade (WK 5)
Time to program completion	Total time (T)

Literature Review

Theoretical

There are at least two assumptions about the way people learn which have various implications for programing. One such assumption regards the learner as a receptive mechanism for whom associative connections take form so as to mirror experience. Luchins (46) has called this conception the "homo mechanicus" model of man. Another assumption is that the learner is a selective self-organizing mechanism which selects and extracts information from his environment. Luchins (46) referred to this conception as a "homo sapiens" model of the learner.

Stolurow (66) indicated that one implication of the first assumption for a method of programing is that the degree of freedom in response be reduced. The program should consider the learner as a responsive system which has to be channeled into the formation of "correct" responses and has to be prevented from making wrong responses. An example of this viewpoint is presented in Appendix B as the Skinnerian or linear approach.

A programer acting on the "homo sapiens" model of the learner would allow the learner greater freedom of response through branching and the use of multiple choice items containing a number of wrong response terms. The Crowderian or non-linear approach to programing represented this viewpoint; an example of it is presented in Appendix C.

A linear form of programing would seem to be advantageous for those of limited intellectual ability. In a study of concept formation, for example,

Detambel and Stolurow (19) found that at low ability levels, an ordered rather than a random sequence of frames allowed for more students to learn the concept. At high ability levels there were no significant differences. These investigators concluded that the best sequence did for the poorest ability group what the highest ability group could do for itself regardless of sequence. This result suggests that the linear program might be effective for the low ability remedial student in the present study. Evidence presented on page 10, however, shows that results conflict as to whether high or low ability individuals benefit more from programed instruction.

Because the Skinner program provided small linear steps, while the Crowder program used large instructional steps, the linear approach might be more adequate for remedial students who have reading difficulties. According to Skinner (65), the Crowderian approach left most of the learning to reading rather than to responding. The linear or "small step" format, on the other hand, placed more emphasis on responding and less on reading. With respect to these differences in programing Hedberg (34) asked, "How important are differences in reading level in the use of a Crowder or Skinner program?" With this question in mind, the present investigator considered that there might be an interaction between reading comprehension and the method of programing.

Trittipoe, Trittipoe, and Hahn (68) recently tested a similar proposition using fourth and sixth grade students and three different approaches to designing linear programs. These investigators believed that prompting

required the most cueing and provided the most voluminous reading task; conversational chaining had less cueing, and was, therefore, the most complex reading task; confirmation provided the least cueing and the easiest reading task. The findings indicated that reading was especially important for the fourth grade group. This was supported by a reading-achievement test correlation of .95 in the conversational chaining treatment. The correlation between reading ability and achievement was .43 for sixth grade students in the conversational chaining group. The investigators concluded that in a program which was difficult to read, achievement would be closely related to reading ability.

The conceptual scheme considered in the present study included learner and instructional variables in view of the possible interaction between them. Past research using such a framework has been limited (66), although a few recent studies have considered interactions. Homme, Willey, and McMahan (35) found interactions between intellectual ability level and methods of instruction such as television, text, machine, and lecture. The teaching machine was poorest for low ability students and best for high ability. This result was found in programs of alternating current but not those of direct current.

Roe (56) could not detect any aptitude-method interaction on an elementary probability criterion test or time to complete instruction. Lambert (42) found no relation between ability and schedules of reinforcement, and Silberman, Coulson, Gunn, and Melaragno (61) did not demonstrate an

interaction between form of program and achievement characteristics of students. The latter researchers went so far as to say that there was no sound basis for exploring relations between task, method, and student variables as these determined the efficiency of student learning under programed instruction.

Although research on the relationship between learner and instructional variables has been limited, some studies have considered the variables of intelligence and reading ability apart from their possible interaction with methods of programing. Wong and Douglass (71) found that students of high intellectual ability proceeded through a program faster than those of low ability. Faltz (22) and Sharf's (57) low ability students made more errors during learning than those of high ability. Skinner (64), Fry (29), and Shay (58) indicated that programed learning was applicable to individuals within a wide intellectual range and that special programs based upon ability were unnecessary. Keisler (38) suggested that programed instruction was more appropriate for brighter students, whereas Little (45), Freeman (27), and Porter (54) showed that programed instruction benefited low ability students more than those of high ability. High ability students using programed instruction were superior to high ability control students in several studies (3, 10). Silberman, et al. (61) concluded, "once an overachiever, always an overachiever."

As to reading ability, Wong and Douglass (71) recognized the possible influence of this variable upon the outcome of research in programed

instruction. They therefore eliminated subjects from their study who did not comprehend the written word. Dite, Woodruff, and Faltz (20) also recognized that reading ability was related to success in programed instruction. Using the Gates Reading Test these researchers found more correct responses to a program for students of high reading ability than for those of low reading ability. It remained, however, for these and other investigators to show that these groups actually differed on a subsequent test of achievement.

The evidence relating to intellectual and reading ability is inconclusive. The sample of remedial students in the present study included both low and high ability students. Therefore, in addition to an investigation of interactions between ability and methods of instruction, some emphasis was placed on the academic consequences of programed instruction for low and high ability individuals.

Practical

The practical purposes of the present study grew out of the nature of the military training environment. A previous study (28) done in the same 19-week basic electronics school within which the present study was conducted, indicated that the school had an overall drop rate of 14 percent. About 6,000 students went through the school in a year. When compared to drop rates of under 5 percent for other technical schools, the present investigator realized the magnitude of the problem. Since there was already a shortage of qualified men for technical jobs in the armed services, the loss of almost 1,000 electronics technicians a year further strained our military defense capabilities.

Our national defense is dependent to a large extent on our technical readiness. The military services, therefore, must turn out as many qualified men as quickly as possible. Bryan and Rigney (6) have noted the special problems facing the military, in this connection, such as the short-term availability of manpower and the scarcity of high grade talent. As already noted, some research evidence suggested that programed instruction might reduce the length of time required for training (24). Results were not conclusive, however. Silberman (60) observed that, of seven studies he had seen, only three showed that linear programs took longer than non-linear, while three studies showed no significant differences. Again, previous work also indicated that low ability students might benefit from programed instruction (54), that is, attain a higher level of academic excellence than would be possible without programed instruction. Bryan and Rigney (6) have supported the use of teaching machines for purposes of training low ability individuals and for reducing the length of time required for training. Military managers, themselves, have viewed the teaching machine as holding some promise for solving such training problems (50).

A previous study by Froehlich (28) was directed primarily toward a solution of the time-in-training problem to the neglect of the problem posed by the lack of ability of many of the students. The present study, on the other hand, evaluated the influence of programed instruction on the low ability and "remedial" student, who, as Mowrey and Webb (52) have

shown, were inadequately prepared, poorly motivated, and unable to comprehend the principles of electronics.

Where there are differences in levels of student ability and motivation, some flexibility in training seems to be necessary. As Crawford (15) noted

> ...Heterogeneity of input places particular burdens on a training system which has a rigid output quota to meet on a fixed schedule. Adaptation of training to varieties of aptitude and background characteristics of trainees constitutes a major research problem.

Both Skinner (65) and Crowder (16) have stated that programed instruction allowed an adaptation of training. The question raised in the present study was whether such adaptation gave practical results, that is whether remedial students would benefit more, academically, from programed instruction than from the conventional lecture.

Past research on this question has been inconclusive. Out of fifteen studies comparing programed instruction with the conventional lecture, six showed no differences; nine favored programed instruction on an achievement dimension, while all fifteen showed that programed instruction on the basis of time to completion was superior (60).

Hughes and McNamara (36) were able to show that programed textbooks were superior to conventional classroom instruction. Wong and Douglass (71) felt that one of the reasons many past studies showed significant differences, especially between programed instruction and the conventional lecture, was because conventional instruction was conducted under unfavorable conditions and so almost had to show significant

differences. Using twelve pairs of subjects and a branching program on direct current electricity, these researchers supported their position by demonstrating that there were no significant differences between an automated programed instruction group and a conventional lecture group given optimal conditions for learning.

Programed instruction has several advantages over the conventional lecture apart from those attributed to the implementation of learning theory. Four of the ten offered by Briggs (4) were of especial interest in the present context. Among these advantages were the fact that (a) an expert program writer could reach a number of students, (b) misconceptions held by minimally qualified instructors would not be passed on to students, (c) slow students would not be embarrassed by their lower rate in learning, and (d) good instructors could use their time to better advantage than providing rote drill for students.

CHAPTER II

HYPOTHESES

Theoretical and practical research directions were outlined in Chapter I. Differences between Skinnerian and Crowderian methods of programing subject matter, as summarized in Table 1, indicated that achievement following either form of programed instruction might depend on the intellectual and reading abilities of the learners.

Practical consequences of programed instruction centered around bringing low achievers to a higher level of achievement than was possible with the conventional lecture. The present investigator indicated that little work had been done in relating learner and instructional variables, and that studies comparing several forms of instruction on achievement and time criteria had been inconclusive.

The present study, therefore, tested several hypotheses concerned with the relation between learner and instructional variables. Table 2 outlines the variables referred to in these hypotheses. In testing these hypotheses, an attempt was made to reduce some of the limitations in previous research. These limitations related to the lack of a sufficient number of subjects, the shortness of time of many of the experiments, and the shortness of many of the programs used. It was because of such shortcomings that Gilpin (33) and Finn and Perrin (25) felt that success in

the field of programed instruction had been limited.

The hypotheses, in null form, are:

1a. On both immediate and delayed tests of retention there will be no interactions between ability and instructional method.

1b. There will be no immediate or delayed posttest differences for remedial students who have been subjected to either the programed presentations or the conventional lecture.

2a. Within programed instruction treatments, there will be no immediate posttest differences for persons of varying intelligence.

2b. Within programed instruction treatments, there will be no immediate posttest differences for persons of varying reading comprehension levels.

3a. With time to program completion as the criterion, there will be no ability and method interaction within programed presentations.

3b. With time to program completion as the criterion, there will be no differences between the Skinner and the Crowder presentations.

4a. There will be no interaction between ability and method with achievement on related subject matter as the criterion.

4b. The academic achievement of students who learned under programed instruction will not differ from students who learned under the conventional lecture on related subject matter.

5. There will be no interaction between the form of response required by the program and the form of response required by the criterion test.

6. There will be no relationship between time to complete the programed instruction and academic achievement.

CHAPTER III

SETTING

Subjects

The subjects of this study were 494 naval trainees undergoing remedial instruction. These students had failed an examination given at the end of the second week of the 19-week basic electronics course. They were required to repeat the second week of instruction at night while continuing the third week of instruction during the day. The remedial class met for two hours each of three nights.

In terms of a combination of verbal intelligence (GCT) and arithmetical reasoning (ARI) the remedial students had a mean of 118.38 with a standard deviation of 7.53. This compared to a mean of 122.71 and a standard deviation of 9.61 for a sample of 500 basic electronics students taken from day school classes. Since this latter sample included some of the remedial students in the present study, an appropriate statistical test of the difference between means could not be made. When the means were considered as independent samples, a "t" of 7.59 was significant beyond the .01 level.

Variables

Intelligence

Intelligence in this study was based on a combination of a verbal (GCT) and an arithmetical reasoning (ARI) test. The GCT consisted of

sentence completion items, opposites, and verbal analogies. The ARI contained both arithmetical reasoning and computational items.

Criterion Tests

In order to evaluate the influence of the instructional procedures on achievement, two 30-item criterion tests were constructed. Each test was used alternately as either pretest or posttest. Appendix F reproduced the final two forms of these criterion tests. Each form contained fifteen construction or fill-in items and fifteen multiple choice items. Item analyses were conducted on experimental forms of the criterion tests and consisted of administering one form (S1) to 323 regular basic electronics students and the other form (S2) to the next 345 students. Item statistics were developed on the thirty-six items contained in each experimental form.

The item analysis was based on one suggested by Mosier and McQuitty (51) for getting difficulty and discrimination indices, and was the method used by the testing section of the basic electronics school. The analysis assumed that knowledge of the item and total score on the test were normally distributed. Data were collected on P_u and P_l, the proportion from the upper and lower quarters, respectively, of the total test score distribution. An abac was used which allowed the reading of the difficulty index of the item and the item-test correlation. The item test correlation was based on Chesire, Saffir, and Thurstone's (12) computing diagrams for the tetrachoric correlation coefficient, and used a

graph for which the division of the test score was at the quartile. This gave the proportion of the upper or lower quarter who would pass an item of any given difficulty with any particular r. These diagrams provided the proportions for P_u and P_l for various values of r.

The investigator selected items for the final form of the criterion tests based on the difficulty and discrimination indices. The difficulty index ranged from 0 to 9 indicating the proportion, low to high, that passed the item. The discrimination index had the same range, although an item with a low index indicated poor discrimination. Table 3 presents the data on the items selected.

Data for Kuder-Richardson reliabilities (KR #20) were collected from the remedial students and involved an analysis of the two criterion test forms when used as pretests. Night classes were used for each form. Table 4 summarizes the data for forms S1 and S2. The means of the two forms are also presented and indicate that S1 was a more difficult test than S2. These means were basically a percent transformation of the raw scores.

Davis Reading Test

The Davis Reading Test (18) was chosen because of favorable critical comments in Buros (7) related to high reliability, high correlations with other reading scores and English grades, and ease of administration. Two scores, reading comprehension and reading speed, were obtained within an hour, without separate timing of the parts. These scores were converted

TABLE 3

ITEM CONTENT, DISCRIMINATION, AND DIFFICULTY INDICES
FOR THE FINAL FORM OF THE CRITERION TESTS
BASED ON TWO SAMPLES OF REGULAR STUDENTS

		Form S1 Fill-in		Form S2 Fill-in	
Item	Content	Discrimination	Difficulty	Discrimination	Difficulty
1	Ohm's Law	4	7	2	9
2	Ohm's Law	3	8	4	8
3	Powers of Ten	5	6	4	5
4	Powers of Ten	6	6	5	6
5	Powers of Ten	6	6	5	6
6	Series Circuits	6	6	6	5
7	Series Circuits	7	5	4	8
8	Series Circuits	5	6	6	4
9	Series Circuits	6	4	7	5
10	Series Circuits	4	7	4	8
11	Parallel Circuits	5	7	5	5
12	Parallel Circuits	6	6	5	6
13	Parallel Circuits	4	5	6	6
14	Parallel Circuits	6	6	4	4
15	Parallel Circuits	5	7	6	6
	Subscore mean	5.20	6.13	4.87	6.07
		Multiple choice		Multiple choice	
16	Ohm's Law	5	7	4	7
17	Ohm's Law	5	7	4	8
18	Powers of Ten	4	8	5	7
19	Powers of Ten	6	4	5	4
20	Powers of Ten	4	7	6	7
21	Series Circuits	4	8	5	7
22	Series Circuits	3	8	4	7
23	Series Circuits	3	8	4	7
24	Series Circuits	5	6	5	7
25	Parallel Circuits	5	6	5	6
26	Parallel Circuits	3	5	6	6
27	Parallel Circuits	5	6	5	7
28	Parallel Circuits	4	7	6	7
29	Parallel Circuits	5	6	6	7
30	Parallel Circuits	6	5	5	6
	Subscore mean	4.46	6.53	5.00	6.67
	Total score mean	4.83	6.33	4.93	6.37

TABLE 4

RELIABILITIES OF FORMS S1 AND S2 WHEN USED AS PRETESTS

Pretest Form	N	Reliability[1]	Mean[2]
S1			
Fill-in	180	.69	37.02
Multiple choice	180	.46	51.74
Total	180	.73	45.48
S2			
Fill-in	184	.59	46.88
Multiple choice	184	.61	56.23
Total	184	.74	51.64

[1]Reliability based on Kuder-Richardson formula #20.

[2]Means based on the percent of total items correct.

by the smoothed equi-percentile method described by Flanagan (26) and allowed their direct comparison. The average parallel form reliabilities for 1,096 grade 12 students as given in the manual were .77 for reading comprehension and .85 for reading speed. Form A was used throughout this study.

Means and standard deviations were computed for 500 regular basic electronics students and were similar to those reported in the manual. The reading comprehension (RC) mean and standard deviation were 73.26 and 6.37 respectively; for the reading speed score (RS) these statistics were, respectively, 74.00 and 6.33. Table 5 shows the intercorrelations among the GCT, ARI, IQ, RC, and RS variables. The scores on the Davis were more closely related to GCT than ARI and they were themselves fairly well related. Other aspects of Table 5 were examined in Chapter 4.

TABLE 5

INTERCORRELATIONS, MEANS, AND STANDARD DEVIATIONS FOR INTELLECTUAL, READING, AND ACADEMIC VARIABLES BASED ON A SAMPLE OF 500 REGULAR STUDENTS[1]

	ARI	IQ	WK 3	WK 5	RC	RS	Mean	SD
GCT	21	84	34	31	59	63	61.87	5.80
ARI		83	39	38	32	26	60.85	5.71
IQ			44	41	54	53	122.71	9.61
WK 3				74	28	24	78.19	10.75
WK 5					23	18	74.20	13.12
RC						69	73.26	6.37
RS							74.00	6.33

[1]Decimal points omitted.

Weekly Examinations

Table 6 presents the reliabilities of tests given at the end of the first, third, and fifth weeks of the 19-week basic electronics training program. Extimates of the Kuder-Richardson reliabilities (KR #20) were made using 400 regular basic electronics students and a standard deviation based, in each instance, on about the first 100 students. Data for estimating these reliabilities were furnished by the testing section of the 19-week basic electronics school. The week one (WK 1) test contained twenty-five items on elementary mathematical manipulations and introductory electronics principles. The week 3 (WK 3) test of fifty items covered direct current electricity. The week 5 (WK 5) test also had fifty items and dealt with alternating current electricity. The tests were designed for use in regular classes and had difficulty indices of 7.4 and discrimination indices of 3.4, as defined above.

TABLE 6

ESTIMATES OF THE KUDER-RICHARDSON RELIABILITIES FOR THREE WEEKLY TESTS ADMINISTERED DURING THE 19-WEEK BASIC ELECTRONICS COURSE[1]

Week		
1	3	5
.52	.69 (.60)	.79 (.66)

[1]Figures in parentheses are reliabilities as estimated for the remedial school sample (67).

Time (T)

The time required to complete the programed instruction was recorded in minutes by the instructor as the student handed in his answer sheet. The highest time score possible in a two-hour evening was 120 minutes. About 5 percent of the students did not finish the booklet on any one night. Therefore, minutes were added to the time score in direct proportion to the time it took a student to complete the number of frames already completed. Since students who did not finish the program nevertheless completed better than 90 percent of the frames, the number of minutes added was quite small. This procedure provided an estimate of the time it would have taken a student to finish had he been given more time.

Development of the Instructional Presentations

The linear program used in this study (Appendix B) was a revision of a navy program originally designed for use in a teaching machine (35). The Crowder program (Appendix C) was adapted from an electronics program

used in the Air Force by Crowder and Zachert (17). Both programs covered the same electronics subject matter as was covered in the 19-week navy basic electronics school including Direct Current and Alternating Current electricity. From this material Ohm's Law, Powers of Ten, Series Circuits, and Parallel Circuits were selected for night school adaptation. These were the concepts presented during the second week of instruction which students in the past had found most difficult to learn according to educational specialists of the basic electronics school.

The main ways of insuring that these programs and the conventional lecture were parallel in depth and extent of coverage were by (a) a master schedule which gave an hourly outline of the curriculum, (b) student work books which clearly defined the subject matter under investigation, (c) manuals of instruction which outlined in detail the subject matter covered in class, and (d) familiarity with the existing electronics curriculum possessed by educational specialists.

The completed programs are presented in the appendix. The linear program has 348 frames included in ninty-six pages. The non-linear program contains a total of 167 "correct" frames. Two to five choices are provided for each instructional frame bringing the total number of pages to 423. Answer sheets designed for use with these programs are reproduced in Appendix D and Appendix E.

These programs were given a trial run on men who were waiting to enter the basic electronics school. No additional work was done on the programs since these men experienced no difficulty in going through them.

In attempting to see how "good" the frames were in practice - how many errors were made per frame - the incorrect answers, as taken from the answer sheets of remedial students were tallied for each frame. For each of the three booklets, Skinner and Crowder versions, the average number of errors per frame was estimated and divided by the number of students in each treatment. When this latter result was multiplied by 100 an estimate of the average error rate for the average student was obtained. This error rate, in percent, for nights one, two, and three was 3.74, 3.49, and 4.54, respectively, for the linear program: it was 7.99, 10.80, and 12.29, respectively, for the scrambled booklets. Apparently, then, the Crowder programs were somewhat more difficult from the first to the last booklet.

The differences in difficulty between Skinner and Crowder programs, for the most part, do not reflect differences in the number of pages or the number of frames contained in each program, but differences in consequence of step size. One of the criteria for designing linear programs was low frame error rates (56).

Design

The basic treatment groups were the lecture, Skinner, and Crowder presentations. These treatment groups were randomly assigned to incoming remedial classes using a table of random numbers though there were some restrictions to the assignment process. An equal number of classes was assigned to each treatment group and each treatment group was exposed

an equal number of times to the criterion tests, which were used alternately as pretest and posttest. One form of the test was designated as S1 and the other as S2. A total of twenty-four classes was used.

Table A in Appendix A indicates the schedule of data collection. (a) Scores on the GCT and ARI were collected while the students were in basic training or "boot" camp. (b) The Davis Reading Test was administered three days before students entered the basic electronics day school. (c) The criterion test which was used as the pretest was given at the first meeting of night school just before instruction began. (d) The criterion test used as posttest was administered immediately after the third night of instruction. (e) Two weeks after remedial instruction all subjects were retested with the form of the criterion test which had been used as the posttest.

A preliminary examination of the total criterion test means of the first six classes indicated that these tests were not parallel. A difference between total score means was significant at the .05 level. The investigator therefore decided to consider the S1-S2 order of presentation as one study and the S2-S1 order as a second study. Table 7 summarizes the data on class assignment with respect to the various forms of instruction.

TABLE 7

BREAKDOWN OF SUBJECTS BY CLASS, TREATMENT, AND FORM OF CRITERION TEST ADMINISTERED FIRST (S1 OR S2)

S1

Lecture		Skinner		Crowder	
Class	N	Class	N	Class	N
1	23	3	19	5	7
10	18	12	23	7	13
22	26	18	25	14	22
24	26	20	22	16	22
Total	93		89		64

S2

Lecture		Skinner		Crowder	
Class	N	Class	N	Class	N
4	10	6	14	2	15
8	20	9	13	11	30
13	26	15	28	19	27
17	20	21	27	23	18
Total	76		82		90

CHAPTER IV

ANALYSIS OF THE DATA

This study, as indicated earlier, involved the analysis of two sets of data. Set I was concerned with the analysis of data on students who took the criterion tests in the order of S1-S2. Set 2 considered those students who took the S2 criterion test as the pretest and the S1 criterion test as the posttest. The analysis described in this chapter applied to both sets of data.

Regression Analysis

The basic analyses centered around regression and correlational analyses. Hypotheses one to five might have been considered in an analysis of variance or analysis of covariance framework (70). That is, we might have considered a 3 x 3 fixed treatment design in which the lecture, Skinner, and Crowder presentations were one factor, and "high," medium," and "low" the levels on the second factor. This second factor might have been any one of the independent variables associated with the five hypotheses, e.g., intellectual ability, reading ability, academic ability - either pretest score or Week 1 score. The dependent variables might have included posttest, retention, Week 3, Week 5, and Time scores. Any one, or some combination of independent variables might have served as covariates.

By means of computers, such as the Data Systems 3600 Computer at

Michigan State University, it was possible to consider an approach which was not before practical. This approach, basically one of regression, was more sensitive than the analysis of variance just described in that it used more of the information contained in the data. The approach was also able to handle the problem of unequal sample sizes which in the past has been handled less satisfactorily through the unweighted means analysis suggested by Bendig (2) and Winer (70).

The first problem encountered in handling the data within the regression framework was to decide what independent variables to include. In the analysis of variance or covariance single variables might have been investigated for their effects on the dependent variable, or any number of variables might have been considered in a factorial design for the purpose of analyzing the interactions produced by the single variables. Winer (70) has described the fixed linear model underlying a 3 x 3 factorial design:

$$Y_{ijk} = \mu.. + \gamma_i + \beta_j + \gamma\beta_{ij} + \epsilon_{ijk}$$

where, Y_{ijk} = an observation on element under treatment combination ab.

$\mu..$ = the overall mean.

γ_i = factor a.

β_j = factor b.

$\gamma\beta_{ij}$ = interaction, ab.

ϵ_{ijk} = error.

In the regression analysis followed in the present study another model was used which made it desirable to include more than one independent variable, but only as many variables as would not result in a singular matrix. To include orthogonal independent variables in the model would, on

the one hand, have provided a more sensitive test of a null hypothesis by creating a smaller error term; though on the other hand, it would not have been possible to calculate a regression if the independent variables explained much of the same variation. A description of the regression program provided by the Michigan State University Computer Center (Appendix C of AES Program Description 4) indicated that under conditions when an independent variable was linearly dependent on other independent variables of the same model, possible solutions to the regression were infinite. It would then be necessary to drop at least one of the independent variables from the regression or to combine them into a smaller number of variables.

It was necessary to decide which independent variables would be included in the model. To include intellectual ability, reading comprehension, pretest, and Week 1 grade (which was the measure of prior academic ability) among the independent variables treated here, would not only have been impractical in terms of handling the statistical decisions required in this procedure, but would also have included variables with much common variance. It was therefore decided to select the two best variables from the above group; "best" in terms of predicting the dependent variable, providing the least variance in common with the other independent variable, and having practical significance for training.

Several two variable models were used. One included IQ (GCT + ARI) and the Week 1 grade (WK 1). Another model included reading comprehension (RC) and the pretest (PRT). The first model met the criteria for inclusion

best. The second model was considered because of the hypothesis related to reading comprehension. However, as can be seen from Table 5, RC added little predictive variance over IQ when considering the prediction of WK 3 and WK 5. The second model was less practical than the first since PRT and RC scores were not usually available in the training situation.

The above discussion suggested that IQ and RC should not be included in the same model. When these variables were included, in a trial run, a singular matrix resulted and the computer provided no meaningful output.

The model and the strategy described below held for any two independent variables which were included in it. Thus, reading comprehension (RC), pretest (PRT) or WK 1 scores were substituted as independent variables in the model. The dependent variable, where appropriate, was the total, multiple choice, or fill-in scores of the PTT and retention test (RT) (hypotheses 1, 2, and 5); the dependent variable was also time (hypothesis 3), WK 3 or WK 5 grade (hypothesis 4).

The general model and the decision strategy employed is outlined below with IQ and WK 1 as the independent variables and total PTT as the dependent variable. Table 8 lists the variables used in this and other regression analyses. The fixed linear model was written as follows:

$$Y_{ij} = \alpha_i + \beta_i X_{10_{ij}} + \gamma_i X_{11_{ij}} + \epsilon_{ij}$$

where, i = method.

j = subject.

Y = dependent variable.

$X_{10_{ij}}$ = WK 1 score for the jth subject in the ith treatment.

$X_{11_{ij}}$ = IQ score for the jth subject in the ith treatment.

α = effect due to treatment.

β = effect due to WK 1.

γ = effect due to IQ.

ϵ = error

The hypotheses tested with this model were

$$H_1: \gamma_1 = \gamma_2 = \gamma_3$$

$$H_2: \beta_1 = \beta_2 = \beta_3$$

$$H_3: \alpha_1 = \alpha_2 = \alpha_3$$

In other words, H_1 stated that with respect to IQ the slopes of the three treatment groups were equal (IQ plotted against posttest), or that there was no interaction between IQ and method. H_2 indicated that there was no interaction between WK 1 and method (WK 1 plotted against posttest), and H_3 that there was no main effect due to the methods of instruction. The main effect for treatments represented a three plane plot (one for each treatment) of IQ and WK 1 against posttest. Where the first two hypotheses considered the slopes of the regression lines, H_3 considered their intercepts.

Table 8 lists the lecture, Skinner, and Crowder presentations as variables. These were "dummy" variables, that is, they were included in the regression as either 1 or O, in other words, included in a calculation or not included. With this in mind, the above model was written

$$\begin{aligned} Y_{ij} = {} & \alpha_1 (1,O) + \alpha_2 (1,O) + \alpha_3 (1,O) \\ & + \beta_1 (1,O) X10_{ij} + \beta_2 (1,O) X10_{ij} + \beta_3 (1,O) X10_{ij} \\ & + \gamma_1 (1,O) X11 + \gamma_2 (1,O) X11_{ij} + \gamma_3 (1,O) X11_{ij} + \epsilon_{ij} \end{aligned}$$

to indicate the existence in the model of the interactions between IQ and method, and WK 1 and method.

TABLE 8

VARIABLES USED IN THE REGRESSION ANALYSIS

Variable Number	Variable Name
1	Multiple choice posttest
2	Fill-in posttest
3	Total posttest
4	Multiple choice retest
5	Fill-in retest
6	Total retest
7	Lecture[1]
8	Skinner[1]
9	Crowder[1]
10	Week 1 score
11	Intelligence
12	Reading comprehension
13	Reading speed
14	Multiple choice pretest
15	Fill-in pretest
16	Total pretest
17	Week 3 score
18	Week 5 score
19	Time

[1]Variables 7, 8, and 9 were coded 100, 010, and 001, respectively, for purposes of analysis.

It can be seen that since interactions were built into the model the assumption of additivity could be directly tested. The assumption of linearity of regression was tested by plotting the scores for the independent and dependent variables of each model used in the study, taken two at a time, against each other. The resulting plots were examined for their lack

of apparent linearity. There was no indication as to a lack of linearity.

Some caution was used in the interpretation of results, especially for just significant F-ratios. The above model assumed that the factors, in addition to the treatments, were fixed by the experimenter prior to the conduct of the study. This, of course, could not be accomplished where the factors were test scores, since the test scores were not under the control of the investigator. In addition, no test for homogeneity of variance was made as this would have proven difficult to do; too many tests were already being made on the same data, and there was little that could have been done if the variance were heterogeneous. The investigator assumed that this condition was satisfied through the random assignment of treatments to subjects.[1] There was no physical evidence, such as suggested in Lindquist (44), that a bias in assignment had been involved.

To the variables listed in Table 8 were added six new or "transformed" variables reflecting the interaction between IQ and method and the interaction between WK 1 and method. In computer terms

```
X(21) = X(7) * X(10)
X(22) = X(8) * X(10)
X(23) = X(9) * X(10)

X(24) = X(7) * X(11)
X(25) = X(8) * X(11)
X(26) = X(9) * X(11)
```

where, for example, variable (21) was the product of variable (7) and variable

[1]The analyses related to interactions, main effects, and tests of assumptions were suggested by Dr. Martin Fox of the Michigan State University Statistics Department. Mr. William Rubel, Dr. Walter Stellwagen, and Dr. Einar Hardin were also consulted.

(10). Variables (21) to (23) reflected the WK 1 and method interaction, and variables (24) to (26) the IQ and method interaction.

In computer terminology, the following regression equations, and those similar to these, were developed to test H_1, H_2, and H_3 which related to hypotheses 1, 3, 4, and 5 of this study:

[1] X(3) = Q(X(7)...X(9), X(21)...X(26))* [Ω]
[2] X(3) = Q(X(7)...X(9), X(11), X(21)...X(23))* [ω_1]
[3] X(3) = Q(X(7)...X(10), X(24)...X(26))* [ω_2]
[4] X(3) = Q(X(7)...X(11))* [ω_3]
[5] X(3) = P(X(10), X(11))* [ω_4]

where the variable to the left of the equation was the dependent variable, in this example PTT tot, and those to the right the independent variables.[1] The Q in the equation indicated that the regression was calculated without a constant term, while the P in equation [5] indicated that a constant was calculated.

AES Program Description 4 indicated the test for the effects of two or more variables in a regression. For this test two regressions were calculated, the overall regression and a regression that contained the same variables, except that the independent variables were omitted. This was, in effect, what was done in equations [1] to [5]. Thus, to test for the interaction between IQ and method equations [1] and [2] were used. Equation [2] did not contain the terms related to the interaction between IQ and method, i.e., variables (24) to (26). The first equation provided an error sum of squares (SS_{Ω}), as did the second (SS_{ω_1}). In other words, SS_{Ω}

[1] The dots in the equation represent "inclusive."

indicated how well the full model fit the data, and $SS_{\omega 1}$ indicated how well the hypothesis fit the data. The F statistic took the form

$$F = \frac{(SS_{\omega 1} - SS_{\Omega})/df}{SS_{\Omega}/df}.$$

and indicated how much better the model was than the hypothesis.

If the first null hypothesis, H_1, was accepted, equation [2] was tested against equation [4]; that is, one behaved as if there was no interaction between IQ and method in testing for the interaction between WK 1 and method. If there was a significant interaction between IQ and method the terms related to this interaction were retained. The interaction between WK 1 and method, in the latter instance, was tested by using equations [1] and [3].

If neither interaction was significant a test was made for treatment main effects. Equations [4] and [5] provided the appropriate error terms. With a significant interaction between WK 1 and method a test for treatment main effects would not be meaningful as the difference in treatment effects would obviously be dependent on the WK 1 grade of the student. In addition, the test for main effects assumed homogeneity of regression, which, with significant interactions, would not be supported.

The above strategy was used for two as well as three treatment groups. Hypothesis 2 examined the IQ and RC main effects across programed instruction treatments. Where no interactions existed these main effects were tested by equations of the form

X(3) = P(X(10),X(11))*
X(3) = P(X(10))*

for the IQ main effects, and

$$X(3) = P(X(12), X(16))*$$
$$X(3) = P(X(16))*$$

for the RC main effects. Total PTT was the dependent variable in the above examples. Tests for interaction effects were made again, especially where they were found in the larger model. Where interactions existed, the test for IQ main effects was made with an equation of the form

$$X(3) = Q(X(8)\ldots X(11))*$$
$$X(3) = Q(X(8)\ldots X(10))*$$

The variables included in the above equations are identified in Table 8.

In summary, the first five hypotheses were tested using a linear regression model. Since this model had the interaction between ability and method built in, a test of hypotheses 1a, 3a, and 4a was possible. Since the same model also provided for the testing of main effects, hypotheses 1b, 2a, 2b, 3b, and 4b were also testable.

Hypothesis 5 suggested that students using the construction or the multiple choice programs would do as well on the fill-in part of the posttest as on the multiple choice part of the posttest. If the null hypothesis did not hold one might expect the Skinner subjects to be superior to the Crowder subjects on the fill-in criterion. The Skinner subjects could conceivably be as good as the Crowder subjects on the multiple choice posttest. These possibilities suggested an analysis of treatment main effects with both the fill-in multiple choice parts of the posttest as the dependent variable in a regression analysis. With parallel fill-in and multiple choice

parts of the criterion test a factorial design would have been feasible, with instructional methods as one factor and mode of response as the other factor.

Correlational Analysis

Hypothesis 6 sought the relationship between time and achievement within each treatment group. An International Business Machines 1620 was used to obtain intercorrelational matrices for each treatment group as well as the means and standard deviations for the variables used in the present study. Except for variables 7, 8, and 9, Table 8 lists these variables. All students had scores on these sixteen variables except the conventional lecture group which had no time scores.

CHAPTER V

RESULTS

There are at least two reasons for the inconclusive results found in past studies of programed instruction. One concerns the inadequacy of measurement and design, the other concerns the effectiveness with which the principles of learning were incorporated within the structure of the program. The latter includes the question of whether investigators could duplicate these principles in the classroom with the same meaning as in the laboratory.

Tables 9 to 13 present data related to measurement and design characteristics of the present study. The principles of learning as incorporated in programed sequences are discussed in Chapter VI. Table 9 confirms the unreliability of the criterion tests noted in Chapter III; Tables 10 and 11 indicate significant differences in the WK 1 and WK 2 means for the Lecture, Skinner, and Crowder Treatments. Tables 12 and 13 provide only a suggestion of possible differences in post-treatment means for the three treatment groups, analyses of variance indicating differences between Time (T) means and Retest (RT) means. Tables B to E in Appendix A show the actual means of the pre- and post-treatment variables. These preliminary results provide the context within which the main results were interpreted.

Table 9 was taken from the intercorrelation matrices of Tables H, I, and J of Appendix A, and provides correlational data on the criterion tests. Since the posttest and retest scores were based on the same form of the criterion test, the (PTT) (RT) correlation might serve as a form of test-retest reliability. The total, multiple choice, and fill-in re-test correlations were somewhat lower than the reliabilities shown in Table 4. The correlations between pretest and posttest were also of the same magnitude, except for the very low (PRT mc) (PTT mc) correlation in set 1. The correlations in Table 9, thus, give additional evidence for low reliabilities. Low reliabilities might be one reason why the components of the pretest (mc and fi) did not correlate well with each other, even though they measured the same content.

TABLE 9

CORRELATIONS WITHIN EACH TREATMENT GROUP BETWEEN PART AND TOTAL SCORES OF THE CRITERION TESTS

	Lecture		Skinner		Crowder	
	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
(PRT mc)(PRT fi)	.44	.55	.39	.48	.44	.56
(PRT)(PTT)	.55	.75	.49	.61	.71	.69
(PRT fi)(PTT fi)	.38	.48	.47	.43	.62	.54
(PRT mc)(PTT mc)	.41	.55	.13	.48	.46	.57
(PTT mc)(PTT fi)	.60	.64	.51	.54	.55	.71
(PTT)(RT)	.58	.72	.50	.65	.62	.68
(PTT fi)(RT fi)	.47	.59	.45	.47	.59	.55
(PTT mc)(RT mc)	.47	.66	.38	.56	.47	.59

Tables 10 and 11 indicate that there were significant differences between the Lecture, Skinner, and Crowder means for WK 1 and WK 2 of set 1, and for WK 1 of set 2. Tables 12 and 13 show significant differences for RT fi and T of set 1, and for RT tot, RT mc, RT fi, WK 3, and T of set 2. An F max (69) of 2.37 for the RT fi variances of set 1 was significant at the .02 level; other variances were homogeneous. The two differences in pre-treatment means were probably due to the method of assigning classes to treatments; the remaining means, however, were equal.

TABLE 10

SUMMARY TABLE FOR DIFFERENCES IN MEANS OF PRE-TREATMENT VARIABLES FOR SUBJECTS IN THE LECTURE, SKINNER, AND CROWDER TREATMENTS (SET 1)

Variable	Source of Variation	Df	SS	MS	F
IQ	Treatment	2	217.98	108.99	2.52
	Within	243	10511.02	43.25	
	Total	245			
RS	Treatment	2	128.92	64.46	2.26
	Within	243	6945.26	28.58	
	Total	245			
RC	Treatment	2	133.05	66.58	2.06
	Within	243	7845.96	32.29	
	Total	245			
WK 1	Treatment	2	1104.38	552.19	3.06*
	Within	243	43904.05	180.68	
	Total	245			
WK 2	Treatment	2	665.76	332.88	4.63**
	Within	243	17480.57	71.94	
	Total	245			
PRT tot	Treatment	2	411.12	205.56	1.00
	Within	243	49947.21	205.54	
	Total	245			

TABLE 10--Continued

Variable	Source of Variation	Df	SS	MS	F
PRT mc	Treatment	2	562.84	286.42	1.19
	Within	243	58627.91	241.27	
	Total	245			
PRT fi	Treatment	2	402.80	201.40	.60
	Within	243	82222.99	338.37	
	Total	245			

*p<.05. **p<.025.

TABLE 11

SUMMARY TABLE FOR DIFFERENCES IN MEANS OF PRE-TREATMENT VARIABLES FOR SUBJECTS IN THE LECTURE, SKINNER, AND CROWDER TREATMENTS (SET 2)

Variable	Source of Variation	Df	SS	MS	F
IQ	Treatment	2	89.22	44.61	.64
	Within	245	17001.28	69.39	
	Total	247			
RS	Treatment	2	81.83	40.91	1.57
	Within	245	6394.01	26.10	
	Total	247			
RC	Treatment	2	125.49	62.75	2.42
	Within	245	6363.98	25.98	
	Total	247			
WK 1	Treatment	2	1688.45	844.22	4.89***
	Within	245	42295.64	172.64	
	Total	247			
WK 2	Treatment	2	90.91	45.45	.54
	Within	245	20517.93	83.75	
	Total	247			
PRT tot	Treatment	2	266.65	133.33	.54
	Within	245	61005.03	249.00	
	Total	247			
PRT mc	Treatment	2	53.84	26.92	.09
	Within	245	75965.48	310.06	
	Total	247			
PRT fi	Treatment	2	1170.92	585.46	1.74
	Within	245	82406.55	336.35	
	Total	247			

***p<.01

TABLE 12

SUMMARY TABLE FOR DIFFERENCES IN MEANS
OF POST-TREATMENT VARIABLES FOR SUBJECTS IN THE
LECTURE, SKINNER, AND CROWDER TREATMENTS (SET 1)

Variable	Source of Variation	DF	SS	MS	F
PTT tot	Treatment	2	143.90	71.95	.33
	Within	243	52447.93	215.84	
	Total	245			
PTT mc	Treatment	2	180.77	95.39	.33
	Within	243	71283.17	293.35	
	Total				
PTT fi	Treatment	2	306.86	153.43	.55
	Within	243	68296.45	281.06	
	Total	245			
RT tot	Treatment	2	403.55	201.78	1.07
	Within	243	45965.80	189.16	
	Total	245			
RT mc	Treatment	2	54.56	27.28	.10
	Within	243	64415.43	265.08	
	Total	245			
RT fi	Treatment	2	2293.92	1146.96	4.62**
	Within	243	60375.34	248.46	
	Total	245			
WK 3	Treatment	2	543.21	271.60	2.99
	Within	243	22065.69	90.81	
	Total	245			
WK 5	Treatment	2	572.74	286.37	2.46
	Within	243	28324.47	116.56	
	Total	245			
T	Treatment	1	44241.20	44241.20	21.14****
	Within	151	315965.10	2092.48	
	Total	152			

** $p < .025$.

**** $p < .005$.

TABLE 13

SUMMARY TABLE FOR DIFFERENCES IN MEANS
OF POST-TREATMENT VARIABLES FOR SUBJECTS IN THE
LECTURE, SKINNER, AND CROWDER TREATMENTS (SET 2)

Variable	Source of Variation	Df	SS	MS	F
PTT tot	Treatment	2	1214.56	607.28	2.43
	Within	245	61340	250.37	
	Total	247			
PTT mc	Treatment	2	1261.51	630.75	2.05
	Within	245	75326.72	307.46	
	Total	247			
PTT fi	Treatment	2	1389.25	694.63	2.18
	Within	245	77902.23	317.97	
	Total	247			
RT tot	Treatment	2	1667.77	833.88	3.51*
	Within	245	58263.57	237.81	
	Total	247			
RT mc	Treatment	2	2867.69	1433.85	5.02***
	Within	245	69929.80	285.43	
	Total	247			
RT fi	Treatment	2	3637.43	1818.72	5.94****
	Within	245	74974.25	306.02	
	Total	247			
WK 3	Treatment	2	656.09	328.05	3.23*
	Within	245	24913.90	101.69	
	Total	247			
WK 5	Treatment	2	45.15	22.57	.17
	Within	245	32068.71	130.89	
	Total	247			
T	Treatment	1	21638.00	21638.00	8.17***
	Within	170	450225.30	2648.38	
	Total	171			

* $p < .05$.
*** $p < .01$.
**** $p < .005$.

Main Analyses

The first five hypotheses were tested by the regression analysis outlined in Chapter IV. In essence, that analysis was an analysis of covariance, and used an F statistic of the form

$$F = \frac{(SS_{\omega 1} - SS_{\Omega})/df}{SS_{\Omega}/df}.$$

As was indicated in Table 2, hypotheses of interaction and main effects were tested against several dependent variables (PTT, RT, WK 3, WK 5, T) within two main regression models. One model included IQ and WK 1 as independent variables, the other used PRT and RC. Tables F and G in Appendix A indicate the appropriate sum of squares for the F tests used. Appendix G presents the raw data available on all individuals included in the study.

Hypothesis 1a

On both immediate and delayed tests of retention there will be no interactions between ability and instructional method.

Table 14 shows that the only interaction between ability and instructional method was that between WK 1 and method (PTT tot and PTT mc as dependent variables) for set 2. In other words, the advantage attributed to one method or the other depended on the subject's WK 1 score.

Figure 1 represents the relationship between WK 1 and instructional method. It shows a plot of the regression coefficients of variables included in the regression equation which was used to test for the interaction between WK 1 and method. For the PTT tot dependent variable, this equation,

TABLE 14

TESTS OF SIGNIFICANCE FOR INTERACTIONS BETWEEN ABILITY AND METHOD WITH POSTTEST AND RETEST DEPENDENT VARIABLES (HYPOTHESIS 1a)

Dependent Variable	IQ-Method[1] Interaction		WK 1-Method[2] Interaction		PRT-Method[1] Interaction		RC-Method[2] Interaction	
	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
PTT tot	1.93	.98	.58	3.81**	1.05[a]	.93[a]	2.18	.25
PTT mc	2.33	1.44	.51	3.60*	2.62[2]	2.34[b]	1.23	.19
PTT fi	.72	.57	.28	2.64	1.05[c]	.61[c]	.94	.21
RT tot	1.26	1.94	1.55	1.47				
RT mc	1.87	1.75	.46	1.44				
RT fi	.33	1.24	3.01	.71				

[1] F-ratios with 2/237 df for set 1 and 2/239 df for set 2.

[2] F-ratios with 2/239 df for set 1 and 2/241 df for set 2.

[a] Total pretest-method interaction.

[b] Multiple choice pretest-method interaction.

[c] Fill-in pretest-method interaction.

* $p < .05$.

** $p < .025$.

in computer terminology, was

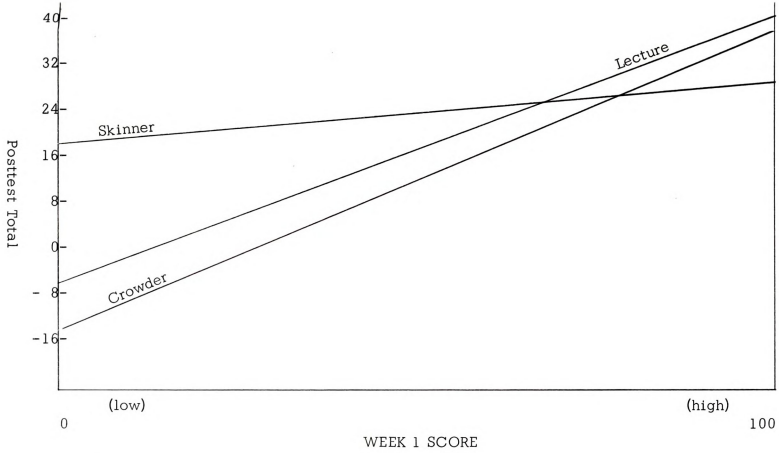
$$X(3) = Q\ (X(7)...X(9), X(11), X(21)...X(23))*,$$

and is the same as equation [2] on page 35. The regression coefficients of the variables included in this equation were

- 7.54579	(Lecture)	(7)
16.54162	(Skinner)	(8)
-13.81762	(Crowder)	(9)
.49373	(WK 1)(Lecture)	(21)
.08428	(WK 1)(Skinner)	(22)
.53467	(WK 1)(Crowder).	(23)

To make the plot for each treatment group, two points were needed: the estimated PTT score for the lowest WK 1 score (taken as 1), and the estimated PTT score for the highest WK 1 score (taken as 100). The first three regression coefficients provided the first point of the Lecture, Skinner, and Crowder methods, respectively. The last three regression coefficients, multiplied by 100 and added to the value of the lowest point, provided the second point. Figure 1, thus, presents the WK 1 - PTT tot plots for the three methods using set 2 data. This figure shows that the Skinner program was best for individuals with low WK 1 scores, while the lecture approach was best for individuals with high WK 1 scores. Figure 2 presents the WK 1 - PTT tot plots for the set 1 data.

A very rough estimate of the same result was obtained by dividing each treatment group into a "high," "average," and "low" WK 1 subgroup. The division was based on the average mean of the three treatments and a range which approximated $\pm$ 1/2 standard deviation. The high subgroup had scores of 74 and above; the low subgroup had scores of 60 and below, and the average subgroup ranged between 61 and 73. Table 15 presents the results and shows the same relationship among treatments as Figures 1 and 2.



[1]The numbers along the ordinate are not the actual PTT tot scores but the regression coefficients for each treatment variable.

FIGURE 1

REPRESENTATION OF THE INTERACTION BETWEEN WK 1 AND METHOD BY PLOTS OF THE TREATMENT REGRESSION COEFFICIENTS WITH PTT tot AS THE DEPENDENT VARIABLE[1] SET 2

TABLE 15

ESTIMATES OF THE PTT tot MEANS FOR HIGH, AVERAGE, AND LOW WK 1 SCORES FOR THE LECTURE, SKINNER, AND CROWDER TREATMENTS

	Lecture		Skinner		Crowder	
	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
High (74 and above)	63.95	63.00	63.27	53.90	65.89	63.62
Average (61 - 73)	58.21	60.30	54.81	52.09	53.96	48.85
Low (60 and below)	51.81	45.88	50.50	51.42	42.40	44.47

Hypothesis 1b

There will be no immediate or delayed posttest differences for remedial students who have been subjected to either the programed presentations or the conventional lecture.

A main effect for method, with the posttest as criterion, was not established in set 2 because of the significant interaction between WK 1 and method that was just noted. There was a treatment main effect in set 2 with the retest criterion. Table 16 shows these results. Table E in Appendix A indicates that on the retest, the Lecture mean was greater than the means for the programed instruction treatments.

TABLE 16

TESTS OF SIGNIFICANCE FOR METHOD MAIN EFFECTS WITH POSTTEST AND RETEST DEPENDENT VARIABLES (HYPOTHESIS 1b)

Dependent Variable	IQ-WK 1 Model		PRT-RC Model	
	Set 1[a]	Set 2[b]	Set 1[a]	Set 2[b]
PTT tot	1.05	____[f]	2.07[c]	2.41[c]
PTT mc	1.39	____[f]	1.19[d]	2.98[d]
PTT fi	.50	1.67	.99[e]	1.11[e]
RT tot	1.51	3.91**		
RT mc	.19	7.18****		
RT fi	5.22***	4.39**		

[a] F-ratios with 2/241 df.

[b] F-ratios with 2/243 df.

[c] Total pretest-RC model.

[d] Multiple choice pretest-RC model.

[e] Fill-in pretest-RC model.

[f] With a significant WK 1 method interaction the test for main effects is not meaningful.

** $p < .025$.

*** $p < .01$.

**** $p < .005$.

Hypothesis 2a

Within programed instruction treatments, there will be no immediate posttest differences for persons of varying intelligence.

This null hypothesis was rejected. The data in Table 17 suggested that a difference in PTT score following programed instruction was dependent on intellectual ability, especially with respect to the more difficult PTT fi subtest.

TABLE 17

TESTS OF SIGNIFICANCE FOR IQ MAIN EFFECTS ACROSS PROGRAMED INSTRUCTION TREATMENTS (HYPOTHESIS 2a)

Dependent Variable	Set 1[a]	Set 2[b]
PTT tot	9.85****	3.84[c]
PTT mc	3.38	.73
PTT fi	11.99****	6.64**

[a] F-ratios with 1/150 df.

[b] F-ratios with 1/167 df for PTT tot and PTT mc, and 1/169 df for PTT fi.

[c] If the interaction between WK 1 and method were disregarded the main effect would be significant at the .05 level.

** $p < .025$.

**** $p < .005$.

Table 18 indicates that high ability individuals had higher PTT tot scores than those of lower ability. The data in Table 18, like those in

Table 15, are only suggestive, and were not suitable for statistical analysis.

TABLE 18

ESTIMATES OF THE PTT tot MEANS FOR HIGH, AVERAGE, AND LOW IQ SCORES FOR THE SKINNER AND CROWDER METHODS

	Skinner		Crowder		Total	
	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
High (122 and above)	61.32	57.15	63.05	59.24	62.12	58.39
Average (115 - 121)	56.11	52.37	56.87	54.82	56.48	53.54
Low (114 and below)	52.00	47.21	50.31	49.77	51.51	48.59

The PRT tot means were grouped in the same manner as the PTT tot means. Table 19 shows that there was only a slight difference in PRT tot for the three ability levels in set 1. This fact, and the greater (and significant) PTT tot differences presented in Table 18, indicated that the high ability subgroup gained more from programed instruction than the low ability subgroup.

The data in set 2 did not reveal similar findings and suggests that performance was related to the form of the criterion test which was administered first. It will be recalled that the less difficult criterion test (S2) was the pretest in set 2, and the more difficult test (S1) the posttest. Thus, when used as either pretest (set 1) or posttest (set 2), the more difficult criterion test did not permit the expression of individual differences.

TABLE 19

ESTIMATES OF THE PRT tot MEANS FOR HIGH, AVERAGE, AND LOW IQ SCORES FOR THE SKINNER AND CROWDER METHODS

	Skinner		Crowder		Total	
	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
High (122 and above)	48.23	56.80	52.74	56.07	50.31	56.37
Average (115 - 121)	48.46	49.12	48.75	52.77	48.60	50.85
Low (114 and below)	50.00	45.47	44.77	46.14	48.40	45.83

Hypothesis 2b

Within programed instruction treatments, there will be no immediate posttest differences for persons of varying reading comprehension levels.

The main RC effects in set 1 were highly significant as Table 20 points out. Thus, while level of reading comprehension did not have a bearing on which form of instruction was superior (Table 14), there was some evidence that achievement was related to level of reading comprehension as measured by the Davis Reading Test.

TABLE 20

TESTS OF SIGNIFICANCE FOR RC MAIN EFFECTS ACROSS PROGRAMED INSTRUCTION TREATMENTS (HYPOTHESIS 2b)

Dependent Variable	Set 1[a]	Set 2[b]
PTT tot	12.39****	.51
PTT mc	5.56**	.25
PTT fi	11.47****	.50

[a] F-ratios with 1/150 df.
** $p < .025$.

[b] F-ratios with 1/169 df.
**** $p < .005$.

Hypothesis 3a

With time to program completion as the criterion, there will be no ability and method interaction within programed presentations.

Table 21 indicates that, with time as the dependent variable, there was no interaction between IQ and method or between WK 1 and method.

TABLE 21

TESTS OF SIGNIFICANCE FOR INTERACTION BETWEEN ABILITY AND FORM OF PROGRAMED INSTRUCTION WITH TIME AS THE DEPENDENT VARIABLE (HYPOTHESIS 3a)

IQ-Method[1] Interaction		WK 1-Method[2] Interaction	
Set 1	Set 2	Set 1	Set 2
.22	.55	.22	.09

[1] F-ratios with 1/147 df for set 1 and 1/166 df for set 2.

[2] F-ratios with 1/148 df for set 1 and 1/167 df for set 2.

Hypothesis 3b

With time to program completion as the criterion, there will be no differences between the Skinner and the Crowder presentations.

As anticipated in Tables 12 and 13, Table 22 shows a significant treatment main effect with respect to time. Tables D and E of Appendix A showed that it took a student longer to proceed through the Skinner than the Crowder program.

TABLE 22

TESTS OF SIGNIFICANCE FOR PROGRAMED INSTRUCTION MAIN EFFECTS WITH TIME AS THE DEPENDENT VARIABLE (HYPOTHESIS 3b)

Set 1[a]	Set 2[b]
17.10***	5.39*

[a] F-ratio with 1/149 df.

[b] F-ratio with 1/168 df.

* $p < .05$.

*** $p < .01$.

It might also be mentioned that there was no IQ main effect, with the time criterion. This was indicated by an F of 2.32 (with 1/150 df) in set 1, and an F of 1.56 (with 1/169 df) in set 2.

Hypothesis 4a

There will be no interaction between ability and method, with achievement on related subject matter as the criterion.

Based on the non-significant F tests in Table 23, the above null hypothesis was accepted.

TABLE 23

TESTS OF INTERACTION BETWEEN IQ AND METHOD WITH ACHIEVEMENT ON RELATED SUBJECT MATTER AS THE DEPENDENT VARIABLE (HYPOTHESIS 4a)

Dependent Variable	IQ-Method[1] Interaction		WK 1-Method[2] Interaction	
	Set 1	Set 2	Set 1	Set 2
WK 3	.64	.35	1.82	1.92
WK 5	1.57	0.00	1.77	1.88

[1]F-ratios with 2/237 df for set 1 and 2/239 df for set 2.

[2]F-ratios with 2/239 df for set 1 and 2/241 df for set 2.

Hypothesis 4b

The academic achievement of students who learned under programed instruction will not differ from students who learned under the conventional lecture on related subject matter.

There were no significant differences among either WK 3 or WK 5 means for the three methods of instruction, as indicated in Table 24.

TABLE 24

TESTS OF SIGNIFICANCE FOR METHOD MAIN EFFECTS WITH ACHIEVEMENT ON RELATED SUBJECT MATTER AS THE DEPENDENT VARIABLE (HYPOTHESIS 4b)

Dependent Variable	Set 1[a]	Set 2[b]
WK 3	.93	1.37
WK 5	.79	.99

[a]F-ratios with 2/241 df.

[b]F-ratios with 2/243 df.

Hypothesis 5

There will be no interaction between the measurement form of the criterion and the form of programed instruction used.

The hypothesis of no interaction between the measurement form of the criterion (mc and fi) and the two forms of programed instruction was not supported under the present technique of testing. The mc and fi means were not equal prior to the period of remedial training (Tables B and C in Appendix A) and could, therefore, not be appropriately analyzed subsequent to training. However, it seemed clear from the insignificant method main effect shown in Table 25 that no interaction existed. Table 25 shows that neither the lecture, Skinner, nor Crowder methods of instruction proved superior when either PTT mc or PTT fi were the dependent variables. The separate analyses of variance conducted on these two dependent variables (Tables 12 and 13) suggested the same result.

TABLE 25

TESTS OF SIGNIFICANCE FOR METHOD MAIN EFFECTS USING PTT mc AND PTT fi AS DEPENDENT VARIABLES (HYPOTHESIS 5)

Dependent Variable	Set 1[a]	Set 2[b]
PTT mc[1]	1.19	2.98
PTT fi[2]	.99	1.11

[a] F-ratios with 2/241 df. [b] F-ratios with 2/243 df.

[1] A dependent variable for a model including RC and PRT mc as independent variables.

[2] A dependent variable for a model including RC and PRT fi as independent variables.

Hypothesis 6

There will be no relationship between time to complete programed instruction and subsequent academic achievement.

The correlations between time to complete programed instruction and achievement on the posttest were negative and non-significant. Tables I and J in Appendix A provide the correlation coefficients.

CHAPTER VI

DISCUSSION

The challenge which some researchers have been trying to meet, seems, has been to discover how closely they could mold human learn to fit sub-human requirements. With the attainment of this goal, the perimenter or teacher could more easily manipulate the behavioral asp of learning than was previously possible. The present research was, part, directed toward an investigation of success in attaining this goa and assumed that linear and non-linear programs of instruction incorp rated the principles of learning developed in the laboratory.

While results of the present investigation indicated that the learn process could not yet be controlled to the extent envisioned by Skinne and Crowder, the results did point to the fact that students were able learn from programed instruction. Unfortunately, neither the high nor low ability remedial students using programed instruction, and those the lecture presentation, achieved at an acceptable level (scores of 8 although the high ability individuals had a greater posttest mean than those of low ability.

It was difficult to reconcile the differences in results between se and set 2, with respect to the RC main effects and the interaction bet WK 1 and method. They might have been due to differences in difficu between the criterion tests, differences between academic performanc

developed by the instructional methods and that required by the criterion tests, or differences as a function of pre-treatment inequalities in WK 1 score. There was no systematic attempt to determine which factor explained the results, although the first factor stood out. A position consonant with that proposed by Skinner (65) would suggest that the interaction between WK 1 and method was primarily due to the fact that the students using the linear program advanced to a common, but low level, of attainment.

The lack of significant results in general, might be viewed in the light of low reliabilities, in addition to the limitations of student assignment and criterion test development. In the present study reliabilities of the total posttest scores were about .74, with the 15-item components even lower. The total reliabilities were somewhat lower than those of .85 reported for typical tests containing between 30 and 50 items (29, 41, 58, 61, 62). As estimated by the Spearman-Brown formula, in this study a 60-item criterion test might have resulted in a test with a reliability of .85.

There were some difficulties in interpretation as a consequence of non-parallel criterion tests and non-parallel subscores within each test. The latter shortcoming found in past studies (13, 21) also restricted the full exploration of the interaction between the measurement form of the criterion and the form of the program. Data suggested that the difference in the RC main effect between set 1 and set 2 was due to the different levels of difficulty of the criterion tests. For example, Table 26 indicates that the more difficult posttest of set 2 placed an upper limit on the academic performance of students within each of the RC levels. On the other hand,

the less difficult posttest of set 1 allowed the expression of individual differences in achievement related to reading ability. Such differences in main effects obtained between set 1 and set 2 pointed to the possibility that the inconsistency in conclusions found among previous studies, was in part, due to the use of criterion tests of unknown but varying levels of difficulty.

TABLE 26

ESTIMATES OF THE PTT tot MEANS FOR HIGH, AVERAGE, AND LOW RC SCORES FOR THE SKINNER AND CROWDER METHODS

	Skinner		Crowder		Total	
	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
High (75 and above)	62.27	55.00	60.91	52.42	61.58	53.49
Average (69 - 74)	54.91	52.46	53.82	55.80	54.54	54.19
Low (73 and below)	51.92	50.57	57.21	56.19	54.26	53.28

Differences between PRT tot and PTT tot for set 1, found in an examination of Tables 18 and 19, suggested that the intellectually able students gained more than the less able. The question raised, in this connection, was why the "high ability" students, and others, did not perform even better than they did. One reason just described, was the difficult posttest, especially in set 2. It was also more likely than not that remedial students reached close to their peak academic performance, regardless of measured intellectual performance. Thus, rather than considering higher

ability remedial students as "underachievers (29)" an equally reasonable proposition, especially in the present study, was that measures of intelligence "overpredicted" students' ability. While achieving somewhat beyond the low ability student, the high ability individual functioned closer to his "real" ability than to his measured ability.

Another question regarding the criterion tasks and their relationship to the research results was raised by the findings. Did the criterion tests measure behavior which the programs were designed to develop? This question did not imply that the content of the criterion and the program differed, but that there was no great transfer of training, as measured by the criterion.[1]

With respect to Skinner-type programs, Briggs, Goldbeck, Campbell, and Nichols (5) indicated that an investigator should not expect even a moderate level of learning of program content which was not elicited during training. Indeed, if the Skinner and Crowder programs emphasized rote learning, and the criterion tests were designed to measure conceptual, analytical, and applied tasks, transfer and measured improvement in performance would be minimal.

As Table 16 showed, there were no method main effects on the post-test criterion. Rather than conclude that there were no treatment differences, it would be more appropriate to conclude that a fair evaluation of possible differences was not made. What was needed for a fair evaluation of method

[1] This point of view was suggested by Dr. M. Ray Denny of the Department of Psychology, Michigan State University.

main effects were criterion tests with a higher ceiling and those which measured the type of academic performance which the programs attempted to develop.

Wong and Douglass (71) suggested one additional reason for a finding of no significant differences among treatment means: the lecture treatment was well presented and organized. This interpretation might have validity in the present study, in as much as the remedial curriculum was highly organized and, according to instructor evaluation reports, well presented.

An interpretation of the interaction between WK 1 and method (set 2) follows the above arguments closely. The interaction may be the consequences of one of several phenomena already mentioned. Reference is made to Figure 1 and Table 15 for another interpretation. The low ability individuals could not organize the subject matter on their own. To the extent that the Skinner program provided this organization, low ability individuals in the Skinner program surpassed those in either the Lecture or Crowder presentations. At the high ability level, individuals in the Crowder and Lecture groups were able to assimilate generalizations provided by the presentations. High ability Skinner students, on the other hand, learned fewer generalizations and relationships, and so could not apply their rote knowledge to the test of transfer which followed.

Because of some superiority in ability, the high ability Skinner students out performed the low ability Lecture and Crowder students. Note that these high ability Skinner individuals in set 1, Table 15, were able

to perform even better on a less difficult posttest; that is, they were not as much restricted by the posttest as the subjects in set 2 were.

Thus, the interaction between WK 1 and method was some function of the low ceiling of the posttest, the applied nature of the posttest, and the rote characteristics of the Skinner program. The minimal Skinner-treatment slope for set 2 in Figure 1, appeared to support a Skinnerian assumption. The assumption was that students using programed instruction would achieve at a common level; in this research, because of the nature of the criterion tests, it was a common but low level of achievement. The set 1 data, however, did not verify this assumption.

The finding of an interaction might also have been a function of pre-treatment inequalities in WK 1 score. The method of assignment did not provide for the level of sophistication which would assure equal means on all significant dimensions. In terms of WK 1, the Skinner group had a significantly lower mean score than the other instructional groups (Table C of Appendix A). The individuals in set 1 also had low WK 1 scores, especially the Lecture and Skinner treatments, but showed no interactions.

No analysis was undertaken to ascertain which set of factors accounted for the interaction between WK 1 and method. The investigator believes that the differences in results between set 1 and set 2 may best be explained by the characteristics of the criterion tests just discussed, i.e., their low ceiling and applied nature.

It was difficult to explain the significant main effect favoring the lecture method on the retest in set 2. In set 1, the only significant difference

occurred on the RT fi criterion; the F test was conducted with heterogeneity of variances (.02 level) and no consideration of a possible interaction between WK 1 and method which was just short of significance at the .05 level. The differences in results were hard to substantiate since there was much uncontrolled variation during the two weeks between the first and second administration of the posttest. All students received the same training between posttest and retest. There was no doubt, though, that differences favoring the Lecture method appeared two weeks after remedial training. These differences were greatest for the fi criterion.

There were clear-cut findings with respect to time (T). It took an average of about 10 percent longer to complete the linear program than the non-linear. One reason for this result is that students had to read all the frames in the linear version, but the brighter students using the non-linear program could skip much of the material. It also took longer to go through the linear program because more writing was involved; this was the difference between constructing an answer and selecting one. This was, of course, not a definitive study of the time dimension and its relationship to programed instruction. Rather, the results show that programed instruction reduced the time usually required for the six hours of remedial instruction.

Tables I and J in Appendix A provide the correlations between time to complete programed instruction and other variables. The negative correlations, of low magnitude, confirmed the findings of past research: higher

ability students take less time to progress through a program than lower ability students. Ruling out an interaction between ability and method, and a significant treatment main effect, the implication of these findings is clear. Educational specialists could design a remedial training program, or any other course of instruction, such that most students would be assigned to programed instruction groups (instead of being required to sit through 360 minutes of the lecture presentation (two hours each of three nights). Each student would progress at his own rate.

The average student, as shown in Tables D and E of Appendix A, completed instruction better than 30 percent quicker than the average student in a lecture group. Some students completed the course even sooner, and were available that much sooner for other activities. It took the fastest student only one hour to complete the six hours of instruction. Students whose estimated completion time for programed instruction was longer than the conventional lecture would be assigned to the conventional lecture, at no loss in academic proficiency.

This research provided little support for a system of differential assignment of students to treatments, such as may be used in making personnel decisions (15). The lack of evidence - for interactions between ability and method - was a consequence not only of the difficult posttest, but also the more limited ability range of remedial students. In fact, the range of measured intellectual ability - IQs of 90 to 149, in this study - may be a phenomenon of poor measuring devices, as already noted. It is hypothesized that the

"real" range of ability in a remedial group is narrower than specified by ability tests.

Perhaps an even larger sample size would have produced method main effects and interactions. Possibly a longer program would have allowed the full potential of programed instruction to be realized. On these points, a study by Campbell (8) which compared programs of three levels of adaptiveness on multiple choice and fill-in criterion tests, showed that each program was equal in teaching effect. His sample included 2,000 students in the fourth through the twelfth grades. Crowder and Zachert (17) evaluated an electronics program of 1600 frames. The study lasted four weeks and showed no differences from a lecture control group.

Most of the studies reported in the literature have used small sample sizes and short programs. While the two studies just mentioned had some favorable characteristics, there were shortcomings. The experimental and control groups in Crowder and Zachert's study contained only 28 subjects. In other words, it does not appear feasible to eliminate all shortcomings in any one study. Thus, there will probably always be some factor, especially in a field experiment, which places a limit on what the investigator can say, or should say, about his data.

In addition to the measurement problem in programed instruction, Roe (56) felt that "...present theories and auto-instructional techniques are inadequate to achieve individualized instruction, and that a usable automated teaching system will require further analytical and hardware development."

The next few paragraphs consider Roe's comment and the theoretical strength of programed instruction, as it relates to practical consequences.

These results invited a serious questioning of the direct application of principles developed in the psychological laboratory to human learning and confirmed past difficulties in assessing this application.

Table 1 indicated that the Skinnerian and Crowderian forms of programed instruction differed, although the principles of learning around which differences in implementation centered were similar. These principles were consistently verified in the laboratory and were demonstrable in rats, pigeons, and dogs by a number of different experimenters. It was shown in the present and previous studies that a direct translation of learning principles to the classroom setting was difficult, in a practical sense. Porter (53) has commented on the difficulty of generalizing results from animal studies to studies concerned with humans. The research results have, thus, been discouraging because of over-conceptualization, improper implementation of learning principles, or, as implied throughout this chapter, poor measurement.

The purpose of the remainder of this section is to review several studies that suggested over-conceptualization; this was certainly one factor which could explain the findings of the present investigation. Since better than 80 percent of the research in programed instruction has used linear programs, these studies deal with the Skinnerian approach.

Although knowledge of results seems to have been particularly advantageous in psychomotor performance (47), investigators reached no clear-

cut conclusions concerning its effectiveness in recent studies in programed instruction. Early studies using the Pressey punch board found that learning was enhanced by immediate knowledge of results (1, 37). There are several reasons why knowledge of results was not effective in studies utilizing linear programs. These reasons relate to the low error rate of linear frames, and the source of reinforcement.

Possibly knowledge of results was not as important to the learner as a "reinforcement" in linear programs as it might have been with a more difficult program sequence. In other words, the satisfying effects were minimal when the students were correct 95 percent of the time. The student knew the answer before confirmation was provided.

A difficulty in studying knowledge of results was that, even without an external source of knowledge of results, there usually was an intrinsic source. As Skinner pointed out (64), completing the task itself was a significant reinforcement. In laboratory studies the intrinsic source was not a confounding variable as in human studies.

In addition to reinforcement and low error rates, Skinner attempted to shape behavior by means of a fixed and logical sequence of instructional frames directed toward the criterion behavior. Recent evidence suggested that the sequence did not have to be fixed, logical, or ordered (43, 48, 49, 55). Mager found that students generated sequences different from those developed by their instructors. It should be pointed out that studies in this area have been limited by the very small number of items included in the program sequence.

Where learning was measured in terms of motor performance, bar pressing, for example, active responding on the part of the subject was reasonable; lower animals are not equipped with other means of communication, and bar-pressing was the behavior being taught. In the laboratory, conditions are such that in order to receive a reinforcement the animal has to trigger the food magazine by responding. In verbal learning by means of programed instruction, the value of active responding seems to be to involve the student in his subject and to draw attention to the appropriate response, rather than to build up the response probability of a single response. But it is begging the question to assume that a one word response is anything more than that; it is certainly a very limited aspect of the terminal behavior being developed.

Since reinforcing, sequencing, and responding have a significance in the laboratory different from that of the classroom, direct application of principles from one environment to the other is limited. Even if this translation were meaningful, present apparatus and programs do not allow faithful duplication of the laboratory principles. And if both translation and duplication were readily effected, investigators would still have to sharpen measurement and design characteristics, especially under practical operating conditions.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The present investigator agrees with Silberman, Coulson, Gunn, and Melaragno (61) that

> ...the appropriate and critical dimensions for specifying the learning task, the teaching method, and the student have not yet been identified. Consequently, there is not a sound basis for exploring relationships between task, method, and student variables as they determine the efficienty of student learning under programed instruction.

There were several reasons for difficulty in identifying the appropriate and critical dimensions of task, method, and student variables in the present study. As indicated in Chapter VI, these reasons related to aspects of measurement and design, the nature of remedial students with respect to measured ability, and limitations in applying laboratory developed principles of learning to students in the classroom. For investigators to define significant aspects of the "instructional gestalt (59)" and make predictions about academic achievement within it, they must provide more meaningful conceptualizations of the learning process and devise more valid instruments for evaluating the outcome of that process.

The Learning Process

The present and previous studies have provided little support for the "homo mechanicus" model of man, developed from insights gained in the animal laboratory, and represented by linear programing. Evidence for the

"homo sapiens" model, as represented by non-linear programing was equally discouraging. In the present study, neither the linear nor non-linear forms of programing provided remedial students with the kind of subject matter organization or development which would allow them to achieve at a level equivalent to their non-remedial fellows. Even those students with high measured intelligence did not perform well, although they performed better than those of low ability. Prior academic ability, intelligence, and reading ability did not interact with the form of subject matter presentation - Lecture, linear, non-linear. The only change brought about by programed instruction was to shorten the time required for training when compared to a conventional lecture. Since little was learned from programed instruction, there was no transfer of advantages to subject matter which followed remedial training.

In spite of the negative results found in the present study, the homo sapiens model seems to have more potential than the homo mechanicus for dealing effectively with learners characterized by a wide range of individual differences in academic achievement, intelligence, and modes of learning. The more flexible branching programs are designed to take into account the initial differences among individuals. Non-linear programs may also be designed to respond more realistically to the needs of the learner as he progresses through the program. A student might find linear programs useful where his reading and verbal skills have not yet matured and where his study habits have not been completely formed.

While the programer incorporates stimulus differentiation and generalization into linear programs to some degree, however unsuccessfully, he neglects other concepts involved in human learning and retention. The programer presumably recognizes and accounts for the effects of proactive and retroactive inhibition by an emphasis on low error rates and repetition of concepts throughout the program. Low error rates, however, do not insure against the accumulation of interferences generated as the student advances through the program. Non-linear programs, on the other hand, provides for some form of branching in recognition of the fact that errors are cumulative throughout learning. Whatever the cause of the errors, either poor communication or inability of the student to discriminate or generalize, the non-linear procedure capitalizes on, rather than overlooks, the kinds of behaviors characteristic of human learning.

In the present study, neither program provided much flexibility in subject matter presentation. In the future investigators should direct more attention toward investigating the various patterns involved in human learning, i.e., the dynamics of acquisition, integration, and retention of verbal material, than emphasizing the application of principles of behavioral control developed in the animal laboratory. Computers might assist in an attempt to integrate past findings in the area of human learning for the purpose of application to program construction and machine presentation. Additional light on human learning might be gained through the use of an artificial subject matter, with computers presenting, modifying, and recording behavior.

The Measurement Process

It is obvious that the outcome of research into the learning process, and its interpretability, depends on the proper application of principles of measurement and design. In the present study, the criterion variables were inappropriate to the tasks being taught by the instructional methods. An adequate evaluation of a theoretical position also depends on the degree to which experimental implementation faithfully reproduces elements of the theoretical model.

Measurement sophistication, as far as programed instruction is concerned, includes (a) adequately developed criterion tests reflecting the tasks taught by the program, (b) adequately designed programs reflecting the process of learning hypothesized by the investigator, and (c) a detailed description of the subjects used in a study on personality, motivational, and ability variables. In order to allow more meaningful interpretation and comparison among several investigations, there should be standardized programs and criterion tests, developed on subjects possessing different patterns of personality, motivation, and ability. The gain in knowledge about human learning stemming from work in programed instruction will certainly be limited, and less meaningful, until a comprehensive and systematic research program is developed. This basic idea is, of course, fundamental to most research, although not always implemented.

APPENDICES

APPENDIX A

SUPPLEMENTARY TABLES A - J

TABLE A

SCHEDULE FOR ADMINISTRATION OF TESTS
AND INSTRUCTIONAL PRESENTATIONS

Class No.	N	Treatment Form	Pretest Date-Form	Posttest Date-Form	Retest Date-Form
1	23	Lecture	Mar 27 S1	Mar 29 S2	Apr 13 S2
2	15	Crowder	Apr 3 S2	Apr 5 S1	Apr 20 S1
3	19	Skinner	Apr 10 S1	Apr 12 S2	Apr 27 S2
4	10	Lecture	Apr 17 S2	Apr 19 S1	May 4 S1
5	7	Crowder	Apr 24 S1	Apr 26 S2	May 11 S2
6	14	Skinner	May 1 S2	May 3 S1	May 18 S1
7	13	Crowder	May 8 S1	May 10 S2	May 25 S2
8	20	Lecture	May 15 S2	May 17 S1	Jun 1 S1
9	13	Skinner	May 28 S2	May 31 S1	Jun 15 S1
10	18	Lecture	Jun 5 S1	Jun 7 S2	Jun 22 S2
11	30	Crowder	Jun 12 S2	Jun 14 S1	Jun 29 S1
12	23	Skinner	Jun 19 S1	Jun 21 S2	Jul 6 S2
13	26	Lecture	Jun 26 S2	Jun 28 S1	Jul 13 S1
14	22	Crowder	Jul 2 S1	Jul 5 S2	Jul 20 S2
15	28	Skinner	Jul 10 S2	Jul 12 S1	Jul 27 S1
16	22	Crowder	Jul 17 S1	Jul 19 S2	Aug 3 S2
17	20	Lecture	Jul 24 S2	Jul 26 S1	Aug 10 S1
18	25	Skinner	Jul 31 S1	Aug 2 S2	Aug 17 S2
19	27	Crowder	Aug 7 S2	Aug 9 S1	Aug 24 S1
20	22	Skinner	Aug 14 S1	Aug 16 S2	Aug 31 S2
21	27	Skinner	Aug 21 S2	Aug 23 S1	Sep 7 S1
22	26	Lecture	Aug 28 S1	Aug 30 S2	Sep 14 S2
23	18	Crowder	Sep 4 S2	Sep 6 S1	Sep 21 S1
24	26	Lecture	Sep 11 S1	Sep 13 S2	Sep 28 S2

TABLE B

MEANS AND STANDARD DEVIATIONS OF PRE-TREATMENT VARIABLES FOR SUBJECTS IN THE LECTURE, SKINNER, AND CROWDER TREATMENTS (SET 1)

	Lecture		Skinner		Crowder	
	Mean	S D	Mean	S D	Mean	S D
IQ	117.60	6.17	117.11	6.49	119.45	7.08
RS	71.80	5.55	72.22	5.12	73.60	5.21
RC	70.83	5.40	71.44	5.53	72.70	6.13
WK 1	64.70*	12.60	66.59	13.51	70.09	14.18
WK 2	52.88**	7.45	54.82	9.04	57.06	8.86
PRT tot	46.58	14.42	49.32	13.05	49.12	15.51
PRT mc	50.89	15.66	54.37	14.30	53.10	16.58
PRT fi	41.12	18.19	43.69	16.77	43.85	20.31

*Difference between means significant at .05 level.

**Difference between means significant at .025.

TABLE C

MEANS AND STANDARD DEVIATIONS OF PRE-TREATMENT VARIABLES FOR SUBJECTS IN THE LECTURE, SKINNER, AND CROWDER TREATMENTS (SET 2)

	Lecture		Skinner		Crowder	
	Mean	S D	Mean	S D	Mean	S D
IQ	119.19	7.84	117.81	8.07	119.51	8.78
RS	73.46	4.70	72.02	5.00	72.88	5.51
RC	72.71	4.91	70.97	4.45	71.83	5.77
WK 1	70.44***	13.31	65.52	11.92	71.28	13.75
WK 2	55.34	8.19	54.01	8.14	54.14	10.49
PRT tot	52.56	15.59	50.14	15.94	52.21	15.62
PRT mc	55.65	19.10	55.29	17.39	57.08	16.71
PRT fi	48.65	17.10	43.30	18.20	46.34	18.80

***Difference between means significant at .01 level.

TABLE D

MEANS AND STANDARD DEVIATIONS OF POST-TREATMENT VARIABLES FOR SUBJECTS IN THE LECTURE, SKINNER, AND CROWDER TREATMENTS (SET 1)

	Lecture		Skinner		Crowder	
	Mean	S D	Mean	S D	Mean	S D
PTT tot	57.59	15.11	55.92	13.31	57.37	15.53
PTT mc	63.06	17.02	61.15	16.11	61.56	18.21
PTT fi	50.78	17.12	49.19	15.53	52.01	17.47
RT tot	64.65	13.16	61.75	11.65	63.89	16.66
RT mc	68.08	16.15	69.14	14.49	68.87	18.29
RT fi	60.29**	15.23	53.25	12.68	57.82	19.54
WK 3	67.83	8.51	68.39	9.24	71.45	10.98
WK 5	62.07	9.88	61.99	10.09	65.51	12.61
T	——a	——a	251.91****	44.31	217.43	46.96

** Difference between means significant at .025 level.

**** Difference between means significant at .005 level.

TABLE E

MEANS AND STANDARD DEVIATIONS OF POST-TREATMENT VARIABLES FOR SUBJECTS IN THE LECTURE, SKINNER, AND CROWDER TREATMENTS (SET 2)

	Lecture		Skinner		Crowder	
	Mean	S D	Mean	S D	Mean	S D
PTT tot	57.86	15.31	52.34	14.06	55.01	17.39
PTT mc	60.86	17.77	55.25	15.40	59.19	19.24
PTT fi	54.06	16.77	48.42	16.79	49.87	18.92
RT tot	63.89*	15.38	59.35	14.44	58.16	15.98
RT mc	64.84***	15.82	65.74	16.67	58.93	17.93
RT fi	61.39	17.55	51.81	17.29	56.14	17.01
WK 3	71.07*	10.34	67.69	9.43	71.52	10.29
WK 5	62.93	12.17	63.57	9.72	64.51	12.37
T	——a	——a	267.51***	44.38	247.67	56.19

[a] Time to complete programed instruction was not applicable to the lecture group.

* Difference between means significant at .05 level.

*** Difference between means significant at .01 level.

**** Difference between means significant at .005 level.

TABLE F.

ERROR SUM OF SQUARES FOR TESTS OF SIGNIFICANCE FOR THE FIRST FIVE HYPOTHESES RELATED TO THE INTERACTION BETWEEN ABILITY AND METHOD, AND INTELLIGENCE, READING ABILITY, AND METHOD MAIN EFFECTS (SET 1)[1]

Hypothesis	Dependent Variable	Test	Error Sum of Squares	Degrees of Freedom	Mean Square	F
1a, 1b	PTT tot	IQ-Method Interaction	SS_{Ω} 42600.12384	237	179.74736	1.93
			$SS_{\omega 1}$ 43294.91272	239		
			$SS_{\omega 1} - SS_{\Omega}$ 694.78888	2	347.39444	
		WK 1-Method Interaction	$SS_{\omega 1}$ 43294.91272	239	181.15026	.58
			$SS_{\omega 3}$ 43504.30635	241		
			$SS_{\omega 3} - SS_{\omega 1}$ 209.39363	2	104.69681	
		Method Main Effects	$SS_{\Omega 3}$ 43504.30635	241	180.59330	1.05
			$SS_{\omega 4}$ 43884.17218	243		
			$SS_{\omega 4} - SS_{\omega 3}$ 379.86583	2	189.93291	
	PTT mc	IQ-Method Interaction	SS_{Ω} 60118.64505	237	253.66517	2.33
			$SS_{\omega 1}$ 61302.49149	239		
			$SS_{\omega 1} - SS_{\Omega}$ 1183.84644	2	591.92322	
		WK 1-Method Interaction	$SS_{\omega 1}$ 61302.49149	239	256.49578	.51
			$SS_{\omega 3}$ 61562.95943	241		
			$SS_{\omega 3} - SS_{\omega 1}$ 260.46794	2	130.23397	

TABLE F -- Continued

Hypothesis	Dependent Variable	Test	Error Sum of Squares	Degrees of Freedom	Mean Square	F
		Method Main Effects	$SS_{\omega 3}$ 61562.95943	241	255.44796	1.39
			$SS_{\omega 4}$ 62275.37146	243		
			$SS_{\omega 4} - SS_{\omega 3}$ 712.41203	2	356.20601	
	PTT fi	IQ-Method Interaction	SS_{Ω} 58109.94289	237	245.18963	.72
			$SS_{\omega 1}$ 58462.43202	239		
			$SS_{\omega 1} - SS_{\Omega}$ 352.48913	2	176.24456	
		WK 1-Method Interaction	$SS_{\omega 1}$ 58462.43202	239	244.61269	.28
			$SS_{\omega 3}$ 58599.19870	241		
			$SS_{\omega 3} - SS_{\omega 1}$ 136.76668	2	68.38334	
		Method Main Effects	$SS_{\omega 3}$ 58599.19870	241	243.15020	.50
			$SS_{\omega 4}$ 58801.38011	243		
			$SS_{\omega 4} - SS_{\omega 3}$ 242.18141	2	121.09070	
	PTT tot	PRT-Method Interaction	SS_{Ω} 32795.63078	237	138.37819	1.05
			$SS_{\omega 1}$ 33085.99919	239		
			$SS_{\omega 1} - SS_{\omega}$ 290.36841	2	145.18420	
		RC-Method Interaction	$SS_{\omega 1}$ 33085.99919	239	138.43514	2.18
			$SS_{\omega 3}$ 33689.26282	241		
			$SS_{\omega 3} - SS_{\omega 1}$ 603.26363	2	301.63181	

TABLE F -- Continued

Hypothesis	Dependent Variable	Test	Error Sum of Squares	Degrees of Freedom	Mean Square	F
		Method Main Effects	$SS_{\omega 3}$ 33689.26282	241	139.78947	2.07
			$SS_{\omega 4}$ 34268.83495	243		
			$SS_{\omega 4} - SS_{\omega 3}$ 579.67213	2	289.83606	
	PTT mc	RC-Method Interaction	SS_{Ω} 60142.94409	237	253.76770	1.23
			$SS_{\omega 1}$ 60766.55817	239		
			$SS_{\omega 1} - SS_{\Omega}$ 311.85704	2	311.85704	
		PRT mc-Method Interaction	$SS_{\omega 1}$ 60766.55817	239	254.25338	2.62
			$SS_{\omega 3}$ 62099.51735	241		
			$SS_{\omega 3} - SS_{\omega 1}$ 1332.95918	2	666.47959	
		Method Main Effects	$SS_{\omega 3}$ 62099.51735[a]	241	257.67435	1.19
			$SS_{\omega 4}$ 62709.95544	243		
			$SS_{\omega 4} - SS_{\omega 3}$ 610.43809	2	305.21904	
	PTT fi	RC-Method Interaction	SS_{Ω} 50009.97139	237	211.01254	.99
			$SS_{\omega 1}$ 50427.70851	239		
			$SS_{\omega 1} - SS_{\Omega}$ 417.73712	2	208.86856	

TABLE F -- Continued

Hypothesis	Dependent Variable	Test	Error Sum of Squares	Degrees of Freedom	Mean Square	F
		PRT fi-Method Interaction	$SS_{\omega 1}$ 50427.70851	239	210.99460	1.05
			$SS_{\omega 3}$ 50871.76169	241		
			$SS_{\omega 3} - SS_{\omega 1}$ 444.05318	2	222.02659	
		Method Main Effects	$SS_{\omega 3}$ 50871.76169	241	211.08615	.99
			$SS_{\omega 4}$ 51290.91243	243		
			$SS_{\omega 4} - SS_{\omega 3}$ 419.15074	2	209.57537	
	RT tot	IQ-Method Interaction	SS_{Ω} 41397.70047	237	174.67384	1.26
			$SS_{\omega 1}$ 41838.69148	239		
			$SS_{\omega 1} - SS_{\Omega}$ 440.99101	2	220.49550	
		WK 1-Method Interaction	$SS_{\omega 1}$ 41838.69148	239	175.05728	1.55
			$SS_{\omega 3}$ 42381.35851	241		
			$SS_{\omega 3} - SS_{\omega 1}$ 542.66703	2	271.33351	
		Method Main Effects	$SS_{\omega 3}$ 42381.35851	241	175.85626	1.51
			$SS_{\omega 4}$ 42911.05867	243		
			$SS_{\omega 4} - SS_{\omega 3}$ 529.70016	2	264.85008	

TABLE F -- Continued

Hypothesis	Dependent Variable	Test	Error Sum of Squares	Degrees of Freedom	Mean Square	F
	RT mc	IQ-Method Interaction	SS_{Ω} 58988.33902	237	248.89594	1.87
			$SS_{\omega 1}$ 59921.17908	239		
			$SS_{\omega 1} - SS_{\Omega}$ 932.84006	2	466.42003	
		WK 1-Method Interaction	$SS_{\omega 1}$ 59921.17908	239	250.71623	.46
			$SS_{\omega 3}$ 60153.78061	241		
			$SS_{\omega 3} - SS_{\omega 1}$ 232.60153	2	116.30076	
		Method Main Effects	$SS_{\omega 3}$ 60153.78061	241	249.60075	.19
			$SS_{\omega 4}$ 60249.75684	243		
			$SS_{\omega 4} - SS_{\omega 3}$ 95.97623	2	47.98811	
	RT fi	IQ-Method Interaction	SS_{Ω} 55659.94754	237	234.85210	.33
			$SS_{\omega 1}$ 55814.07198	239		
			$SS_{\omega 1} - SS_{\Omega}$ 154.12444	2	77.06222	
		WK 1-Method Interaction	$SS_{\omega 1}$ 55814.07198	239	233.53168	3.01
			$SS_{\omega 3}$ 57221.67590	241		
			$SS_{\omega 3} - SS_{\omega 1}$ 1407.60392	2	703.80196	
		Method Main Effects	$SS_{\omega 3}$ 57221.67590	241	237.43434	5.22
			$SS_{\omega 4}$ 59701.45450	243		
			$SS_{\omega 4} - SS_{\omega 3}$ 2479.77860	2	1239.88930	

TABLE F -- Continued

Hypothesis	Dependent Variable	Test	Error Sum of Squares	Degrees of Freedom	Mean Square	F
2a	PTT tot	IQ Main Effects	SS_{Ω} 23407.64533	150	156.05100	9.85***
			$SS_{\omega 1}$ 24945.04856	151		
			$SS_{\omega 1} - SS_{\Omega}$ 1537.40329	1	1537.40329	
	PTT mc	IQ Main Effects	SS_{Ω} 35968.90302	150	239.79269	3.38
			$SS_{\omega 1}$ 36780.24509	151		
			$SS_{\omega 1} - SS_{\Omega}$ 811.34207	1	811.34207	
	PTT fi	IQ Main Effects	SS_{Ω} 32691.14940	150	217.94100	11.99****
			$SS_{\omega 1}$ 35306.30043	151		
			$SS_{\omega 1} - SS_{\Omega}$ 2615.15103	1	2615.15103	
2b	PTT tot	RC Main Effects	SS_{Ω} 18512.44856	150	123.41632	12.39****
			$SS_{\omega 1}$ 20041.20688	151		
			$SS_{\omega 1} - SS_{\Omega}$ 1528.75832	1	1528.75832	
	PTT mc	RC Main Effects	SS_{Ω} 32100.11934	150	214.00080	5.56**
			$SS_{\omega 1}$ 33290.94408	151		
			$SS_{\omega 1} - SS_{\Omega}$ 1190.82474	1	1190.82474	
	PTT fi	RC Main Effects	SS_{Ω} 27539.84129	150	183.59894	11.47****
			$SS_{\omega 1}$ 29645.99299	151		
			$SS_{\omega 1} - SS_{\Omega}$ 2106.15170	1	2106.15170	

TABLE F -- Continued

Hypothesis	Dependent Variable	Test	Error Sum of Squares		Degrees of Freedom	Mean Square	F
3a, 3b	T	IQ-Method Interaction	SS_{Ω}	298038.9260	147	2027.4757	.22
			$SS_{\omega 1}$	298478.7205	148		
			$SS_{\omega 1} - SS_{\Omega}$	439.7945	1	439.7945	
		WK 1-Method Interaction	$SS_{\omega 1}$	298478.7205	148	2016.7481	.22
			$SS_{\omega 3}$	298921.4456	149		
			$SS_{\omega 3} - SS_{\omega 1}$	442.7251	1	442.7251	
		Method Main Effects	$SS_{\omega 3}$	298921.4456	149	2006.1842	17.10***
			$SS_{\omega 4}$	333231.7688	150		
			$SS_{\omega 4} - SS_{\omega 3}$	34310.3232	1	34310.3232	
4a, 4b	WK 3	IQ-Method Interaction	SS_{Ω}	17299.95654	237	72.99560	.64
			$SS_{\omega 1}$	17392.63055	239		
			$SS_{\omega 1} - SS_{\Omega}$	92.67401	2	46.33700	
		WK 1-Method Interaction	$SS_{\omega 1}$	17392.63055	239	72.77251	1.82
			$SS_{\omega 1}$	17657.94370	241		
			$SS_{\omega 3} - SS_{\omega 1}$	265.31315	2	132.65657	
		Method Main Effects	$SS_{\omega 3}$	17657.94370	241	73.26948	.93
			$SS_{\omega 4}$	17793.44928	243	67.75279	
			$SS_{\omega 4} - SS_{\omega 3}$	135.50558	2		

TABLE F -- Continued

Hypothesis	Dependent Variable	Test	Error Sum of Squares		Degrees of Freedom	Mean Square	F
	WK 5	IQ-Method Interaction	SS_{Ω}	22767.23761	237	96.06429	1.57
			$SS_{\omega 1}$	23069.11928	239		
			$SS_{\omega 1} - SS_{\Omega}$	301.88167	2	150.94083	
		WK 1-Method Interaction	$SS_{\omega 1}$	23069.11928	239	96.52321	1.77
			$SS_{\omega 3}$	23410.85368	241		
			$SS_{\omega 3} - SS_{\omega 1}$	341.73440	2	170.86720	
		Method Main Effects	$SS_{\omega 3}$	23410.85368	241	97.14047	.79
			$SS_{\omega 4}$	23564.26283	243		
			$SS_{\omega 4} - SS_{\omega 3}$	153.40915	2	76.70457	

[1] The form of the F- test for which these are the error sum of squares and the mechanics behind the tests of significance are presented on pages 30 to 37.

[a] This is also the error sum of squares for hypothesis 5.

** $p < .025$.

*** $p < .01$.

**** $p < .005$.

TABLE G

ERROR SUM OF SQUARES FOR TESTS OF SIGNIFICANCE FOR THE FIRST FIVE HYPOTHESES RELATED TO THE INTERACTION BETWEEN ABILITY AND METHOD AND INTELLIGENCE, READING ABILITY, AND METHOD MAIN EFFECTS (SET 2)[2]

Hypothesis	Dependent Variable	Test	Error Sum of Squares		Degrees of Freedom	Mean Square	F
1a, 1b	PTT tot	IQ-Method Interaction	SS_{Ω}	49900.53607	239	208.78885	.98
			$SS_{\omega 1}$	50308.53960	241		
			$SS_{\omega 1} - SS_{\Omega}$	408.00353	2	204.00176	
		WK 1-Method Interaction	$SS_{\omega 1}$	50308.53960	241	208.74913	3.81**
			$SS_{\omega 3}$	51897.29480	243		
			$SS_{\omega 3} - SS_{\omega 1}$	1588.75520	2	794.37760	
		Method Main Effects	---a				
	PTT mc	IQ-Method Interaction	SS_{Ω}	64012.89760	239	267.83639	1.44
			$SS_{\omega 1}$	64785.26602	241		
			$SS_{\omega 1} - SS_{\Omega}$	772.36842	2	386.18421	
		WK 1-Method Interaction	$SS_{\omega 1}$	64785.26602	241	268.81853	3.60*
			$SS_{\omega 3}$	66718.93608	243		
			$SS_{\omega 3} - SS_{\omega 1}$	1933.67006	2	966.83503	
		Method Main Effects	---a				

TABLE G -- Continued

Hypothesis	Dependent Variable	Test	Error Sum of Squares		Degrees of Freedom	Mean Square	F
	PTT fi	IQ-Method	SS_{Ω}	64927.68088	239	270.67962	.57
		Interaction	$SS_{\omega 1}$	65233.78874	241		
			$SS_{\omega 1} - SS_{\Omega}$	306.10786	2	153.05393	
		WK 1-Method	$SS_{\omega 1}$	65233.78874	241	270.67962	2.64
		Interaction	$SS_{\omega 3}$	66662.62097	243		
			$SS_{\omega 3} - SS_{\omega 1}$	1428.83223	2	714.41611	
		Method Main	$SS_{\omega 3}$	66662.62097	243	274.33177	1.67
		Effects	$SS_{\omega 4}$	67581.04103	245		
			$SS_{\omega 4} - SS_{\omega 3}$	918.42006	2	459.21003	
	PTT tot	PRT-Method	SS_{Ω}	32051.60358	239	134.10713	.93
		Interaction	$SS_{\omega 1}$	32750.59740	241		
			$SS_{\omega 1} - SS_{\Omega}$	248.99382	2	124.49691	
		RC-Method	$SS_{\omega 1}$	32750.59740	241	135.89459	.25
		Interaction	$SS_{\omega 3}$	32818.22450	243		
			$SS_{\omega 3} - SS_{\omega 1}$	67.62710	2	33.81355	
		Method Main	$SS_{\omega 3}$	32818.22450	243	135.05442	2.41
		Effects	$SS_{\omega 4}$	33468.85437	245		
			$SS_{\omega 4} - SS_{\omega 3}$	650.62987	2	325.31493	

TABLE G -- Continued

Hypothesis	Dependent Variable	Test	Error Sum of Squares		Degrees of Freedom	Mean Square	F
	PTT mc	RC-Method	SS_{Ω}	48976.62416	239	204.92311	.19
		Interaction	$SS_{\omega 1}$	49056.06596	241		
			$SS_{\omega 1} - SS_{\Omega}$	79.44180	2	39.72090	
		PRT mc-Method	$SS_{\omega 1}$	49056.06596	241	203.55214	2.34
		Interaction	$SS_{\omega 3}$	50007.44463	243		
			$SS_{\omega 3} - SS_{\omega 1}$	951.37867	2	475.68933	
		Method Main	$SS_{\omega 3}$	50007.44463[b]	243	205.79120	2.98
		Effects	$SS_{\omega 4}$	51235.31816	245		
			$SS_{\omega 4} - SS_{\omega 3}$	1227.87353	2	613.93676	
	PTT fi	RC-Method	SS_{Ω}	57915.78061	239	242.32544	.21
		Interaction	$SS_{\omega 1}$	58020.77591	241		
			$SS_{\omega 1} - SS_{\omega}$	104.99530	2	52.49765	
		PRT fi-Method	$SS_{\omega 1}$	58020.77591	241	240.75011	.61
		Interaction	$SS_{\omega 3}$	58314.39999	243		
			$SS_{\omega 3} - SS_{\omega 1}$	293.62408	2	146.81204	
		Method Main	$SS_{\omega 3}$	58314.39999[b]	243	239.97695	1.11
		Effects	$SS_{\omega 4}$	58849.19116	245		
			$SS_{\omega 4} - SS_{\omega 3}$	534.79117	2	267.39558	

TABLE G -- Continued

Hypothesis	Dependent Variable	Test	Error Sum of Squares		Degrees of Freedom	Mean Square	F
	RT tot	IQ-Method Interaction	SS_{Ω}	48045.60523	239	201.02764	1.94
			$SS_{\omega 1}$	48825.16232	241		
			$SS_{\omega 1} - SS_{\Omega}$	779.55709	2	389.77854	
		WK-1 Method Interaction	$SS_{\omega 1}$	48825.16232	241	202.59403	1.47
			$SS_{\omega 3}$	49420.12039	243		
			$SS_{\omega 3} - SS_{\omega 1}$	594.95807	2	297.47903	
		Method Main Effects	$SS_{\omega 3}$	49420.12039	243	203.37498	3.91**
			$SS_{\omega 4}$	51011.82707	245		
			$SS_{\omega 4} - SS_{\omega 3}$	1591.70668	2	795.85334	
	RT mc	IQ-Method Interaction	SS_{Ω}	61813.33281	239	258.63319	1.75
			$SS_{\omega 1}$	62719.88115	241		
			$SS_{\omega 1} - SS_{\Omega}$	906.54834	2	453.27417	
		WK 1-Method Interaction	$SS_{\omega 1}$	62719.88115	241	260.24847	1.44
			$SS_{\omega 3}$	63469.31767	243		
			$SS_{\omega 3} - SS_{\omega 1}$	749.43652	2	374.71826	
		Method Main Effects	$SS_{\omega 3}$	63469.31767	243	261.19061	7.18****
			$SS_{\omega 4}$	67219.26579	245		
			$SS_{\omega 4} - SS_{\omega 3}$	3749.94812	2	1874.97406	

TABLE G -- Continued

Hypothesis	Dependent Variable	Test	Error Sum of Squares		Degrees of Freedom	Mean Square	F
	RT fi	IQ-Method Interaction	SS_{Ω}	63044.73494	239	263.78550	1.24
			$SS_{\omega 1}$	63697.11865	241		
			$SS_{\omega 1} - SS_{\Omega}$	652.38371	2	326.19185	
		WK 1-Method Interaction	$SS_{\omega 1}$	63697.11865	241	264.30340	.71
			$SS_{\omega 3}$	64074.90616	243		
			$SS_{\omega 3} - SS_{\omega 1}$	377.78751	2	188.89375	
		Method Main Effects	$SS_{\omega 3}$	64074.90616	243	263.68274	4.39**
			$SS_{\omega 4}$	66390.13259	245		
			$SS_{\omega 4} - SS_{\omega 3}$	2315.22643	2	1157.61321	
2a	PTT tot	IQ Main Effects	SS_{Ω}	36369.00343[c]	167	217.77846	3.84
			$SS_{\omega 2}$	37207.24955	168		
			$SS_{\omega 2} - SS_{\Omega}$	838.24612	1	838.24612	
	PTT mc	IQ Main Effects	SS_{Ω}	44794.58839[c]	167	268.23107	.73
			$SS_{\omega 2}$	44991.43340	168		
			$SS_{\omega 2} - SS_{\Omega}$	196.84501	1	196.84501	
	PTT fi	IQ Main Effects	SS_{Ω}	49153.42141	169	290.84865	6.64**
			$SS_{\omega 2}$	51086.38367	170		
			$SS_{\omega 2} - SS_{\Omega}$	1932.96226	1	1932.96226	

TABLE G -- Continued

Hypothesis	Dependent Variable	Test	Error Sum of Squares		Degrees of Freedom	Mean Square	F
2b	PTT tot	RC Main Effects	SS_{Ω}	24994.44508	169	147.89612	.51
			$SS_{\omega 1}$	25070.23852	170		
			$SS_{\omega 1} - SS_{\Omega}$	75.79344	1	75.79344	
	PTT mc	RC Main Effects	SS_{Ω}	34043.34853	169	201.43993	.25
			$SS_{\omega 1}$	34093.18535	170		
			$SS_{\omega 1} - SS_{\Omega}$	49.83682	1	49.83682	
	PTT fi	RC Main Effects	SS_{Ω}	37285.72196	169	220.62557	.50
			$SS_{\omega 1}$	37395.96353	170		
			$SS_{\omega 1} - SS_{\Omega}$	110.24157	1	110.24157	
3a, 3b	T	IQ-Method Interaction	SS_{Ω}	439579.1382	166	2648.0671	.55
			$SS_{\omega 1}$	440998.2222	167		
			$SS_{\omega 1} - SS_{\Omega}$	1419.0840	1	1419.0840	
		WK 1-Method Interaction	$SS_{\omega 1}$	440998.2222	167	2640.7079	.09
			$SS_{\omega 3}$	441239.0588	168		
			$SS_{\omega 3} - SS_{\omega 1}$	240.8366	1	240.8366	
		Method Main Effects	$SS_{\omega 3}$	441239.0588	168	2626.4230	5.39*
			$SS_{\omega 4}$	455391.3469	169		
			$SS_{\omega 4} - SS_{\omega 3}$	14152.2881	1	14152.2881	

TABLE G -- Continued

Hypothesis	Dependent Variable	Tests	Error Sum os Squares		Degrees of Freedom	Mean Square	F
4a, 4b	WK 3	IQ-Method Interaction	SS_{Ω}	21387.17651	239	89.48609	.35
			SS_{ω_1}	21449.55841	241		
			$SS_{\omega_1} - SS_{\Omega}$	62.38190	2	31.19095	
		WK 1-Method Interaction	SS_{ω_1}	21449.55841	241	89.00232	1.92
			SS_{ω_3}	21791.68301	243		
			$SS_{\omega_3} - SS_{\omega_1}$	342.12460	2	171.06230	
		Method Main Effects	SS_{ω_3}	21791.68301	243	89.67771	1.37
			SS_{ω_4}	22036.52301	245		
			$SS_{\omega_4} - SS_{\omega_3}$	244.85000	2	122.42500	
	WK 5	IQ-Method Interaction	SS_{Ω}	27041.82381	239	113.14570	0.00
			SS_{ω_1}	27044.06867	241		
			$SS_{\omega_1} - SS_{\Omega}$	2.24486	2	1.12243	
		WK 1-Method Interaction	SS_{ω_1}	27044.06867	241	112.21605	1.88
			SS_{ω_3}	27466.41147	243		
			$SS_{\omega_3} - SS_{\omega_1}$	422.34280	2	211.17140	
		Method Main Effects	SS_{ω_3}	27466.41147	243	113.03049	.99
			SS_{ω_4}	27690.58106	245		
			$SS_{\omega_4} - SS_{\omega_3}$	224.16959	2	112.08479	

[1] The form of the F- test for which these are the error sum of squares and the mechanics behind the tests of significance are presented on pages 30 to 37.

TABLE G -- Continued

[a]Method main effects were not tested because of the significant WK 1-Method interaction.

[b]This is also the error sum of squares for Hypothesis 5.

[c]The error sum of squares for a model in which the WK 1-Method interaction was significant at the .05 level.

*$p < .05$.

**$p < .025$.

****$p < .005$.

TABLE H

INTERCORRELATIONS AMONG INTELLECTUAL, READING, ACADEMIC, AND CRITERION VARIABLES FOR STUDENTS IN THE LECTURE TREATMENT[1]

	IQ	RC	RS	PRT mc	PRT fi	PRT tot	PTT mc	PTT fi	PTT tot	RT mc	RT fi	RT tot	WK 1	WK 2	WK 3	WK 5
IQ		38	46	24	16	25	-04	10	03	-01	09	04	08	08	07	05
RC	46		84	08	16	15	03	19	13	21	09	18	09	01	18	10
RS	48	74		14	18	19	17	24	23	24	08	19	13	00	11	16
PRT mc	13	02	03		44	83	41	42	45	28	38	39	39	28	46	37
PRT fi	23	05	06	55		85	39	38	43	32	44	45	26	12	37	34
PRT tot	20	04	06	90	85		50	50	55	36	50	51	40	23	52	44
PTT mc	17	-00	03	72	59	75		60	89	47	39	51	27	38	45	49
PTT fi	19	06	04	56	48	60	64		89	40	47	52	24	34	44	44
PTT tot	19	04	04	72	59	75	92	89		49	48	58	28	41	51	52
RT mc	10	08	-02	58	52	62	66	53	67		44	86	22	31	37	33
RT fi	29	22	22	47	37	47	52	59	62	60		84	36	32	49	42
RT tot	24	19	13	58	49	61	66	64	72	86	90		34	38	51	44
WK 1	20	11	-03	46	38	48	40	44	46	37	38	43		25	30	42
WK 2	22	05	07	54	24	47	45	34	45	39	23	33	29		37	14
WK 3	21	05	09	57	56	65	62	58	66	44	41	48	49	49		54
WK 5	16	11	09	61	48	63	53	52	59	51	39	48	45	43	62	

[1]Set 1 is above the diagonal (N=93), set 2 is below the diagonal (N=76). For significance at the .05 level, correlation coefficients of .20 and .22 are required, respectively.

TABLE I

INTERCORRELATIONS AMONG INTELLECTUAL, READING, ACADEMIC, AND CRITERION VARIABLES FOR STUDENTS TAKING THE SKINNER PROGRAM[1]

	IQ	RC	RS	PRT mc	PRT fi	PRT tot	PTT mc	PTT fi	PTT tot	RT mc	RT fi	RT tot	WK 1	WK 2	WK 3	WK 5	T
IQ		40	58	-08	-04	-07	13	31	25	03	05	04	23	12	15	12	-10
RC	48		79	-09	-01	-07	21	26	28	-02	09	04	05	09	19	12	17
RS	47	75		00	-09	-10	09	19	16	-03	16	07	07	15	13	10	01
PRT mc	20	12	07		39	77	13	17	18	23	25	28	18	29	22	16	-43
PRT fi	38	30	26	48		86	52	47	57	46	38	49	31	43	54	44	-37
PRT tot	28	15	08	82	75		43	40	49	46	41	51	29	46	49	39	-47
PTT mc	23	06	-06	48	44	57		51	87	38	35	42	39	34	53	30	-11
PTT fi	28	12	-04	45	43	50	54		85	33	45	45	34	37	52	47	-22
PTT tot	29	10	-06	52	50	61	86	89		41	45	50	41	40	62	41	-19
RT mc	24	05	02	59	47	58	56	51	60		50	88	22	22	49	46	-17
RT fi	35	02	-02	43	48	51	43	47	51	48		84	04	37	44	42	-16
RT tot	35	04	00	59	56	63	57	57	65	86	86		15	33	54	51	-19
WK 1	26	18	04	15	13	15	11	10	11	14	19	19		26	46	30	-25
WK 2	05	-01	01	35	32	44	25	17	24	25	18	25	08		35	26	-22
WK 3	26	11	15	26	52	41	32	39	41	37	54	53	26	25		58	-17
WK 5	17	18	03	41	54	52	37	53	52	38	40	46	23	19	47		-09
T	-17	-09	-32	-20	-39	-30	-12	-12	-14	-18	-20	-22	-01	-24	-32	-19	

[1] Set 1 is above the diagonal (N=89), set 2 below the diagonal (N=82). For significance at the .05 level, correlation coefficients of .21 and .22 are required, respectively.

TABLE J

INTERCORRELATIONS AMONG INTELLECTUAL, READING, ACADEMIC, AND CRITERION VARIABLES FOR STUDENTS TAKING THE CROWDER PROGRAM[1]

	IQ	RC	RS	PRT mc	PRT fi	PRT tot	PTT mc	PTT fi	PTT tot	RT mc	RT fi	RT tot	WK 1	WK 2	WK 3	WK 5	T
IQ		52	50	13	33	29	38	38	43	31	20	28	30	18	33	38	-17
RC	46		83	-09	14	05	09	15	14	-02	04	03	06	-17	16	12	06
RS	54	86		-10	20	08	11	31	23	-00	07	05	19	-07	20	10	-07
PRT mc	30	09	13		44	81	46	49	55	46	32	42	36	33	52	58	-06
PRT fi	18	-03	07	56		88	49	62	63	50	39	50	36	37	62	50	-28
PRT tot	27	03	11	86	90		57	67	71	57	43	56	43	42	68	64	-22
PTT mc	14	-02	05	57	54	63		55	88	47	29	42	45	61	54	61	-22
PTT fi	26	-07	-06	57	54	63	71		88	62	59	68	42	47	57	53	-15
PTT tot	22	-05	-00	63	60	69	92	93		62	49	62	50	60	63	65	-20
RT mc	10	-09	-08	54	50	59	59	57	63		61	89	32	37	55	54	-12
RT fi	22	04	07	60	38	54	56	55	60	68		90	23	29	28	35	02
RT tot	18	-03	-00	62	48	62	63	62	68	92	91		31	37	47	49	-06
WK 1	38	21	20	44	44	50	48	40	47	41	34	42		33	54	50	-18
WK 2	37	-01	04	52	50	59	50	55	58	44	42	48	42		35	30	-37
WK 3	17	-14	-08	48	47	54	53	45	54	42	46	46	27	47		73	-34
WK 5	24	12	09	54	51	39	49	52	57	62	59	66	45	44	50		-09
T	-06	18	05	-08	-30	-23	-13	-10	-13	-21	02	-10	-06	-24	-32	-05	

[1]Set 1 is above the diagonal (W=64), set 2 is below the diagonal (N=90). For significance at the .05 level, correlation coefficients of .24 and .21 are required, respectively.

APPENDIX B

SKINNER PROGRAM

OHM'S LAW AND POWERS OF TEN

1-S



NAVAL AIR TECHNICAL TRAINING COMMAND

Acknowledgements

This program was adapted by the Naval Air Technical Training Center, Memphis, Tennessee, from a larger one developed under contract No. N 61339-1000 between the U.S. Naval Training Device Center and Teaching Machines, Inc. In a letter dated 29 December, 1961 from the U.S. Naval Training Device Center, unrestricted use of this material by any governmental agency was confirmed. Appreciation is expressed to the U.S. Naval Training Device Center and to Teaching Machines, Inc. for assistance in making the original program available.

OHM'S LAW and POWERS OF TEN

1. If your answer to a question is a single word, you will see a single line, like this: _____

   George Washington was the first president of the United _____ .

2. If your answer is two words, you will see two lines: _____ _____

   George Washington was the first president of the _____ _____ .

3. If your answer to a question is in your own words, you will see a dashed line: ----------

   Who was the first President? ----------

   What did he chop down? ----------

4. When the answer is a number, symbol, or letter, it is marked like this: ( )

5. A multiple choice question has a series of items separated by slashes.

   George Washington was the (1st/2nd/3rd) president.

6. Some questions are test questions. The answer is not given, but you will see the word "TEST" where the answer should be.

The steps in this program are fixed so that you should be right most of the time. If you are doubtful about how to answer a question, read the whole step over. It is important that you read and understand every word of instruction before you answer. The answer to the question is on the next page. For the answer to any question coming at the end of the book, turn the page -- and then turn the book upside-down. The answer to your question will be in the appropriate answer space. Continue as usual. If you write a wrong answer, study the correct answer carefully. Compare the incorrect response with the correct one. Careful comparison of answers will help you to move smoothly through the entire course. Always read the answer in the answer frame. Do not neglect or rush by the answer frame, even though you may feel certain that your answer is correct. COMPARE.

1.

Georg Simon Ohm was the first man to study resistance, and the unit of resistance is named for him.

Units of R are called _____.

---

35. Answer

current and voltage (either order)

36.

Ohm's Law in symbols states $I = \frac{(\quad)}{(\quad)}$.

---

71. Answer (E)
(I)
(R)

72.

Here is an important word you should know: "ampere" (AM-peer).

One coulomb passing a point in 1 second equals 1 ampere.

How many electrons flowing past a point in 1 second equal an ampere? ( )

---

107. Answer

10^2

108.

$(2 \times 10^1)\ (3 \times 10^4) = 6 \times 10^5$, because $2 \times 3 = 6$ and $10^1 \times 10^4 = 10^5$.

We check the answer by changing the numbers back to the originals.

$(2 \times 10^1)\ (3 \times 10^4) = (20)\ (30{,}000) = (\quad)$ $\qquad$ $600{,}000 = 6 \times (\quad)$

34-A Answer

Because his old man was in the Pen and he didn't know how long the sentence was.

35.

Ohm's Law gives the relationship between resistance, _____, and _____.

---

70. Answer

(6.28) coulomb

71.

Name	Symbol
emf	( )
current	( )
resistor	( )



---

106. Answer

73,600,000 7.36×10^7

107.

To multiply factors that are expressed as powers of 10, add the exponents.

$10^4 \times 10^3 = 10^7$

$10^{-2} \times 10^4 =$ ( )

---

1. Answer

ohms

2.

Ohms are units of _____.

---

36. Answer

$$\frac{E}{R}$$

37.

Georg Ohm found that current varies directly as _____ and inversely as _____.

---

72. Answer

TEST

73.

If you say one coulomb per second is passing a point, it is the same as saying ( ) _____ of current is flowing past this point.

---

108. Answer

600,000 10^5

109.

(1) $10^{4} \times 10^{-2} = 10^{2}$ $\quad 4 \quad -2 \quad 2$

(2) or (10,000) (.01) = (100)

This checks with equation (1).

(A) $10^5 \times 10^{-3} = 10^2$ $\qquad 5 - 3 = 2$

(B) or (100,000) ( ) = ( )

This must check with equation (A).

34. Answer

NAME	UNITS	SYMBOLS
resistance	ohms	(R)
emf or voltage	volts	(E)
current	amperes	(I)

34-A

Why was the little ink drop sad?

69. Answer

(6.28×10^{18})

70.

( ) $\times 10^{18}$ electron = 1 _____.

105. Answer $(2.3 \times 10^3)\ (3.2 \times 10^4) =$

$(2.3 \times 3.2)\ (10^3 \times 10^4) = (2.3 \times 3.2) \times 10^{(3+4)} =$

$(2.3 \times 3.2)\ 10^7 = 7.36 \times 10^7$

106.

We may check our multiplication by multiplying the original numbers,

2,300 × 32,000 = ( ) = ( ) power of 10.

2. Answer

Resistance

3.

The symbol used for resistance is ( ).

---

37. Answer

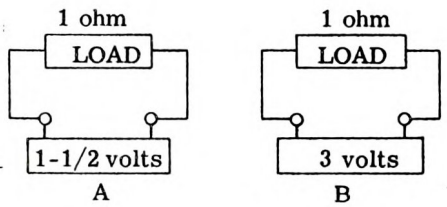
TEST

38.

In which circuit does the most current flow? ( )

Which has the highest emf? ( )

What is the value of R in A? ( ) _____; in B? ( ) _____



---

73. Answer

(1) ampere

74.

The number 6,000,000 can be written $6 \times 10^{(\quad)}$.

---

109. Answer

.001 Note that $.001 = 10^{-3}$

100 Note that $100 = 10^{2}$

110.

$(2 \times 10^{4})\ (4 \times 10^{-2}) = 8 \times 10^{2} = 800$; because $2 \times 4 = 8$ and $10^{4} \times 10^{-2} = 10^{2}$

Check, using the original numbers.

$2 \times 10^{4} = 20,000$; $4 \times 10^{-2} = .04$; $20,000 \times (\quad) = (\quad)$

33. Answer

more, greater (either is correct)

34.

NAME	UNITS	SYMBOLS
resistance	_____	( )
_____	volts	( )
current	_____	I

Copy and complete the table.

---

68. Answer

coulomb

69.

One coulomb = 6.28×10^{18} electrons.

One coulomb per second = ( ) electrons per second.

---

104. Answer

(1)

105.

We wish to multiply these numbers: $46,000 \times 5,200$.
First, change them to their powers of 10.
$(4.6 \times 10^4)\ (5.2 \times 10^3) = (4.6 \times 5.2)\ (10^4 \times 10^3)$
$(4.6 \times 5.2) \times 10^7 = 23.92 \times 10^7$
Change these to powers of 10 and multiply them: $2,300 \times 32,000$. (Show all work.)

---

3. Answer

(R)

4.

Current varies directly with the voltage and inversely with the resistance; this is called Ohm's Law.

Copy Ohm's Law.

---

38. Answer (B)
(B)
1 ohm
1 ohm

39.

Ohm's Law written in words is: current = $\frac{\text{emf}}{\text{resistance}}$

Ohm's Law states in symbols: ( ) = $\frac{(\quad)}{(\quad)}$

---

74. Answer

(6)

75.

One ampere equals ( ) _____ passing a point each second.

---

110. Answer

.04 800

111.

$(2.4 \times 10^{4})\ (2.0 \times 10^{6}) = 2.4 \times 2.0 \times 10^{4+6} = 4.8 \times 10^{10}$

$(3.0 \times 10^{3})\ (4.0 \times 10^{-4}) = (\quad)$

32. Answer

(A)

33.

The more the electrical pressure (emf), the _____ the electron flow (current) through a given resistance. "If I push harder will I get more or less through?"



---

67. Answer

10^{18}

68.

6.28×10^{18} electrons = 1 _____.



---

103. Answer

(15×10^{2})

104.

10^{0} = ( )

---

4. Answer

Current varies directly with the voltage and inversely with the resistance.

5.

The law relating to voltage, current and resistance is _____ law.

---

39. Answer

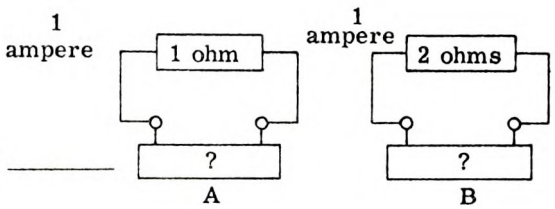
$$I = \frac{E}{R}$$

40.

In which circuit is the voltage the greatest? ( )

Which has the greatest R? ( )

What is the current in A? ( ) _____ in B? ( ) _____



---

75. Answer

(1) coulomb

76.

Very small numbers can also be changed to powers of 10.

Moving the decimal point 3 places, .001 = $1 \times 1/1,000 = 1 \times 1/10^{3}$.

.01 = $1 \times 1/10^{2}$ .00001 = $1 \times 1/10^{(\quad)}$

---

111. Answer

12×10^{-1} or 1.2×10^{0} or 1.2

112.

$(2.4 \times 10^{4})\ (2.0 \times 10^{6}) = (\quad) \times 2.0 \times 10^{(\quad)}$
A. B.

$(3.0 \times 10^{3})\ (4.0 \times 10^{-4}) = (\quad)$
C.

31. Answer

Test

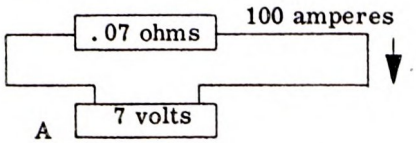
(B)

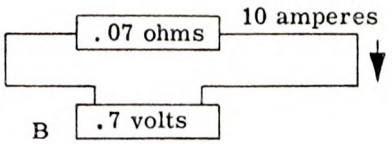
1 ampere

1 ampere

32.

Which circuit has the most volts? ( )





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66. Answer

1. 10^3
2. 10^3
3. 10^5
4. 10^2
5. 10^6
6. 10^0 or 1

67.

Here is an important word you should know: "coulomb." (koo-LOM)

6, 280, 000, 000, 000, 000, 000 electrons = 1 coulomb.

This could be written as $6.28 \times$ ( ) = 1 coulomb.

---

102. Answer

$(6.2 \times 1.5) \times 10^{-3} \times 10^3 = 9.3 \times 10^0 =$

$9.3 \times 1 = 9.3$

103.

Several factors, expressed as powers of 10, may be multiplied by the methods we have learned.

$(3 \times 10^3)\ (4 \times 10^{-4})\ (5 \times 10^5) = (3 \times 4 \times 5)\ (10^3 \times 10^{-4} \times 10^5) = 60 \times 10^4$

Multiply these factors:

$(2 \times 10^4)\ (5 \times 10^6)\ (1.5 \times 10^{-8}) =$ ( )

---

5. Answer

Ohm's

6.

If the voltage is not changed, and resistance (load) is increased, the electron current flow _____

---

40. Answer (b)

(B)

1 ampere 1 ampere

41.

E stands for _____

I stands for _____

R stands for _____

---

76. Answer

(5)

77.

625 = 6.25×10^{2} $32.35 = 32.35 \times (\quad)$

.0625 = $6.25 \times 1/10^{2}$ $1250 = 12.35 \times (\quad)$

---

112. Answer

A. 2.4

C. 12×10^{-1} or 1.2×10^{0} or 1.2

113.

$10^{4} \times 10^{-4} = 10^{0}$

We know that 10^{0} = 1, so $10,000 \times .0001 = (\quad)$

30. Answer

3 amperes

15 ohms

45 volts

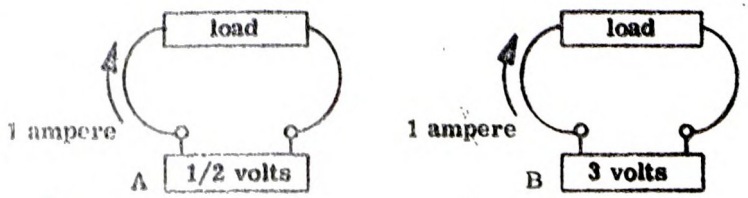
31.

Which figure has the most R? ( )

Which has the highest emf? ( )

What current flows in A?

What current flows in B?



---

65. Answer

0

66.

1. $12,800 = 12.8 \times 10^{3}$

2. $4,620 = 4.62 \times (\quad)$

3. $126,000 = 1.26 \times (\quad)$

4. $1,492 = 14.92 \times (\quad)$

5. $2,000,000 = 2 \times (\quad)$

6. $1.5 = 1.5 \times (\quad)$

---

101. Answer

(4.8×10^{3})

102.

$10^{0} = 1$

Multiply these factors.

$(6.2 \times 10^{9})\ (1.5 \times 10^{-3}) = (\quad)$

---

137. Answer

TEST

---

6. Answer

decreases

7.

The single letter for resistance is R.

The single letter for voltage or emf is ( );

for current, the letter is ( ).



---

41. Answer E = emf or voltage

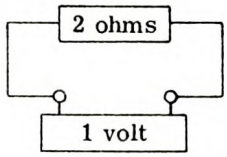
I = current

R = resistance

42.

Write Ohm's Law in symbols. ( ) = $\frac{(\quad)}{(\quad)}$

In the diagram, I = ( ) amperes.



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77. Answer

(10^2)

($1/10^2$)

78.

For ease of writing, we say that $1/10^2 = 10^{-2}$,

and $1/10^3 = 10^{-3}$;

then $1/10^4 =$ ( ).



---

113. Answer

10^0 or 1

114.

$(8 \times 10^3)\ (3 \times 10^{-3}) = 8 \times 3 \times 10^{3-3} = 24 \times 10^0 = 24 \times 1 = 24$

$(6 \times 10^2)\ (2 \times 10^{-2}) =$ ( )

29. Answer

(5) (4)

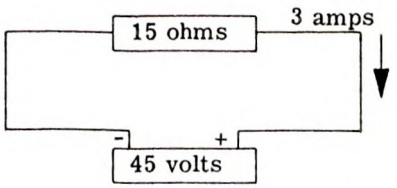
30.

In this circuit:

I = ( ),

R = ( ),

E = ( ).



---

64. Answer

TEST

65.

$140 = 140 \times 10^{0}$: we moved the decimal point 0 places.

$1.65 = 1.65 \times 10^{(\quad)}$

---

100. Answer

(10^{-2})

101.

Multiply these factors:

$(2.8 \times 10^{-5})\ (1.2 \times 10^{6}) = (2.8 \times 1.2) \times 10^{(-5+6)} = 3.36 \times 10^{1}$.

Multiply these factors.

$(1.2 \times 10^{8})\ (4.0 \times 10^{-5}) = (\quad)$

---

136. Answer

4 milliamps = 4×10^{-3} a

137.

SYMBOL	NAME	POWER OF 10
M	_____	( )
m	_____	10^{-3}
k	_____	( )
μ	micro	( )

7. Answer

(E)

(I)

8.

Ohm's Law relates to _____, _____, and _____.

---

42. Answer

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

I = 1/2 ampere

43.

$\frac{E}{R}$ = ( ) is _____ Law.

---

78. Answer

(10^{-4})

79.

One ampere (one amp. or one a.) equals one coulomb per _____.

---

114. Answer

TEST

115.

When we multiply a string of numbers, we add all the exponents and multiply the numbers remaining.

$(2 \times 10^{2})\ (4 \times 10^{4})\ (3 \times 10^{+2}) = 2 \times 4 \times 3 \times 10^{(2+4+2)} = 24 \times 10^{8}$

$(8 \times 10^{3})\ (6 \times 10^{-2})\ (2 \times 10^{4}) =$ ( ) ( ) ( ) $\times 10^{(3-2+4)} =$ ( ) $\times$ ( )

28. Answer

(B)

29.

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

If E is 200 volts and R is increased from 40 to 50 ohms, then I decreases from

( ) amperes to ( ) amperes.

---

63. Answer 2

3

4

64.

12700. = 12.7×10^{3}

by moving 3 decimal places, then 469. = $4.69 \times 10^{(\ \ )}$.

---

99. Answer

$(5 \times 3)\ (10^{4} \times 10^{-2}) = 15 \times 10^{2}$

100.

Multiply these powers of 10.

$10^{4} \times 10^{-6} =$ ( )



---

135. Answer

(-6)

136.

4 Ma is read 4 Megamps, which = 4×10^{6} a.

4 ma is read ( ) _____, which = ( ) a.

8. Answer

voltage, current, resistance (any order)

9.

Ohm's Law states:

The number of electrons that flow in a circuit (the current) depends on the circuit resistance and the _____.

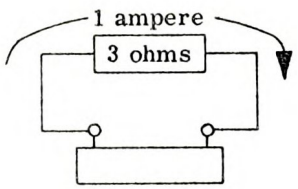
---

43. Answer

(I) Ohm's

44.

What is the emf in this diagram? ( ) _____



---

79. Answer

second

80.

$1246.78 = 12.4678 \times 10^{+2}$

If we move the decimal point to the left, the power of 10 is +.

$3,579. = 3.579 \times (\quad)$

---

115. Answer

8 6 2 (any order)

96×10^5

116.

$(2 \times 10^4)\ (2 \times 10^6)\ (4 \times 10^4)\ (8 \times 10^{-8}) = (2 \times 2 \times 4 \times 8) \times 10^{\quad 4 + 6 + (\quad) - (\quad)}$

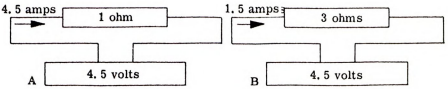
$= (\quad) \times (\quad)$

27. Answer

less

28.

Which circuit has the most ohms? ( )



---

62. Answer

(2)

63.

All of these numbers equal 1400.

Moving the decimal point 1 place results in 140×10^1.

Moving the decimal point ( ) places results in 14×10^2.

Moving the decimal point ( ) places results in 1.4×10^3.

Moving the decimal point ( ) places results in $.14 \times 10^4$.

---

98. Answer

$(8 \times 6)\ (10^2 \times 10^4) = (8 \times 6) \times 10^6$

99.

After multiplying the powers of 10, the other terms are multiplied.

$(3 \times 10^8)\ (2 \times 10^{-5}) = (2 \times 3)\ (10^8 \times 10^{-5}) = (2 \times 3) \times 10^{(8-5)} = 6 \times 10^3$

Multiply these factors.

$(5 \times 10^4)\ (3 \times 10^{-2}) = ($ $)$

---

134. Answer

micro

mega

135.

10^6 = mega = M (remember megaphone)

$10^{(\ )}$ = micro = μ (remember microscope)



9. Answer

voltage

10.

MEASUREMENT	SYMBOL	UNIT
current	( )	_____
pressure	( )	_____
resistance	( )	_____

---

44. Answer

(3) volts

45.

Ohm's Law in symbols is $I = \frac{E}{R}$.

Write Ohm's Law in words. (current) = _____

---

80. Answer

(10^{+3})

81.

$1,246.78 = 124,678. \times 10^{-2}$

If we move the decimal point to the right, the power of 10 is -. $3.579 = 3,579. \times (\quad)$

---

116. Answer

4 8 128×10^6

117.

$1,000 \times 31,000 \times .000002 = 10^3 \times (3.1 \times 10^4)\ (2 \times 10^{-6}) = 3.1 \times 2 \times 10^1$

$2,000 \times 40 \times .00012 = (\quad)$ $= 6.2 \times 10^1$

$= 62$

26. Answer

3 amperes

6 ohms

18 volts

27.

Inverse means opposite in effect or action.

Ohm's Law states that current varies inversely as the resistance; which means that as resistance increases, the current decreases. The more the resistance (R), the _____ the current (electron flow).

---

61. Answer

1,200

12,000

62.

12,000. If we move the decimal point 3 places we can write it like this: 12×10^3.

4,600 could be written as $46 \times 10^{(\quad)}$.

---

97. Answer

add

98.

When the terms have been separated, multiply the powers of 10 as we learned earlier.

$(2 \times 10^1)\ (4 \times 10^3) = (2 \times 4)\ (10^1 \times 10^3) = (2 \times 4) \times 10^{(1+3)} = (2 \times 4) \times 10^4$

Separate these terms and multiply the powers of 10.

$(8 \times 10^2) \times (6 \times 10^4) = (\qquad\qquad)$

---

133. Answer k

m

μ

134.

μ = _____ = $10^{-6} = \frac{1}{1,000,000}$

M = _____ = $10^{+6} = 1,000,000$

10. Answer

current	I	ampere
pressure (emf)	E	volt
resistance	R	ohm

11.

In symbols, Ohm's Law states $I = \frac{E}{R}$.

If E = 100 volts and R = 20 ohms, $I = \frac{100}{20} = 5$ amperes.

If E = 175 volts, and R = 25 ohms, compute the value of I.

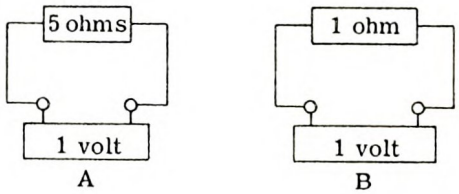
45. Answer

$$\text{current} = \frac{\text{emf}}{\text{resistance}} \text{ or } \frac{\text{voltage}}{\text{resistance}}$$

46.

Which circuit has the greatest resistance? ( )

Which has the greatest current? ( )



81. Answer

(10^{-3})

82.

$246.810 = 2.46810 \times 10^{+2}$, moving the decimal point ( ) places to the _____.

$246.810 = 24,681.0 \times 10^{-2}$, moving the decimal point ( ) places to the _____.

117. Answer

$$(2 \times 10^{3})\,(4 \times 10^{1})\,(12 \times 10^{-5}) = 2 \times 4 \times 12 \times 10^{-1}$$

$$= 96 \times 10^{-1} = 9.6$$

118.

In electronics we have names for the powers of 10.

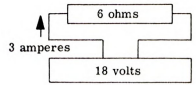
What would be the exponent of 10 for 1 million? ( )

25. Answer

(4)

26.

In this circuit:
the current is ( ) amperes,
the resistance is ( ) ohms,
the emf is ( ) volts.



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60. Answer

2 10^2

4 10^4

61.

$12 \times 1 = 12$
$12 \times 10 = 120$
$12 \times 100 = 1200$
$12 \times 1{,}000 = 12{,}000$

could be written

$12 \times 10^0 = 12$
$12 \times 10^1 = 120$
$12 \times 10^2 = (\quad)$
$12 \times 10^3 = (\quad)$

---

96. Answer

$(4 \times 6)\ (10^2 \times 10^4)$

97.

When multiplying powers of 10, we _____ the exponents.

---

132. Answer

milli

133.

To make them easier to write, we abbreviate the names:

mega = M	capital M	10 meg = 10 M
kilo = k	small k	10 kilo = 10 ( )
milli = m	small m	10 milli = 10 ( )
micro = μ	Greek letter μ called mu (mew)	10 micro = 10 ( )

11. Answer

$$I = \frac{E}{R} = \frac{175}{25} = 7 \text{ amperes}$$

12.

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

When E was 100 volts and R was 20 ohms, I equaled 5 amps.

If E is increased from 100 to 200 volts, but R is unchanged at 20 ohms, then $I = \frac{200}{20} = 10$ amps.

E has increased from 100 to 200, R is the same, and I has _____ from 5 to 10 amps.

---

46. Answer

(A)

(B)

47.

Which is the correct formula for Ohm's Law?

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

---

82. Answer

2 left

2 right

83.

1. $.0625 = 6.25 \times (\quad)$
2. $.000000125 = 12.5 \times (\quad)$
3. $125,000,000 = 12.5 \times (\quad)$
4. $36.921 = 3.6921 \times (\quad)$
5. $.036921 = 3.6921 \times (\quad)$

---

118 Answer

(6)

119.

NAME	AMOUNT	POWER OF 10	WRITTEN NUMBERS
mega	1 million	10^6	1,000,000
kilo	1 thousand	10^3	( )
milli	1 thousandth	10^{-3}	$\frac{1}{1000}$
micro	1 millionth	10^{-6}	( )

24. Answer

.2 amperes
2 volts
10 ohms

25.

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

When E was 100 volts and R was 20 ohms, I equaled 5 amps.

If E is unchanged at 100 volts and R is increased to 25 ohms, then I is decreased to ( ) amps.

---

59. Answer

(10^6)

60.

1 has 0 zeros, so $1 = 10^0$

100 has ( ) zeros, so 100 = ( ).

10,000 has ( ) zeros, so 10,000 = ( ).

---

95. Answer

TEST

96.

$(3 \times 10^2) \times (4 \times 10^3)$

To multiply these numbers, we first separate the powers of 10 from the other terms like this:

$(3 \times 4)\ (10^2 \times 10^3)$.

Separate these: $(4 \times 10^2) \times (6 \times 10^4)$

---

131. Answer

.000001 10^{-6}

132.

A microammeter would measure microamps.

A _____ ammeter would measure milliamps.

12. Answer

increased or doubled

13.

Current varies directly with voltage.

When E increases, I increases.

When E decreases, I _____.

---

47. Answer

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

48.

A circuit component designed to impede or resist the flow of current is called a resistor.

It is easy to remember that a component to resist current flow is called a _____.

---

83. Answer

1. 10^{-2}
2. 10^{-8}
3. 10^{7}
4. 10^{1}
5. TEST

84.

$37.91246 \times 10^{4} = 379124.6$

$26.9142 \times 10^{3} = (\quad)$

$46 \times 10^{8} = 4,600,000,000$

---

119. Answer

1,000 $\qquad \frac{1}{1,000,000}$

120.

mega	**1 million**	10^{6}
kilo	**1 thousand**	10^{3}
milli	**1 thousandth**	10^{-3}
micro	**1 millionth**	( )

23. Answer

more

less

TEST

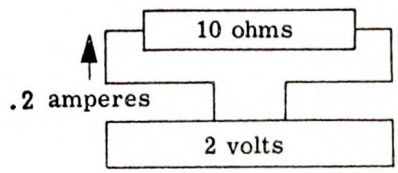
24.

In this circuit:

I = ( ) amperes,

E = ( ) volts,

R = ( ) ohms.



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58. Answer

(4)

59.

To change a multiple of 10 into a power of 10, count the number of zeros and put that number above the 10.

1,000 has 3 zeros, so $1,000 = 10^3$.

1,000,000 has 6 zeros, so 1,000,000 = ( ).

---

94. Answer

(10^{-2})

95.

Multiply these powers of 10.

$10^{-6} \times 10^{8}$ = ( )

---

130. Answer

3 thousand

131.

A milliamp is .001 amp. or 10^{-3} amp.

A microamp is ( ) amp. or ( ) amp.

Use the power of 10.

13. Answer

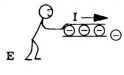
decreases

14.

Look at Ohm's Law.

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

E is emf. It does the pushing.
The larger E is, the (more/less) current flows.



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48. Answer

resistor

49.

The symbol for a resistor is —/\/\/\—.

It looks like the blade of a saw or a rough surface.

It shows that current does not _____ easily through a resistor.

---

84. Answer

(26914.2)

85.

$37.91246 \times 10^{-4} = .0037,91246$ $\qquad$ $26.9142 \times 10^{-3} = (\quad)$

$46 \times 10^{-8} = .00000046$

---

120. Answer

(10^{-6})

121.

To remember micro, think of microscope.

A microscope is used to look at very (small/large) things.

22. Answer

more

more

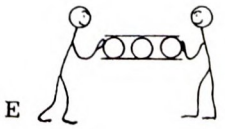
less

23.

With the same R and more E, (more/less) I flows.

With the same E and more I, (more/less) R is needed.

With the same I and more R, (more/less) E is needed.



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57. Answer

(12,000)

58.

Instead of using 10, 100, or 1,000, we can just use the powers of 10.

$10 = 10^{1}$

$100 = 10^{2}$

$1,000 = 10^{3}$

$10,000 = 10^{(\quad)}$

---

93. Answer

1,200,000

1,200,000

94.

$10^{-4} \times 10^{2} = 10^{(-4+2)} = 10^{-2}$

Multiply these powers of 10.

$10^{3} \times 10^{-5} = (\quad)$

---

129. Answer

mega kilo milli

130.

Kilo means $10^{(\quad)}$ or 1 _____.

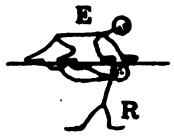
14. Answer

more

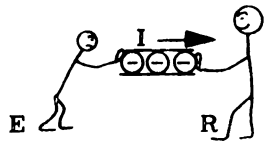
15.

R is resistance. It tries to hold back or resist the current flow.

If R gets larger, (more/less) current flows.

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





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49. Answer

flow, pass, or move (any answer is correct)

50.

The symbol for ohms is Ω.

The Ω looks like a horseshoe.

A resistance of 50 ohms is written 50 ( ).

---

85. Answer

(.0269142)

86.

We call the number above the 10 the "exponent" (eks-PO-nent).

The number 2 is the _____ in 10^2.

---

121. Answer

small

122.

A microscope is used to look at very small things.

Very small numbers (10^{-6}) have the name _____.

21. Answer

more

22.

With the same R and more I, (more/less) E is needed to push it through.

With the same I and more E, (more/less) R is needed to hold it back.

With the same E and more R, (more/less) I flows.



---

56. Answer

12 12

57.

12 × 1 = 12

12 × 10 = 120

12 × 100 = 1200

12 × 1,000 = ( )

---

92. Answer

(10^3)

93.

12 × 10^5 = ( )

1.2 × 10^6 = ( )

---

128. Answer (-3)

(3)

(6)

129.

10^6 is _____.

10^3 is _____.

10^{-3} is _____.

10^{-6} is micro.

15. Answer

less

16.

The more the resistance, the (more/less) the current.

The more the emf, the (more/less) the current.

---

50. Answer

(Ω)

51.

A resistor ($_{\text{draw symbol}}$) is a circuit component with a certain amount of

_____ in it.

---

86. Answer

exponent

87.

In 10^3 the exponent is 3.

In 2^4 the exponent is 4.

In 12^9 the exponent is ( ).

---

122. Answer

micro

123.

To remember mega, think of megaphone

A megaphone is used to make a very (small/large) sound.

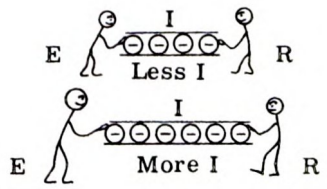
20. Answer

more

21.

To make more current flow, more E is needed.

To make I increase, (more/less) E is needed.



---

55. Answer

E

56.

All these numbers have the same first two numbers.

12	If we move the decimal point over beside	12.	Then they look	12.
120	the 2 in each number, they would all look	12 0.	like this: ⟶	12. 0
1200	the same.	12 00.		( ). 00
12000		12 000.		( ). 000

---

91. Answer

4

480

92.

When powers of 10 are multiplied, the exponents are added.

$10^4 \times 10^3 = 10^{(4+3)} = 10^7$

Multiply these powers of 10.

$10^2 \times 10^1 =$ ( )

---

127. Answer (3)

(10^{-3})

micro

128.

milli means $10^{(\ )}$

kilo means $10^{(\ )}$

mega means $10^{(\ )}$

16. Answer

less

more

17.

Current varies directly with _____.

Current varies inversely (indirectly) with _____.

---

51. Answer

(—WWW—) resistance

52.

NAME	SYMBOL	UNITS
Voltage or emf	E	4. _____
Current	2. ( )	5. _____
1. _____	3. ( )	Ohms

---

87. Answer

(9)

88.

When we multiply powers of 10, it is just like adding their exponents.

We can see that exponent (1) + exponent (2) = exponent ( ).

$10 \times 100 = 1,000$ $10^1 \times 10^2 = 10^{1+2} = 10^3$

---

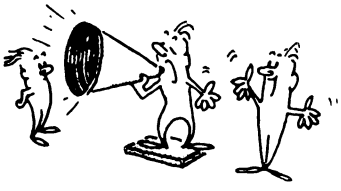
123. Answer

large

124.

A megaphone is used to make a very large sound.

Very large numbers (10^6) have the name _____.



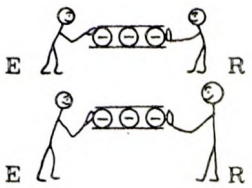
19. Answer

current resistance

20.

If R gets larger to keep I the same, we need more E to push it through.

So as R increases, (more/less) E is needed.



---

54. Answer resistance

ohm

resistor

55.

The symbol for voltage is (R/E/Q/Ω).

---

90. Answer

4 5 9

91.

Express these numbers as powers of 10.

$12,000 = 1.2 \times 10^{(\quad)}$

$(\quad) = 4.8 \times 10^{2}$

---

126. Answer

(-6)

127.

mega $= 10^{6}$

kilo $= 10^{(\quad)}$

milli $= (\quad)$

____ $= 10^{-6}$

17. Answer

TEST

18.

We know from algebra that we can multiply both sides by the same quantity.

$A = \frac{B}{C}$ then, $(C)A = \frac{B}{C}(C)$ or $AC = B$ or $= AC$

Solve this equation for E.

$I = \frac{E}{R}$ $\quad E = (\quad)$

---

52. Answer

2. (I) 4. Volts

1. Resistance 3. (R) 5. Amperes

53.

This is a —/\/\/\— , it has many Ω of R.

This is a 1. _____, it has many 2. _____ of 3. _____.

Put in words for the symbols.

---

88. Answer

(3)

89.

$10^4 \times 10^3 = 10^7$ (4 + 3 = 7) $10^4 \times 10^5 = (\quad)$

$10^6 \times 10^5 = 10^{11}$ $10^9 \times 10^9 = (\quad)$

---

124. Answer

mega

125.

mega	1 million	10^6
kilo	1 thousand	( )
milli	1 thousandth	( )
micro	1 millionth	( )

18. Answer

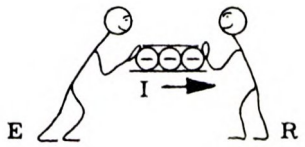
E = IR

19.

Ohm's Law can be written as E = IR.

Write the formula in words:

emf = _____ times _____.



---

53. Answer

1. resistor 2. ohms 3. resistance

54.

A toaster has resistance.

Fill in the names of these symbols.

R is _____

Ω is _____

 is _____

---

89. Answer

10^{9} 10^{18}

90.

10,000 × 100,000 = 1,000,000,000, or $10^{(\ \ )} \times 10^{(\ \ )} = 10^{(\ \ )}$

---

125. Answer

10^{3} 10^{-3} 10^{-6}

126.

"Micro" means one-millionth, which = $10^{(\ \ )}$.



SERIES CIRCUITS

2-S



NAVAL AIR TECHNICAL TRAINING COMMAND

Acknowledgements

This program was adapted by the Naval Air Technical Training Center, Memphis, Tennessee, from a larger one developed under contract No. N 61339-1000 between the U.S. Naval Training Device Center and Teaching Machines, Inc. In a letter dated 29 December, 1961 from the U.S. Naval Training Device Center, unrestricted use of this material by any governmental agency was confirmed. Appreciation is expressed to the U.S. Naval Training Device Center and to Teaching Machines, Inc. for assistance in making the original program available.

SERIES CIRCUITS

1. If your answer to a question is a single word, you will see a single line, like this: _____

   George Washington was the first president of the United _____

2. If your answer is two words, you will see two lines: _____ _____

   George Washington was the first president of the _____ _____.

3. If your answer to a question is in your own words, you will see a dashed line: _____

   Who was the first President? _____

   What did he chop down? _____

4. When the answer is a number, symbol, or letter, it is marked like this: ( )

5. A multiple choice question has a series of items separated by slashes.

   George Washington was the (1st/2nd/3rd) president.

6. Some questions are test questions. The answer is not given, but you will see the word "TEST" where the answer should be.

The steps in this program are fixed so that you should be right most of the time. If you are doubtful about how to answer a question, read the whole step over. It is important that you read and understand every word of instruction before you answer. The answer to the question is on the next page. For the answer to any question coming at the end of the book, turn the page -- and then turn the book upside-down. The answer to your question will be in the appropriate answer space. Continue as usual. If you write a wrong answer, study the correct answer carefully. Compare the incorrect response with the correct one. Careful comparison of answers will help you to move smoothly through the entire course. Always read the answer in the answer frame. Do not neglect or rush by the answer frame, even though you may feel certain that your answer is correct. COMPARE.

1.

E = IR.

This formula is called _____ _____.

30. Answer

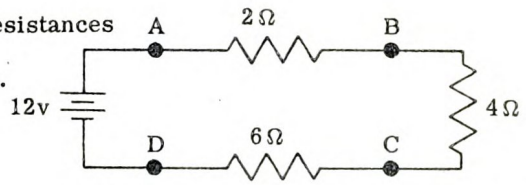
	AB	BC	CD	Total
R				
I				
E				

31. We put into the table all the values we know.

	AB	BC	CD	Total
R	2Ω	( )Ω	( )Ω	
I				
E				( )v

Fill in only the parentheses.

First, put in the resistances and battery voltage.



60. Answer

100v .5a

P = IE = (.5a)(100v) = 50w

61.

A toaster draws 2 amps from a 100v line.

How much power does the toaster use? ( )

Which power formula did you use? ( )

90. Answer

20w

91.

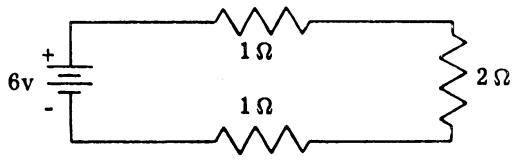
You can see that all the columns in this table obey Ohm's Law.

In column AC, $2\Omega\ (4a) = 8v$ or $2\Omega = \frac{8v}{4a}$ or $4a = \frac{8v}{2\Omega}$.

What is I_{EF}? ( )

	AC	BD	EF
R	2Ω	4Ω	1Ω
I	4a	1a	( )
E	8v	4v	4v

29. Answer



30.

One way to solve circuit problems is to make a table.

Copy this table.

	AB	BC	CD	Total
R				
I				
E				

---

59. Answer

$$I = \frac{P}{E} = \frac{50 \text{ watts}}{2 \text{ volts}} = 25 \text{ amps}$$

60.

A light bulb draws .5 amp from a 100-volt line.

What is E? ( ) What is I? ( )

Use the formula P = IE to find P. ( )

---

89. Answer

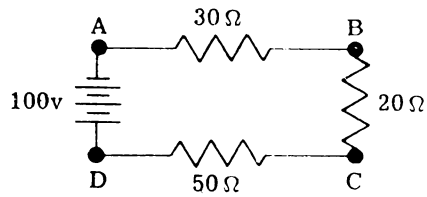
A. (15Ω)

B. (2a)

C. (30v)

90.

In the circuit shown, what is P_{BC}? ( )



---

119. Answer

$$P = I^2R, \text{ so } I^2 = \frac{P}{R}, \quad I^2 = \frac{P_{BC}}{R_{BC}} = \frac{4w}{4\Omega}$$

$I^2 = 1a$, $I = 1a$

---

1. Answer

Ohm's Law

2.

As you remember, E_T = the total voltage applied to the circuit.

You might guess that R_T = the _____ resistance in a circuit.

---

31. Answer

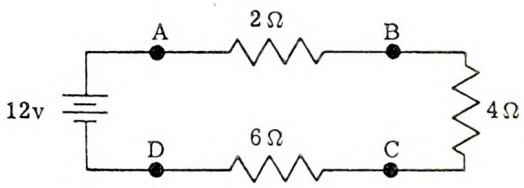
(4) (6) (12)

32.

We can find R_{Total} by adding all the resistors.

	AB	BC	CD	Total
R	2Ω	4Ω	6Ω	( )Ω
I				
E				12 v

Now find R_{Total}.



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61. Answer

P = (2a) (100v) = 200 w

TEST

62.

If $E = \frac{P}{I}$ and $P = IE$, then I = ( ).

---

91. Answer

(4a)

92.

I_{AC} = ( )

R_{BD} = ( )

E_{EF} = ( )

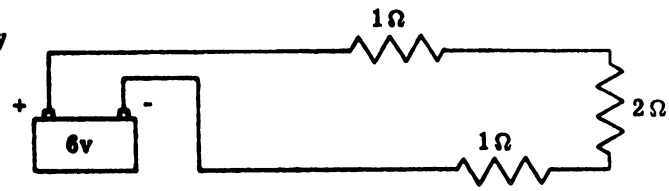
	AC	BD	EF
R	2Ω	( )	4Ω
I	( )	6a	3a
E	4v	12v	( )

28. Answer $I = \frac{E_T}{R_T} = \frac{16v}{8\Omega} = 2a$

$E_{AD} = IR_{AD} = (2a)(8\Omega) = 16v$

29.

Redraw this circuit with the symbol for a battery in place of the battery.



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58. Answer

100 v

1 a

59.

P = 50 watts

E = 2 volts

Use the formula $I = \frac{P}{E}$ to find I. ( )

---

88. Answer

TEST

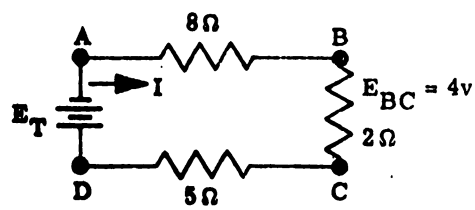
89.

In the circuit shown, find:

A. R_T = ( )

B. I = ( )

C. E_T = ( )



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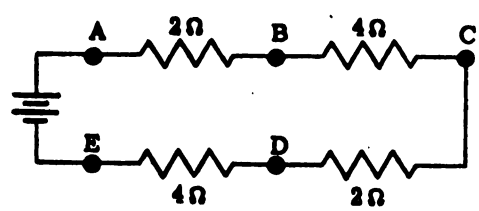
118. Answer $I = \frac{18v}{6\Omega} = 3a$

$E_T = IR_{Total} = 3a\,(12\Omega) = 36v$

119.

P_{BC} = 4 watts

What is the current? ( )

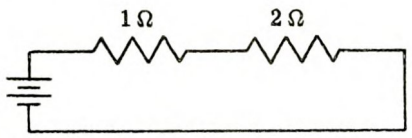


2. Answer

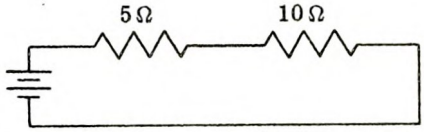
total

3.

The total resistance of a series circuit is the sum of all the resistors.



Total
3Ω



Total
( )

---

32. Answer

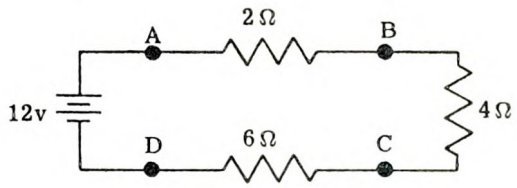
(12)

33.

The total I is equal to

	AB	BC	CD	Total
R	2Ω	4Ω	6Ω	12Ω
I				( )a
E				12v

Find I.



---

62. Answer

$(\frac{P}{E})$

63.

$I = \frac{(\quad)}{(\quad)}$ Complete the power formula.

---

92. Answer

(2a)
(2Ω)
(12v)

93.

R_{AB} = ( )
E_{CD} = ( )
R_{EF} = ( )

I_{GH} = ( )
I_{IJ} = ( )
E_{KL} = ( )

	AB	CD	EF	GH	IJ	KL
R	( )	3/4Ω	( )	1Ω	2/3Ω	1/2Ω
I	4a	4a	4a	( )	( )	4a
E	3v	( )	5v	8v	6v	( )

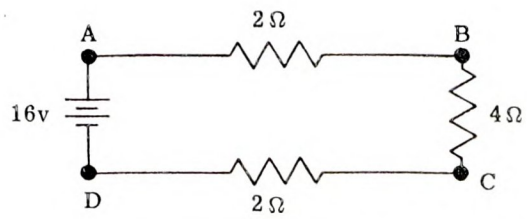
27. Answer

(1v) (5v) (1v)

28.

I = ( )

E_{AD} = ( )



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57. Answer

(E)

58.

A soldering iron draws 1 amp from a 100-volt line, therefore

E = ( ), and

I = ( ).

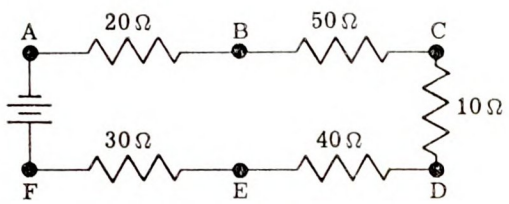
---

87. Answer

400 watts

88.

What is the total resistance in this circuit? ( )



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117. Answer

$I = \frac{E}{R} = \frac{24v}{12\Omega} = 2a \qquad I^2 = 4a$

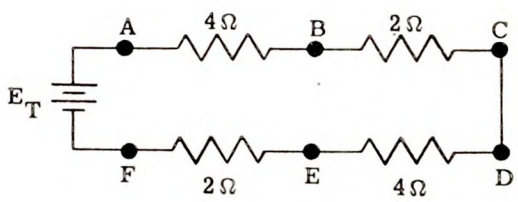
4(8) = 32 watts, 4(4) = 16 watts, 4(12) = 48 watts

118.

E_{AC} = 18v

What is the voltage of the battery? ( )

Remember: $I = \frac{E_{AC}}{R_{AC}}$

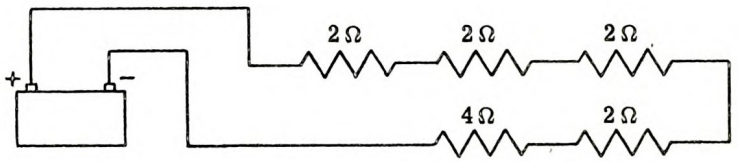


3. Answer

(15Ω)

---

4. What is the total resistance of this circuit? ( )



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33. Answer

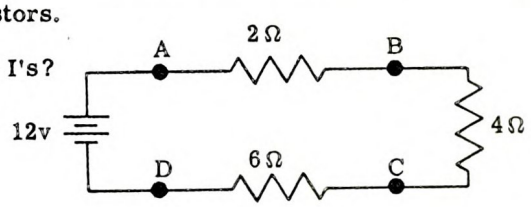
(1)

---

34. The current is the same through all the resistors.

	AB	BC	CD	Total
R	2Ω	4Ω	6Ω	12Ω
I	( )	( )	( )	1a
E				12v

What are all the I's?



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63. Answer

$\frac{P}{E}$ or $\frac{P}{E}$

64.

$\frac{P}{E}$ = ( )

---

93. Answer (3/4Ω) (8a)
(3v) (9a)
(5/4Ω) (2v)

94.

When we make a table that includes P, we can see that the columns also obey the power formula IE = P. In column CD: P = (3a) (18v) = 54w, or I = $\frac{54w}{18v}$ = 3a, or E = $\frac{54w}{3a}$ = 18v. What is P_{EF}? ( )

	AB	CD	EF
R	2Ω	6Ω	3Ω
I	2a	3a	1a
E	4v	18v	3v
P	8w	54w	( )

26. Answer

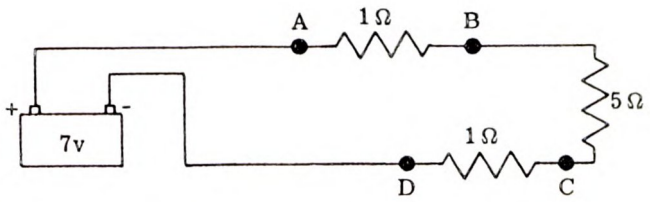
$$I = \frac{E}{R} \qquad E = IR \qquad R = \frac{E}{I}$$

27.

E_{AB} = ( )

E_{BC} = ( )

E_{CD} = ( )



---

56. Answer

$$E = IR$$

57.

$$I = \frac{P}{(\quad)}$$

---

86. Answer

2 amps

87.

A stove draws 10 amps from a 100v line.

1000 watts of power are used.

(10 amps) (100v) = 1000w

A stove draws 2 amps from a 200v line.

( ) _____ of power are used.

---

116. Answer

You must find I first; $I = \frac{E}{R_T} = 2a$

$E_{AE} = 2a\ (8) = 16v$

$E_{AF} = 2a\ (10) = 20v$

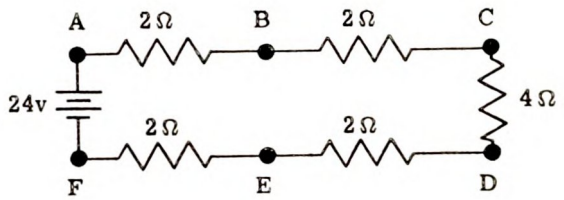
117.

P_{AD} = ( )

P_{CD} = ( )

P_{AF} = ( )

HINT: First find I and I^2.



4. Answer

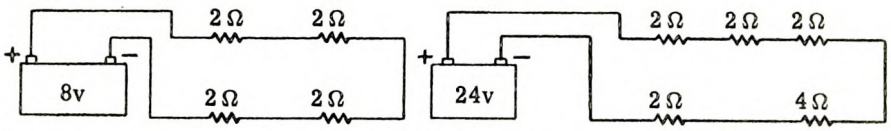
(12Ω)

5.

If the voltage source is an 8 volt battery the current in this circuit will be:

$I = \frac{E}{R_T} = \frac{8v}{2+2+2+2}$ or $\frac{8v}{8\Omega}$

I = 1 amp



What is the current here? ( ) _____

---

34. Answer

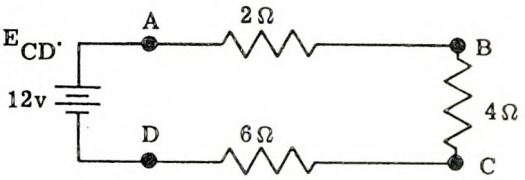
(1a) (1a) (1a)

---

35. Now each voltage is equal to I times its resistance.

	AB	BC	CD	Total
R	2Ω	4Ω	6Ω	12Ω
I	1a	1a	1a	1a
E	( )	( )	( )	12v

Find E_{AB}, E_{BC}, E_{CD}.



---

64. Answer

(I)

65.

If a 200-watt lamp is connected across a 100-volt line, 2 amps will flow. $\frac{200 \text{ watts}}{100 \text{ volts}} = 2 \text{ amps}$

What is P? ( ) _____

What is I? ( ) _____

What is E? ( ) _____

---

94. Answer

(3w)

95.

I_{AB} = ( )

E_{CD} = ( )

P_{EF} = ( )

	AB	CD	EF
R	1Ω	4/3Ω	7/2Ω
I	( )	3a	2a
E	5v	( )	7v
P	25w	12w	( )

25. Answer

(6v)

26.

What is Ohm's Law?

Write all three forms.

( ) ( ) ( )

---

55. Answer

$\frac{P}{I}$

56.

What is the formula for Ohm's Law which gives E in terms of I and R? ( )

---

85. Answer

$(\frac{P}{I})$ $(\frac{P}{E})$ (EI)

86.

A soldering iron takes 50 watts from a 100v line. 1/2 amp of current is drawn.

$\frac{P}{E} = I$ $\frac{50w}{100v} = \frac{1}{2}a$

A soldering iron takes 200 watts from a 100v line.

( ) _____ of current are drawn.

---

115. Answer

$(3)^2 (3) = 27$ watts

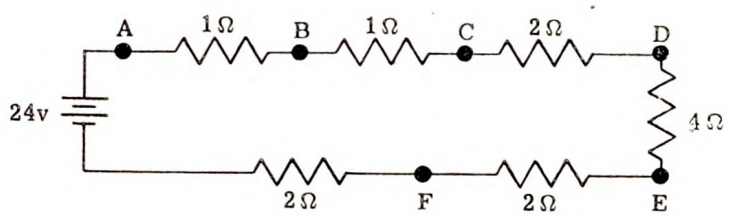
$P = I^2 R$, because R and I are known.

116.

E_{AE} = ( )

E_{AF} = ( )

Make a table if you need it.



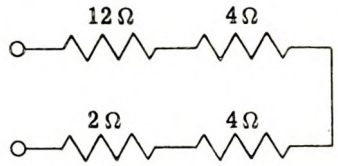
5. Answer

$R_{Total} = 2+2+2+4+2 = 12\ \Omega$

$I = \frac{E}{R} = \frac{24v}{12\Omega} = 2$ amps

6.

What is the total resistance? ( ) _____



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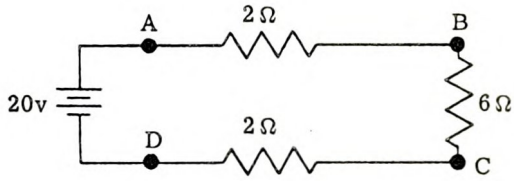
35. Answer

(2v) (4v) (6v)

36.

Draw a table. Fill in all the blanks.

	AB	BC	CD	Total
R				
I				
E				



---

65. Answer P = 200 watts

I = 2 amps

E = 100 volts

66.

The current in a resistor is 10 amps and the voltage across the circuit is 20 volts.

What is the power in the resistor? ( )

Which power formula did you use? ( )

---

95. Answer (5a)

(4v)

(14w)

96.

1. E_{AB} = ( )
2. I_{CD} = ( )
3. R_{EF} = ( )
4. E_{GH} = ( )
5. P_{GH} = ( )
6. I_{IJ} = ( )
7. R_{KL} = ( )
8. P_{KL} = ( )

		AB	CD	EF	GH	IJ	KL
	R	10Ω	5Ω	( )	8Ω	4Ω	( )
	I	1a	( )	3a	2a	( )	3a
	E	( )	10v	6v	( )	12v	9v
	P	10w	20w	18w	( )	36w	( )

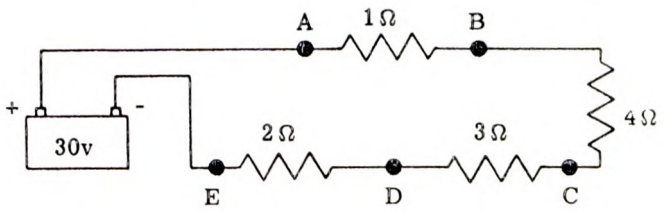
24. Answer

$$I = \frac{E_T}{R_T} = \frac{30v}{(1+4+3+2)\Omega} = \frac{30v}{10\Omega} = 3a$$

$$E_{BC} = (R_{BC})(I) = (4\Omega)(3a) = 12v$$

25.

$E_{DE} = (\quad)$



---

54. Answer

$$\frac{P}{E}$$

55.

$P = IE$ and $E = (\quad)$

---

84. Answer

(1250)

85.

The power formula, $P = IE$, can be written three ways.

$E = (\quad)$

$I = (\quad)$

$P = (\quad)$

---

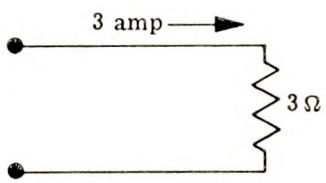
114. Answer

(E_{BC}) (E_{CD})

115.

What is the power loss in this resistor? ( )

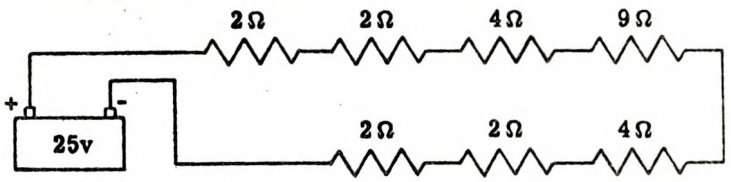
Which power formula should be used? ( )



6. Answer

Test

7.



What is the R_T? ( )

What is the current? ( ) _____

---

36. Answer

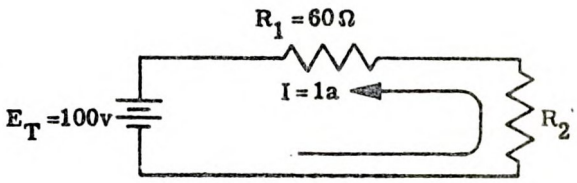
	AB	BC	CD	Total
R	2Ω	6Ω	2Ω	10Ω
I	2a	2a	2a	2a
E	4v	12v	4v	20v

37.

In the circuit shown, the value R_2 is not known.

But we know that

$R_2 = R_T - R_1$ and $R_T = \frac{E_T}{I_T}$, so R_2 = ( )



---

66. Answer

200w Test

67.

In an electrical circuit, some power is converted to heat.

A light bulb gets hot because some of the is converted to heat.

---

96. Answer

1. (10v)
2. (2a)
3. (2Ω)
4. (16v)
5. (32w)
6. (3a)
7. (3Ω)
8. (27w)

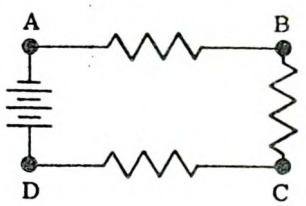
97.

In the circuit shown:

E_{AB} = the voltage between A and B

R_{AB} = the resistance between ( ) and ( )

P_{AB} = the _____ between ( ) and ( )



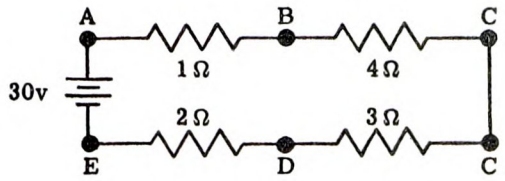
23. Answer

$$R_T = R_1 + R_2 + R_3$$

24.

$I = (\quad)$

$E_{BC} = (\quad)$



---

53. Answer

(P) (I) (either order)

54.

We can change this formula into different forms. P = IE, therefore, I = ( ).

---

83. Answer

Test

84.

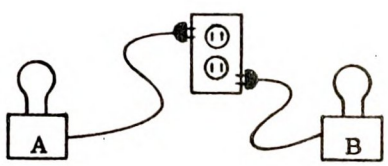
Lamp A draws 5 amps from a 100-volt line.

It uses 500 watts.

EI = P and (100v) (5a) = 500w.

Lamp B draws 12.5 amps from a 100-volt line.

It uses ( ) watts.



---

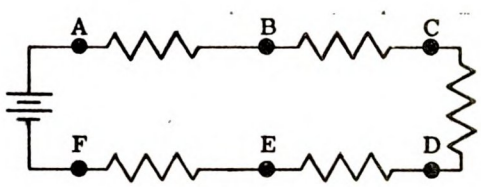
113. Answer

$$P = I^2R$$

114.

The total voltage in a circuit equals the sum of the individual voltages.

$E_{AF} = E_{AB} + (\quad) + (\quad) + E_{DE} + E_{EF}$



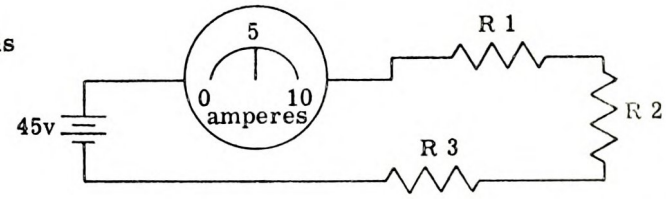
7. Answer

$$R_{Total} = 2 + 2 + 4 + 9 + 4 + 2 + 2 = 25\Omega$$

$$I = \frac{E}{R_T} = \frac{25v}{25\Omega} = 1 \text{ amp}$$

8.

What is the value of R_T (total resistance) in this circuit? ( )



---

37. Answer

$$R_T = \frac{E_T}{I_T} = \frac{100v}{1a} = 100\Omega$$

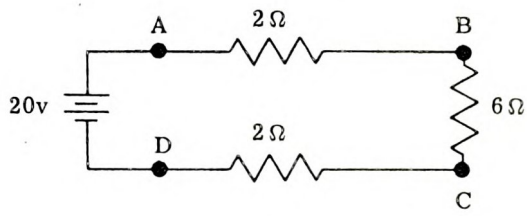
$$R_T = 100\Omega = R_1 + R_2 = 60\Omega + R_2$$

$$R_2 = 100\Omega - 60\Omega = 40\Omega$$

38.

$E_{AB} = 4v$

Fill in the table.



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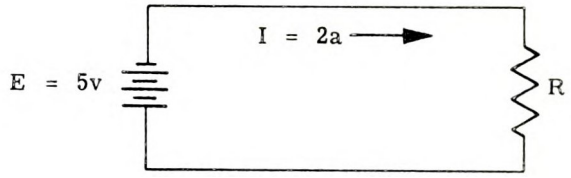
67. Answer

power

68.

In the circuit shown, what is the power in the resistor? ( )



---

97. Answer

(A) (B)

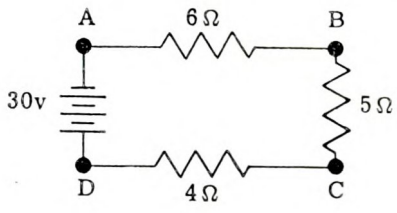
power (A) (B)

98.

When solving any series circuit problem, make a table.

Fill in the table with the known values first.

Fill in only the parentheses.



22. Answer

$R_T = 2 + 2 + 4 + 4 = 12\Omega$

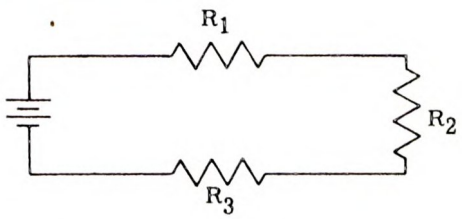
$I = \frac{E}{R_T} = \frac{24v}{12\Omega} = 2a$

$E_{AB} = (I)(R_{AB})$ $E_{AB} = 2a(2\Omega) = 4v$

23.

Write an equation for the value of R_T in the circuit shown. ( )

Note: Do not use Ohm's Law.



---

52. Answer

volts or emf amperes or current flow

53.

The formula for power can be remembered by looking at the word "PIE."

The equal sign goes between ( ) and ( ).

---

82. Answer

(I)(E) or (E)(I)

83.

What is the formula for Ohm's Law? ( )

---

112. Answer

$I = 4a$

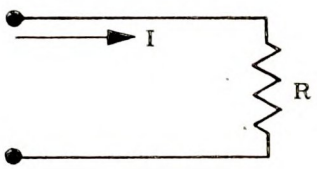
$I^2 = (4)(4) = 16a^2$

$I^2R = (16)(2) = 32w$

113.

Which formula would you use to find the power loss in the resistor?

Note: current = I and resistance = R.

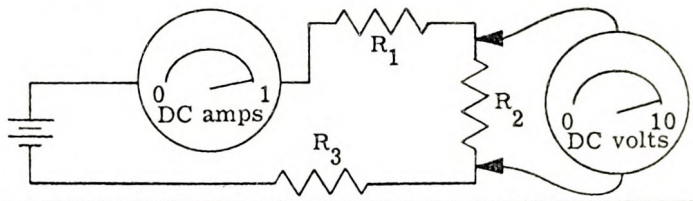


8. Answer

$$R_T = \frac{E_T}{I_T} = \frac{45v}{5a} = 9\Omega$$

---

9. Use the current and voltage shown on the meters to find the value of R_2. ( )



---

38. Answer

	AB	BC	CD	Total
R	2Ω	6Ω	2Ω	10Ω
I	2a	2a	2a	2a
E	4v	12v	4v	20v

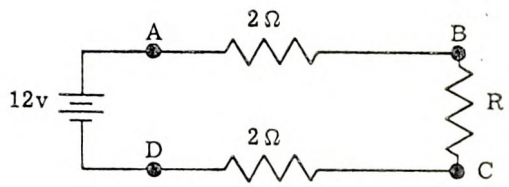
39.

I = 2 amp

Remember: $E_{BC} = E_T - E_{AB} - E_{CD}$ and

$$R_{BC} = \frac{E_{BC}}{I}$$

Fill in the table completely.



---

68. Answer

$$P = IE = (2a)(5v) = 10w$$

69.

All the power in a resistor is converted to heat.

A resistor has 100 watts of power.

How much power is converted to heat? ( ) _____

---

98. Answer

	AB	BC	CD	Total
R	6Ω	5Ω	4Ω	15Ω
I				
E				30v

99.

From the information in the table, find current and voltage in the rest of the table.

Remember that E in each column = I × R and that the current is the same in each resistor.

Fill in the parentheses.

21. Answer

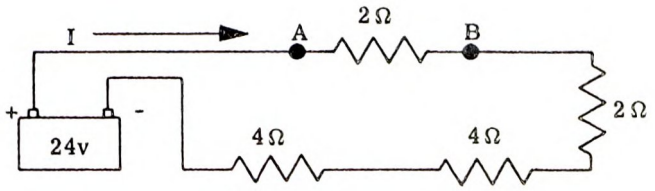
$$E = (3a)(2+2+4+2) = (3)(10) = 30$$

22.

R_T = ( ).

I = ( )

E_{AB} = ( )



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51. Answer

$$\left(\frac{P}{E}\right)$$

52.

The power formula is P(ower) = IE.

As you remember, E represents _____ and I represents _____.

---

81. Answer

$$I = \frac{P_{BC}}{E_{BC}} = \frac{100w}{50v} = 2a$$

82.

P = ( )( )

---

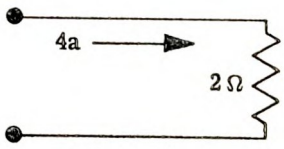
111. Answer

$$I = \frac{E}{R} = \frac{16}{2+2+4} = \frac{16}{8} = 2a \qquad E_{AC} = IR_{AC} = (2a)(6\Omega) = 12v$$

$$R_{AC} = R_{AB} + R_{BC} = 2\Omega + 4\Omega = 6\Omega$$

112.

What is the I^2R loss of this resistor? ( )



9. Answer

$$R_2 = \frac{E_2}{I} = \frac{10v}{1a} = 10\Omega$$

10.

I = ( ).

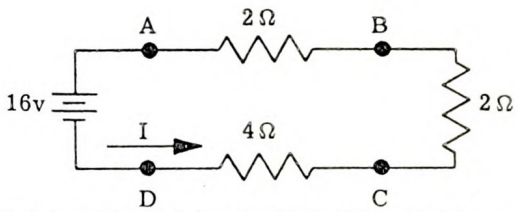
---

39. Answer

	AB	BC	CD	Total
R	2Ω	2Ω	2Ω	6Ω
I	2a	2a	2a	2a
E	4v	4v	4v	12v

40.

1. I = ( )
2. E_{AB} = ( )
3. E_{BC} = ( )
4. E_{CD} = ( )



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69. Answer

Test

70.

A 100-watt light bulb is connected to a 100-volt line.

Put the values into the power equation and find I.

$$I = \frac{P}{E} = \frac{(\quad)}{(\quad)} = (\quad)$$

---

99. Answer

	AB	BC	CD	Total
R	6Ω	5Ω	4Ω	15Ω
I	2a	2a	2a	2a
E	12v	10v	8v	30v

100.

When all of the currents and voltages are known, power for each column can be found from the power formula,

P = (I)(E).

Note: P has been added to the table. Finish the table.

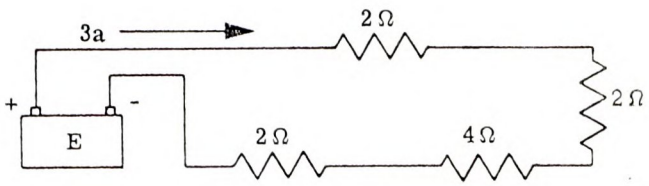
20. Answer

Test

21.

In the circuit shown:

E = ( ) volts



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50. Answer

(I)

51.

The power formula or power equation for I, in terms of P and E is I = ( ).

---

80. Answer (20v)

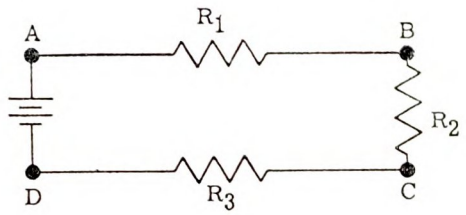
(10)

(2a)

81.

In the circuit shown, E_{BC} = 50v, and the power in R_2 is 100w.

What is the current flow (I) in the circuit? ( )



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110. Answer

(P)

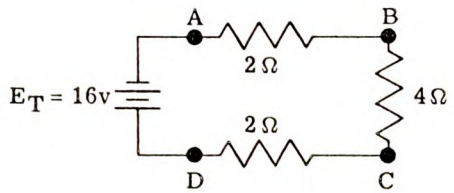
power or heat

111.

$E_{AC} = IR_{AC}$

E_{AC} = ( )

Hint: first find I; make a table if you need it.



10. Answer

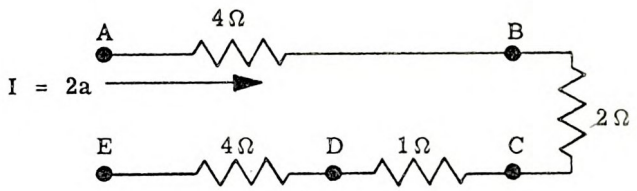
$$\left(\frac{E}{R}\right)$$

11.

E_{AB} (the voltage drop between A and B) is 8v.

$E_{CD} = (2a)(1\Omega) = 2v$

$E_{DE} = (\quad)$ $E_{BC} = (\quad)$ $E_{AE} = (\quad)$



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40. Answer

1. 2a
2. 4v
3. 4v
4. 8v

41.

The path around which a current may flow is called a _____.

---

70. Answer

$$\frac{100\,w}{100\,v} = 1 \text{ amp}$$

71.

The current through a resistor is 2 amps.

The voltage across the resistor is 50 volts.

Put the values into the power formula and find P.

$P = IE = (\quad)(\quad) = (\quad)$

---

100. Answer

	AB	BC	CD	Total
R	6Ω	5Ω	4Ω	15Ω
I	2a	2a	2a	2a

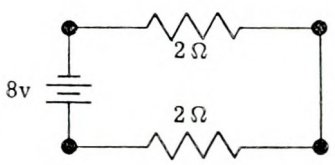
	AB	BC	CD	Total
E	12v	10v	8v	30v
P	24w	20w	16w	60w

101.

$I = (\quad)$

$P_T = (\quad)$

If you have trouble solving the problem, make a table.



19. Answer

$$R_{AB} = R_1 = \frac{E_{AB}}{I} = \frac{16v}{4a} = 4\Omega$$

20.

Ohm's Law

R = ( )

---

49. Answer

P = IE

50.

We can solve the power equation for I by dividing both sides by E, like this:

P = IE, dividing $\frac{P}{E} = \frac{IE}{E}$ and cancelling the E's on the right gives $\frac{P}{E}$ = ( )

---

79. Answer

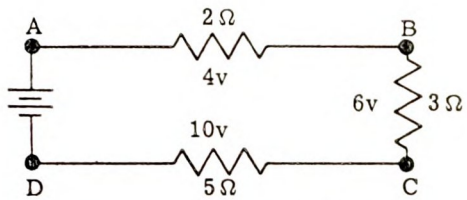
$P_{AB} + P_{BC}$

80.

E_{AD} = ( )

R_{AD} = ( )

I = ( )



---

109. Answer

(32w)

(16v)

110.

The power used in a resistor is changed to heat and lost to the air.

We call this the "I^2 R loss" because I^2 R = ( ).

I^2 R loss = _____ loss.

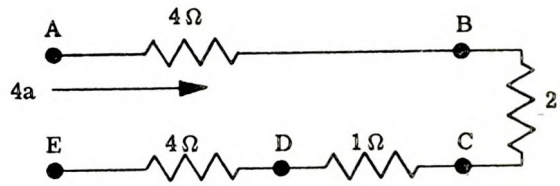
11. Answer $E_{DE} = IR_{DE} = 2a\,(4\Omega) = 8v$

$E_{BC} = IR_{BC} = 2a\,(2\Omega) = 4v$

E_{AE} or $E_T = E_{AB} + E_{BC} + E_{CD} + E_{DE} = 22v$

12.

$E_{BC} = (\quad)$



---

41. Answer

circuit

42.

Power is the time rate of doing work; that is, when we do work for a period of time we use power

We use _____ if we push a car for 5 minutes.

---

71. Answer

$(2a)(50v) = 100w$

72.

Power Formula	Ohm's Law
$E = (\quad)$	$E = (\quad)$

---

101. Answer

$$I = \frac{E}{R} = \frac{8}{2 + 2\Omega} = \frac{8v}{4\Omega.} = 2a$$

$P = IE = (2a)(8v) = 16w$

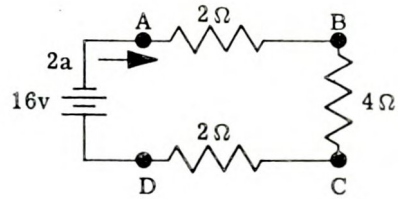
102.

$E_{AB} = (2a)(2\Omega) = 4v$

$P_{AB} = IE_{AB} = 2a\,(4v) = 8$ watts

$P_{BC} = (\quad)$

Make a table on scratch paper, if you need it.



18. Answer

(8v)

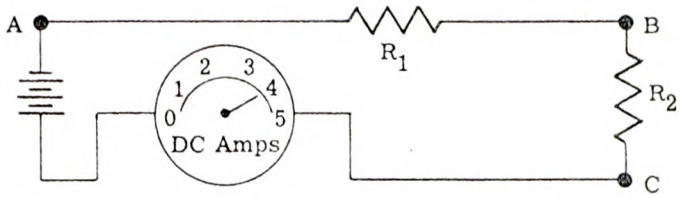
(16v)

(24v)

19.

In this circuit E_{AB} = 16v.

What is the value of R_1? ( )



---

48. Answer

volts

49.

The power formula can also be called the power equation.

Write the power equation. ( )

---

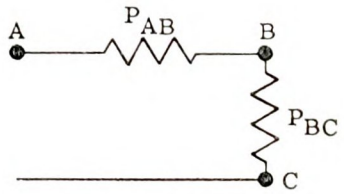
78. Answer

$R_{AB} + R_{BC} + R_{CD}$

79.

The total power in a circuit is equal to the sum of the individual powers.

What is the total power in this circuit? P_T = ( )



---

108. Answer

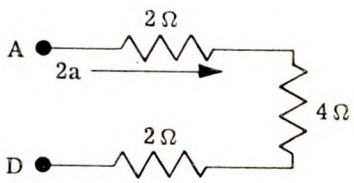
$P_{AB} = I^2 R_{AB} = (2a)^2(2 + 2 + 2) = 4a^2(6\Omega)$

P_{AB} = 24 w

109.

P_{AD} = ( )

E_{AD} = ( )

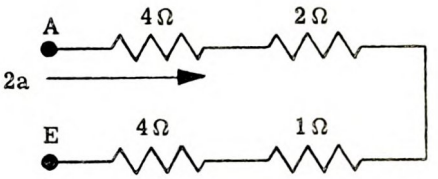


12. Answer

$$E_{BC} = IR_{BC} = (4a)(2\Omega) = 8v$$

13.

$E_{AE} = (\quad)$



Hint: Find R_T and use Ohm's Law.

---

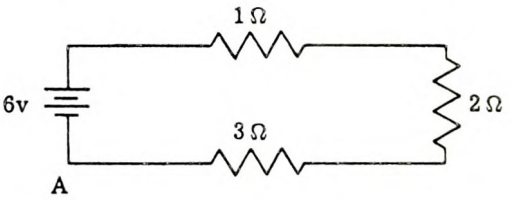
42. Answer

power

43.

Figure A is a series circuit.

All the parts of the _____ are in a line.



---

72. Answer

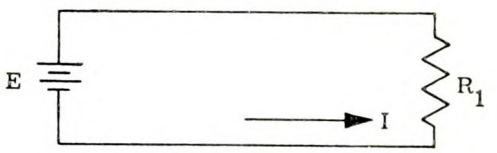
$(\frac{P}{I})$ (IR)

73.

In this circuit, the power lost in R_1 is 50 watts, and

I = 2 amps.

What is the value of E? (\quad) _____



---

102. Answer

$E_{BC} = (2a)(4\Omega) = 8v$

$P_{BC} = (I)(E_{BC}) = (2a)(8v) = 16\ w$

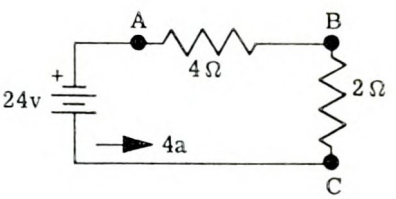
103.

$E_{BC} = IR_{BC} = 4a\,(2) = 8v$

$E_{AB} = (\quad)v$

$P_{AB} = (\quad)w$

Make a table if you get stuck.



17. Answer

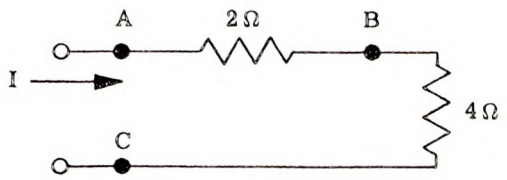
(8)
(4)
(12)

18.

E_{AB} = ( ) I = 4a

E_{BC} = ( )

E_{AC} = ( )



---

47. Answer

watts

48.

The power formula is P = IE;

I is measured in amperes and E is measured in _____.

---

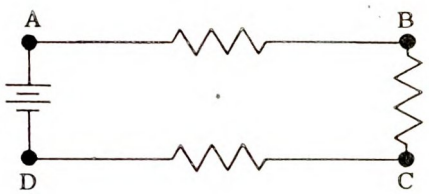
77. Answer

(I)
(R)
(E)

78.

$E_{AD} = E_{AB} + E_{BC} + E_{CD}$

R_{AD} = ( ) + ( ) + ( )



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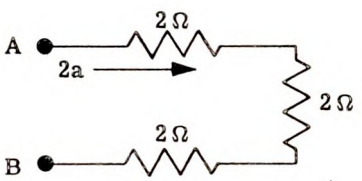
107. Answer

32 w

$I^2 R$

108.

P_{AB} = ( )



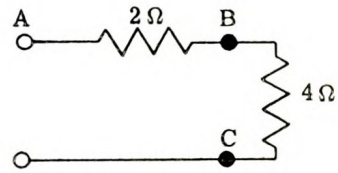
13. Answer

22v

14.

The symbol for the voltage drop between A and B is E_{AB}.

The voltage drop between B and C would be $E_{(\ \ )(\ \ )}$.



---

43. Answer

circuit

44.

_____ is the time rate of doing work.

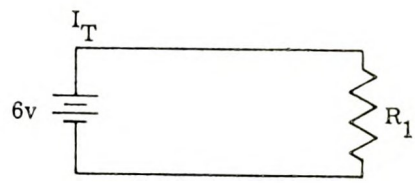
---

73. Answer

$$E = \frac{P}{I} = \frac{50w}{2a} = 25 \text{ volts}$$

74.

If we put another resistor in series with R_1, would I_T be smaller or larger? _____



---

103. Answer

$E_{AB} = IR_{AB}$ $4(4) = 16$

$P_{AB} = E_{AB}I$

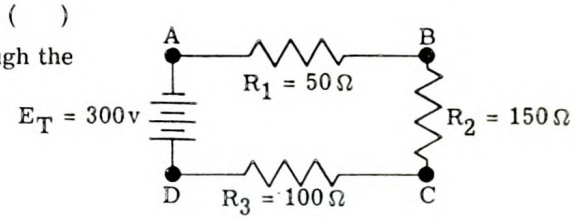
$P_{AB} = (16)(4)w = 64$

104.

How much current is flowing in this series circuit? ( )

The power in a resistor is equal to the current through the resistor squared times the resistance.

What is the power in R_3? ( )



16. Answer

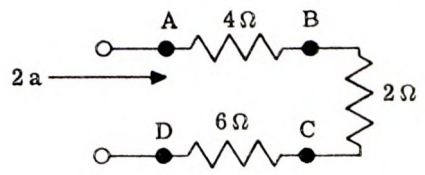
the voltage or potential drop between points A and E

17.

E_{AB} = ( )v

E_{BC} = ( )v

E_{CD} = ( )v



---

46. Answer

1. 1/2 or .5

2. (2)

47.

Power is measured in watts.

The power used in a light bulb is measured in _____.

---

76. Answer

current voltage

77.

The symbol for current is ( ).

The symbol for resistance is ( ).

The symbol for voltage is ( ).

---

106. Answer

$I = 2a$

$I^2 = 4a$

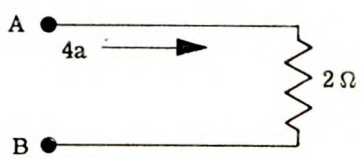
$P = I^2R = (4a)(4\Omega) = 16$ watts

107.

P_{AB} = ( )

Since I and R are given, you would use the

P = ( ) power formula.



14. Answer

(B)(C)

15.

What is the symbol for the voltage drop between C and D? ( )

---

44. Answer

Power

45.

The symbol for power is P.

We use ( ) to lift a box.

---

74. Answer

Test

75.

Power Formula	Ohm's Law
I = ( )	I = ( )

---

104. Answer

I = 1a

$P = I^2R_3 = 100$ watts

105.

I^2 ( ) = ( )

15. Answer

E_{CD}

16.

The symbol E_{AE} indicates _____.

---

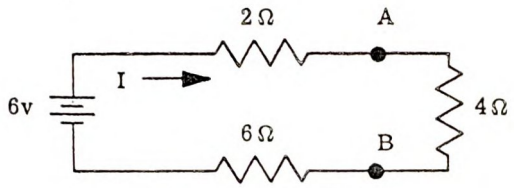
45. Answer

(P)

46.

In this circuit :

1. I = ( ) a
2. E_{AB} = ( ) v



---

75. Answer

$(\frac{P}{E})$ $(\frac{E}{R})$

76.

The power in a resistor is equal to the product of the _____ through the resistor and the _____ across the resistor.

---

105. Answer

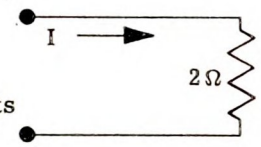
(R) (P)

106.

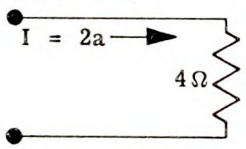
I = 5 amps

I^2 = 5(5) = 25 amps

P = 25(2Ω) = 50 watts



Do this problem.



P = ( ) _____

PARALLEL CIRCUITS

3-S



NAVAL AIR TECHNICAL TRAINING COMMAND

Acknowledgements

This program was adapted by the Naval Air Technical Training Center, Memphis, Tennessee, from a larger one developed under contract No. N 61339-1000 between the U.S. Naval Training Device Center and Teaching Machines, Inc. In a letter dated 29 December, 1961 from the U.S. Naval Training Device Center, unrestricted use of this material by any governmental agency was confirmed. Appreciation is expressed to the U.S. Naval Training Device Center and to Teaching Machines, Inc. for assistance in making the original program available.

PARALLEL CIRCUITS

1. If your answer to a question is a single word, you will see a single line, like this: _____

   George Washington was the first president of the United _____.

2. If your answer is two words, you will see two lines: _____ _____

   George Washington was the first president of the _____ _____.

3. If your answer to a question is in your own words, you will see a dashed line:_____

   Who was the first President?_____

   What did he chop down?_____

4. When the answer is a number, symbol, or letter, it is marked like this: ( )

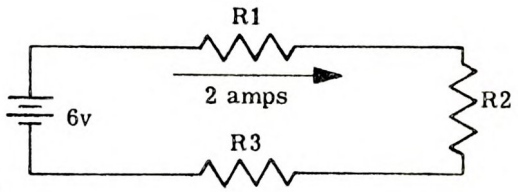
5. A multiple choice question has a series of items separated by slashes.

   George Washington was the (1st/2nd/3rd) president.

6. Some questions are test questions. The answer is not given, but you will see the word "TEST" where the answer should be.

The steps in this program are fixed so that you should be right most of the time. If you are doubtful about how to answer a question, read the whole step over. It is important that you read and understand every word of instruction before you answer. The answer to the question is on the next page. For the answer to any question coming at the end of the book, turn the page -- and then turn the book upside-down. The answer to your question will be in the appropriate answer space. Continue as usual. If you write a wrong answer, study the correct answer carefully. Compare the incorrect response with the correct one. Careful comparison of answers will help you to move smoothly through the entire course. Always read the answer in the answer frame. Do not neglect or rush by the answer frame, even though you may feel certain that your answer is correct. COMPARE.

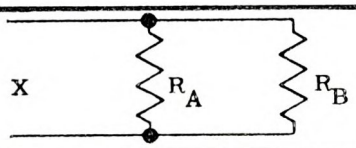
1.



R_T = ( )

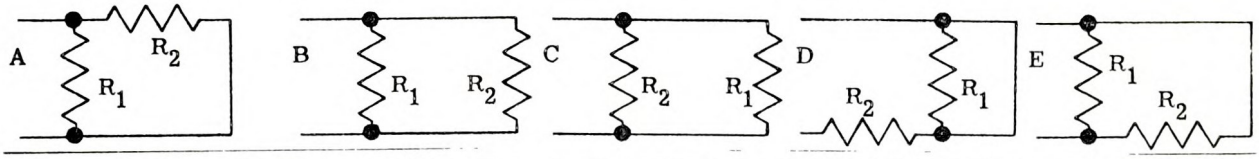
---

30. Answer



31.

Which circuit is different? ( )



---

60. Answer

(R_2)

61.

$$R_T = \frac{R_1 \quad R_2}{(\quad)(\quad)(\quad)}$$

---

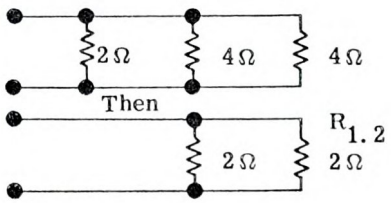
90. Answer

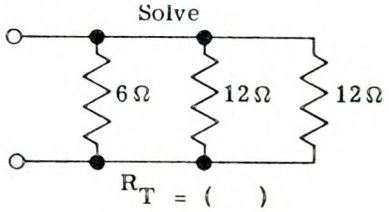
($R_{1.2}$)

91.

$$R_{1.2} = \frac{(4)\ (4)}{4+4} = \frac{16}{8} = 2\Omega$$

$$R_T = \frac{(2)\ (2)}{2+2} = \frac{4}{4} = 1\Omega$$



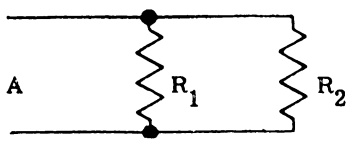


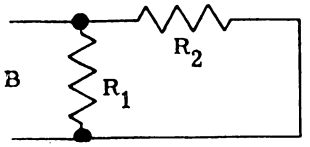
29. Answer

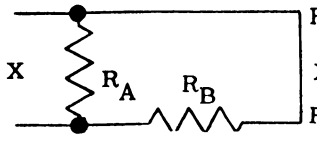
(2a)

30.

Circuits A and B are the same because both ends of each resistor are connected together.







Redraw circuit X with R_A and R_B side by side.

---

59. Answer

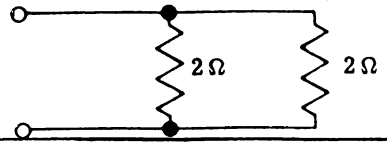
$$R_T = \frac{(8)(8)}{8+8} = \frac{64}{16} = 4\Omega$$

60.

$$R_T = \frac{R_1 \quad R_2}{R_1 + (\quad)}$$

---

89. Answer



90.

We can find the R_T of the whole circuit by first breaking R_1 and R_2 down to $R_{1.2}$ and then taking ( ) in parallel with R_3.



---

119. Answer

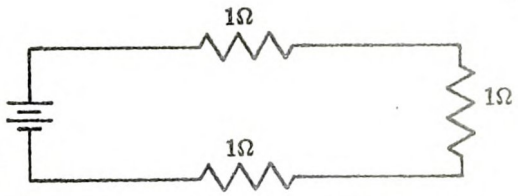
	AB	BC	CD	Total
R	10Ω	30Ω	60Ω	100Ω
I	10a	10a	10a	10a
E	100v	300v	600v	1000v
P	1,000w	3,000w	6,000w	10,000w

1. Answer

(3Ω)

2.

R_T = ( )



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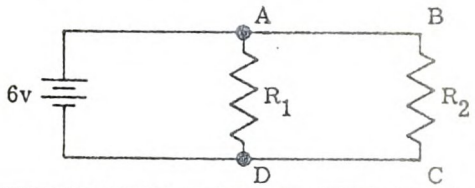
31. Answer

(D)

32.

E_{AD} = ( )

E_{BC} = ( )



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61. Answer

$R_1 + R_2$

62.

I_T = ( )



---

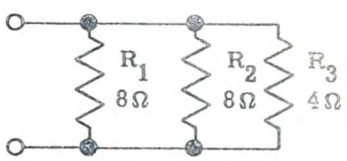
91. Answer

(3Ω)

92.

To solve any parallel circuit, take any two resistors and put an equivalent resistance in their place.

Redraw this circuit with the $R_{1.2}$ of the two 8Ω resistors.



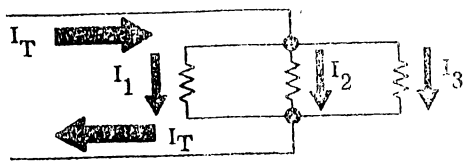
28. Answer

(I_T)

29.

If there are three parallel branches, the current splits into three parts.

If I_T = 6a; and I_1, I_2 and I_3 each split the current equally; I_1 = ( ).



---

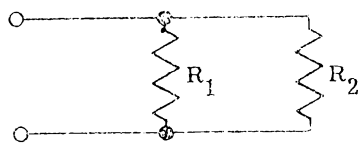
58. Answer

$$\frac{E_T}{I_T}$$

59.

In a parallel circuit, $R_T = \frac{R_1 \ R_2}{R_1 + R_2}$.

If R_1 = 8Ω and R_2 = 8Ω, using the formula above, R_T = ( ).



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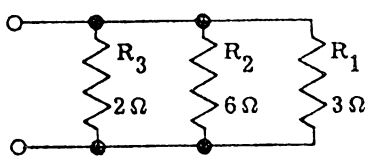
88. Answer

(R_3)

89.

We can break down any combination of resistors.



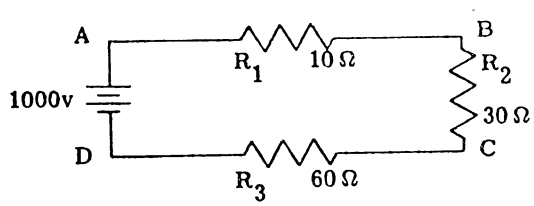
$$R_{1.2} = \frac{(3)(6)}{3+6} = \frac{18}{9} = 2\Omega$$

Redraw the circuit with $R_{1.2}$ in parallel with the 2Ω resistor.

---

118. Answer (2Ω)
(4a)
(8w)

119.



Complete the table for this circuit.

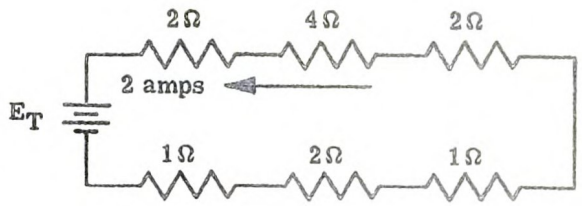
2. Answer

(3Ω)

3.

R_T = ( )Ω

E_T = ( )v



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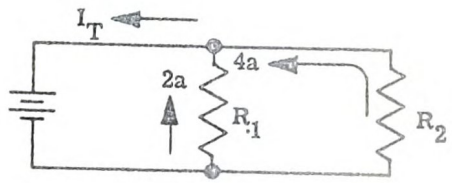
32. Answer

Remember that the voltage across each branch of a parallel circuit is equal to E_T.

(6v) (6v)

33.

I_T = ( )



---

62. Answer

$$\frac{E_T}{R_T}$$

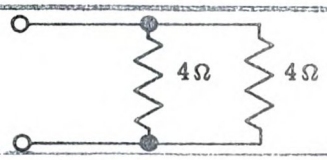
63.

In a parallel circuit, R_T = ( ).

Do NOT use $\frac{E_T}{I_T}$.

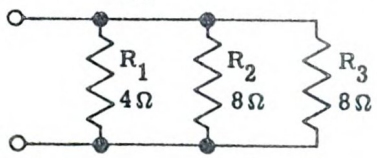
---

92. Answer

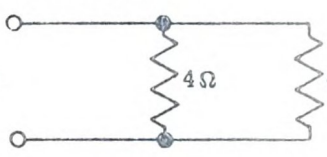


93.

After you find $R_{2,3}$, combine this with the other resistor in parallel.



is the same as



Draw the R_T of these two resistors.

27. Answer

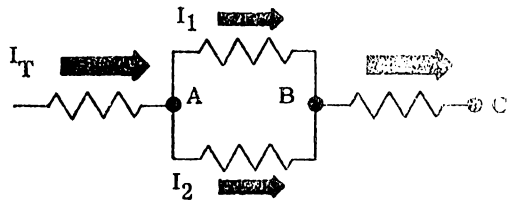
1. voltage 2. currents

3. current 4. voltages

28.

The current I_T splits at point A into I_1 and I_2.

I_1 and I_2 join up at point B so that ( ) flows to C.



---

57. Answer

smaller

58.

In a series circuit, we have two ways of finding R_T;

$R_T = R_1 + R_2$ and $R_T = \frac{E_T}{I_T}$.

In a parallel circuit, we have two ways of finding R_T; $R_T = \frac{R_1 \quad R_2}{R_1 + R_2}$ and $R_T = \frac{(\quad)}{(\quad)}$

---

87. Answer

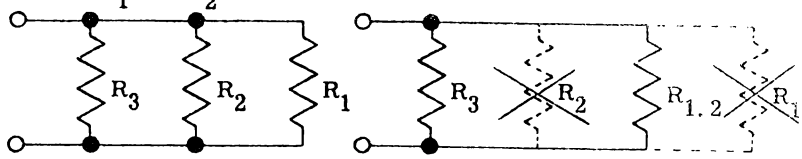
(2Ω)

(2Ω)

88.

We can find $R_{1.2}$ and put it in place of R_1 and R_2.

$R_{1.2}$ would be in parallel with ( ).



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117. Answer

	AB	CD	Total
R	12Ω	4Ω	3Ω
I	2a	6a	8a
E	24v	24v	24v
P	48w	144w	192w

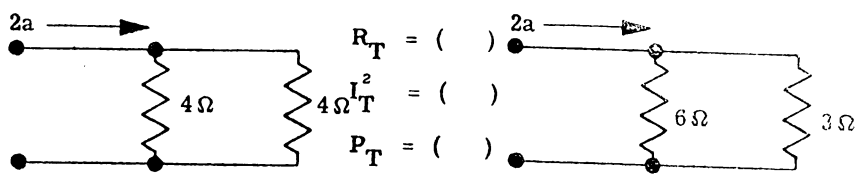
118.

$R_T = \frac{(4)(4)}{4+4} = 2\Omega$

$I_T^2 = 2(2) = 4a$

$P_T = (I_T)^2 R_T$

$P_T = (4)(2) = 8$ watts



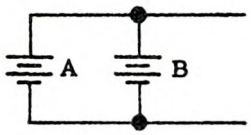
3. Answer

(12) (24)

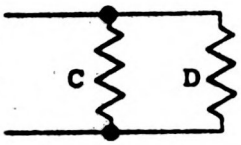
4.

When two electrical devices are connected with both ends together, we say they are in parallel.

Batteries A and B are in parallel.



Resistors C and D are in _____.



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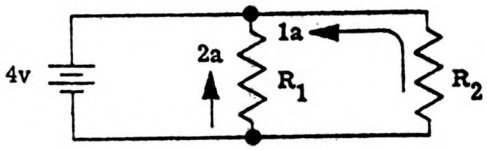
33. Answer

(6a)

34.

$R_1 = \frac{E}{I_1} = \frac{4v}{2a} = 2\Omega$

$R_2 = (\quad)$



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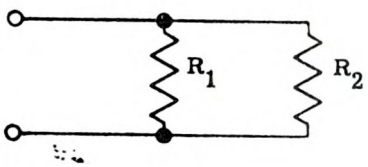
63. Answer

TEST

64.



If $R_1 = 6\Omega$, $R_2 = 3\Omega$ $\frac{(6)(3)}{6+3} = \frac{18}{9} = 2\Omega$

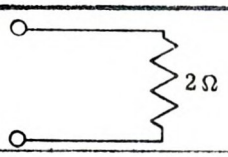
$R_T = 2\Omega$

If $R_1 = 6\Omega$, $R_2 = 6\Omega$

$R_T = (\quad)$

---

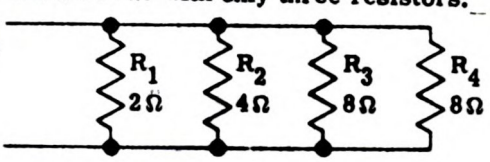
93. Answer



94.

If we have four or more resistors, the way we solve them is the same as with only three resistors.

Redraw this circuit with an $R_{3,4}$ for the R_3 and R_4 resistors.



26. Answer

(4a)

27.

Parallel circuits all have the same 1. _____ and the 2. _____ add.

Series circuits all have the same 3. _____ and the 4. _____ add.

---

56. Answer

(2a) (4a)

(2a) (2Ω)

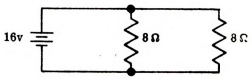
57.

$I_T = 2a + 2a = 4a$

$R_T = \frac{E_T}{I_T} = \frac{16v}{4a} = 4\Omega$

In a parallel circuit, the R_T is always smaller than any resistor in the circuit.

4Ω is _____ than 8Ω.



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86. Answer $R_{1.2}$

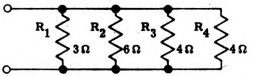
$R_{1.2}$ is a single resistor whose value is equal to the parallel value of R_1 and R_2.

87.

$R_{1.2} = (\quad)$

$R_{3.4} = (\quad)$

$R_{1.2} = \frac{R_1 \quad R_2}{R_1 + R_2}$



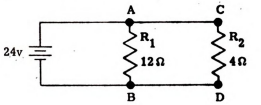
---

116. Answer

	AB	CD	Total
R	6Ω	3Ω	2Ω
I	1a	2a	3a
E	6v	6v	6v
P	6w	12w	18w

117.

Fill in the table

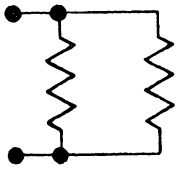


4. Answer

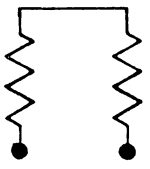
parallel

5.

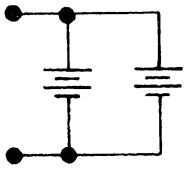
These resistors are in parallel.



These resistors are in series.



These batteries are in _____.



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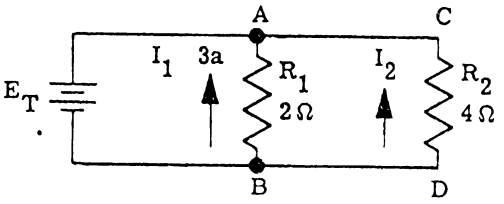
34. Answer

$\frac{4v}{1a} = 4\Omega$

35.

$E_{AB} = E_{CD} = E_T$ $\qquad E_{CD} = (\quad)$

$E_{AB} = I_1 R_1 = 3a\,(2\Omega)$ $\qquad E_T = (\quad)$



---

64. Answer

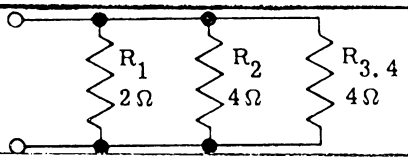
$R_T = \frac{(6)(6)}{6+6} = \frac{36}{12} = 3\Omega$

65.

$R_T = \frac{\text{the product of } R_1 \text{ and } R_2}{\text{the sum of } R_1 \text{ and } R_2} = \frac{(\quad)}{(\quad)}$

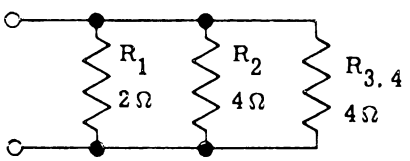
---

94. Answer



95.

Now draw the circuit with the R_2 and $R_{3,4}$ resistors combined.



25. Answer

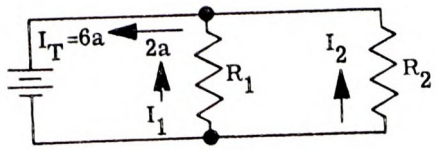
TEST

26.

$I_1 + I_2 = I_T$, then

$I_2 = I_T - I_1$

$I_2 = (\quad)$



---

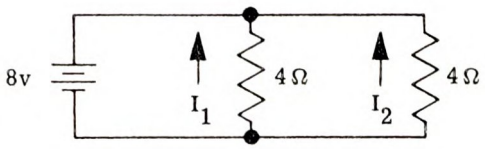
55. Answer (6v) (1Ω)

(6a) $\frac{6}{9}\Omega$ or $\frac{2}{3}\Omega$ or .667Ω

56.

$I_1 = (\quad)$ $I_T = (\quad)$

$I_2 = (\quad)$ $R_T = (\quad)$



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85. Answer

$I_T = \frac{12v}{2\Omega} + \frac{12v}{4\Omega} + \frac{12v}{4\Omega}$ $\quad R_T = \frac{E}{I_T} = \frac{12v}{12a} = 1\Omega$

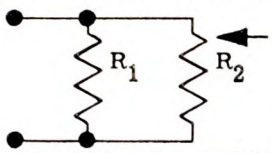
$I_T = 6a + 3a + 3a = 12a$

86.

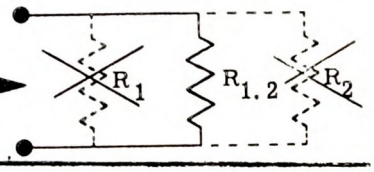
The R_T of resistors R_1 and R_2 is noted by the symbol $R_{1.2}$.

We can take out R_1 and R_2

and put in ( ).



This circuit is the same as this circuit



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115. Answer

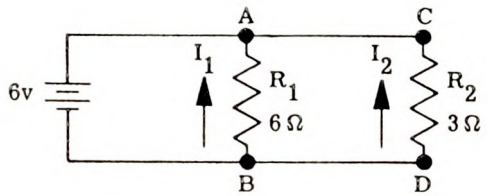
	AB	CD	Total
R	6Ω	3Ω	Test
I	1a	2a	3a
E	6v	6v	6v
P			

116.

Power in each column obeys the power law.

Complete the table.

As a check, P_T should equal $P_{AB} + P_{CB}$.

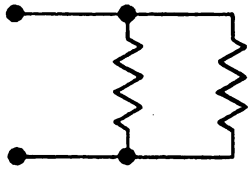


5. Answer

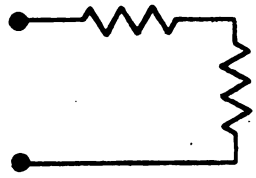
parallel

6.

These resistors are in _____.



These resistors are in _____.



---

35. Answer

(6v)

(6v)

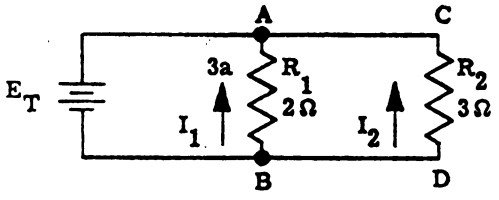
36.

$E_T = E_{AB} = E_{CD}$

$E_T = (\quad)$

$I_T = (\quad)$

To find I_T, you must first find I_2. $I_2 = (\quad)$



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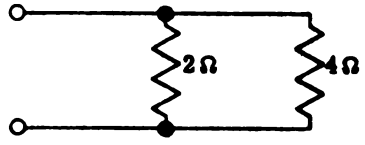
65. Answer

$$\frac{R_1 \quad R_2}{R_1 + R_2}$$

66.

$R_T = (\quad)\Omega$



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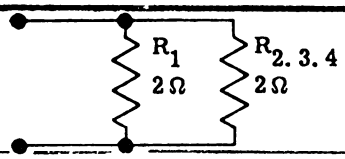
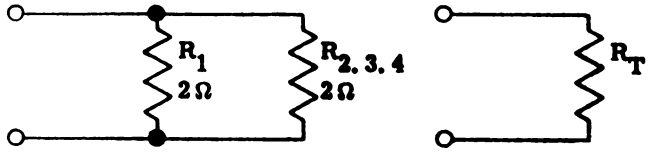
95. Answer



96.

The final R_T would be ( ).

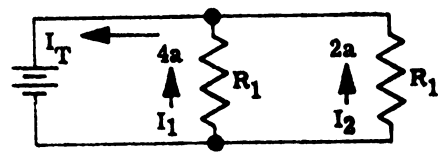


24. Answer

4Ω	6Ω	
3a	2a	5a
12v	12v	12v

25.

I_T = ( )



54. Answer

$E_T = E_{AB}$

$E_T = (2a)(4\Omega)$

$E_T = 8v$

$I_2 = I_T - I_1$

$I_2 = 8a - 2a$

$I_2 = 6a$

$R_T = \frac{E_T}{I_T} = \frac{8v}{8a}$

$R_T = 1\Omega$

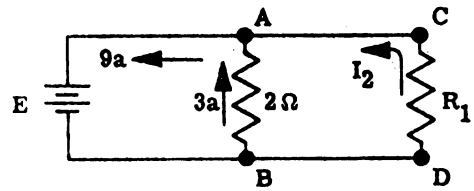
55.

E = ( )

I_2 = ( )

R_1 = ( )

R_T = ( )



If you need it, make a table.

84. Answer

$I_T = \frac{16v}{2\Omega} + \frac{16v}{4\Omega} + \frac{16v}{4\Omega} + \frac{16v}{2\Omega}$

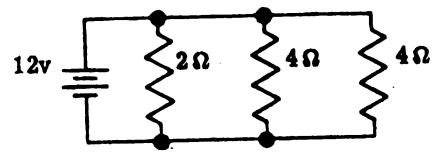
$I_T = 8a + 4a + 4a + 8a$

$I_T = 24a$

85.

I_T = ( )

R_T = ( )

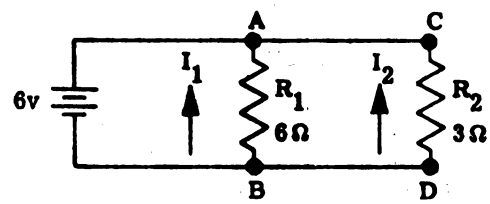


114. Answer

	AB	CD	Total
R	6Ω	3Ω	
I	1a	2a	3a
E	6v	6v	6v
P			

115.

From the values of E_T and I_T, find R_T in the table.

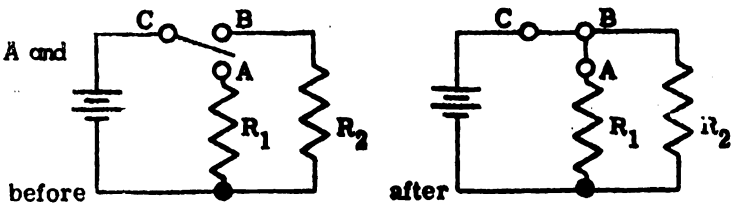


6. Answer

parallel series

7.

If we took out the switch and connected A and B to C, R_1 and R_2 would be in



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36. Answer E_T = TEST

$I_T = I_1 + I_2 = 3a + 2a = 5a$

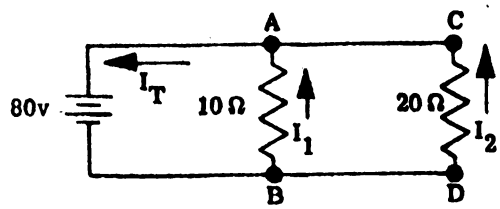
$I_2 = \frac{8v}{3\Omega} = 2a$

37.

I_1 = ( )a E_{AB} = ( )v

I_2 = ( )a E_{CD} = ( )v

I_T = ( )a



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66. Answer

$\frac{2(4)}{2+4} = \frac{8}{6}\Omega = \frac{4}{3}\Omega = 1\frac{1}{3}\Omega = 1.33\Omega$ (any of these answers)

67.

We have two ways of finding R_T in a parallel circuit.

Write them both.



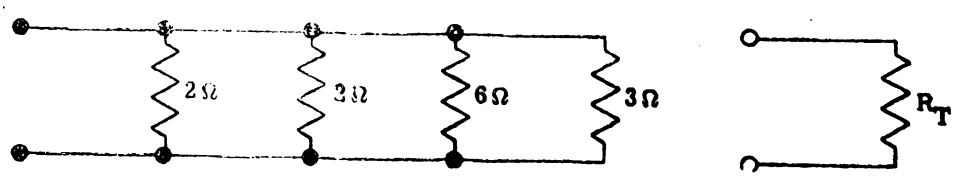
---

96. Answer

TEST

97.

What is the final R_T of this circuit? ( )

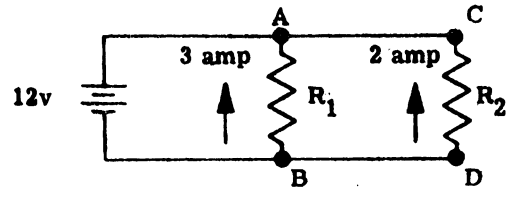


23. Answer Note that the currents add (2a + 1a = 3a) and the voltages are all 4v.

	1a	
4v	4v	

24.

Make a table for this circuit. (Leave out R total.)



Note that each column obeys Ohm's Law.

---

53. Answer

(4Ω) (4a)

(4Ω) (2Ω)

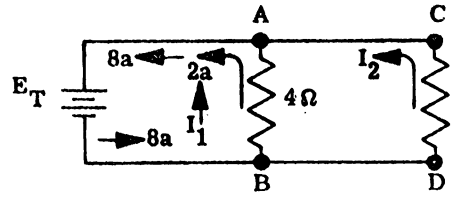
54.

E_T = ( ) Remember: $E_T = E_{AB} = E_{CD}$

I_2 = ( )

R_T = ( )

Make a table on scratch paper.



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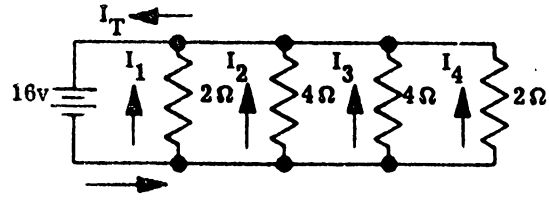
83. Answer $I_2 = \frac{12v}{3\Omega} = 4a$

$I_3 = \frac{12v}{4\Omega} = 3a$ $I_4 = \frac{12v}{6\Omega} = 2a$

84.

$I_T = I_1 + I_2 + I_3 + I_4$

I_T = ( )



---

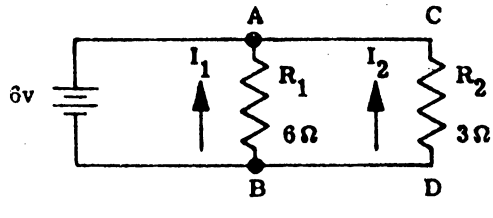
113. Answer

	AB	CD	Total
R	6Ω	3Ω	
I			
E	6v	6v	6v
P			

114.

From the values now in the table, find I_1 and I_2.

Remember that I_T = sum of branch currents.

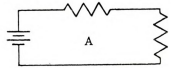


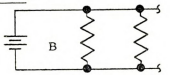
7. Answer

parallel

8.

Circuit A is a series circuit. Circuit B is a _____.





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37. Answer

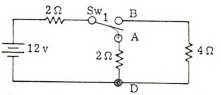
TEST

38.

If Sw_1 is in A, E_{AD} = ( ).

If Sw_1 is in B, E_{BD} = ( ).

Hint: first find I in each case.



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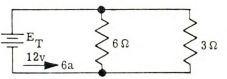
67. Answer

$R_T = \frac{E_T}{I_T}$ and $R_T = \frac{R_1 R_2}{R_1 + R_2}$ (either order)

68.

We work this problem both ways to check the answer.

$R_T = \frac{E_T}{I_T}$ = ( ) $R_T = \frac{R_1 R_2}{R_1 + R_1}$ = ( )



---

97. Answer

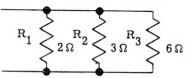
2/3Ω or .667Ω

98.

When we reduce a parallel circuit, it doesn't make any difference which pair we reduce first.

$R_{1,2}$ = ( ) $R_{1,3}$ = ( )

$R_{2,3}$ = ( )

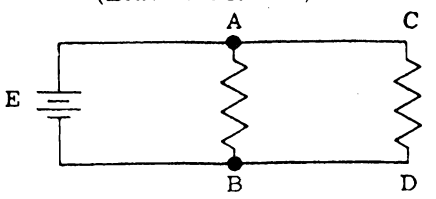


22. Answer

the same or equal

23.

(Leave out R total)



We can use a table for solving parallel circuits too.

In a parallel circuit, the voltages are all the same and the currents add. Finish this table.

---

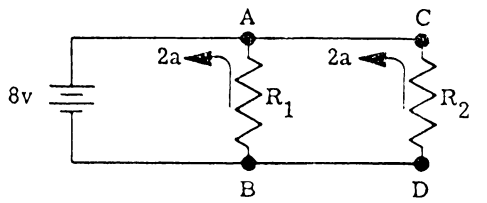
52. Answer

$I_T = I_1 + I_2 = \frac{12v}{6\Omega} + \frac{12v}{3\Omega} = 2 + 4 = 6a$ $\quad R_T = \frac{E_T}{I_T} = \frac{12v}{6a} = 2\Omega$

53.

$R_1 = (\quad)$ $\quad I_T = (\quad)$

$R_2 = (\quad)$ $\quad R_T = (\quad)$



Make a table on scratch paper.

---

82. Answer

$E_{BC} = E_{AD} = E_T$ $\quad E_{AD} = (2a)(2\Omega) = 4v$ $\quad E_T = 4v$ $\quad I_2 = \frac{E_{BC}}{4\Omega} = 1a$

$E_{AD} = (I_1)(R_{AD})$ $\quad E_{BC} = 4v$

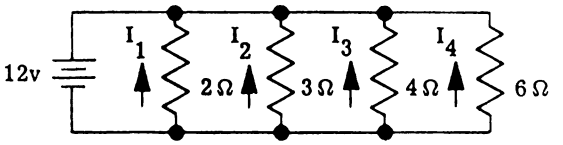
83.

$I_1 = \frac{12v}{2\Omega} = 6a$

$I_2 = (\quad)$

$I_3 = (\quad)$

$I_4 = (\quad)$



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112. Answer

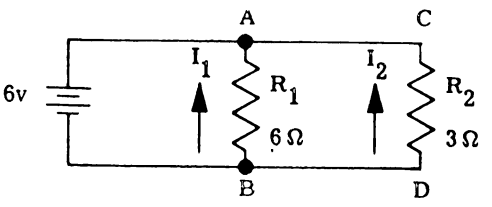
Yes No

113.

We can use a table to find power in parallel circuits.

Put the known values into the tables.

Remember that in a parallel circuit, E is the same, and R_T is NOT the sum of the resistances, but is always smaller then the smallest R.



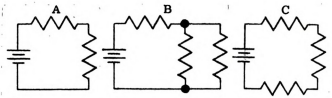
8. Answer

parallel circuit

9.

In a parallel circuit, there is more than one path for current flow.

Which diagram shows more than one path for current to flow? ( )



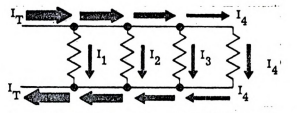
38. Answer

(6v)

(8v)

39.

If the currents are all equal through one branch and I_T = 20a, I_1 = ( ).



68. Answer $R_T = \frac{12v}{6a} = 2\Omega$

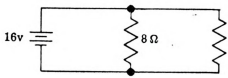
$$R_T = \frac{(6)(3)}{6+3} = \frac{18}{9} = 2\Omega$$

Note that the answer is 2Ω both ways.

69.

R_T = ( ); use $R_T = \frac{R_1 R_2}{R_1 + R_2}$

I_T = ( ); use $I_T = \frac{E_T}{R_T}$



98. Answer $R_{1.2} = \frac{(2)(3)}{2+3} = \frac{6}{5} = 1\frac{1}{5}\Omega$

$R_{2.3} = \frac{(3)(6)}{3+6} = \frac{18}{9} = 2\Omega$

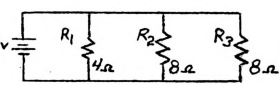
$R_{1.3} = \frac{(2)(6)}{2+6} = \frac{12}{8} = \frac{3}{2}\Omega$

99.

$R_{2.3} = \frac{(8)(8)}{8+8} = \frac{64}{16} = 4\Omega$

$R_T = \frac{(4)(4)}{4+4} = \frac{16}{8} = 2\Omega$

$I_T = \frac{E_T}{R_T}$ = ( )



21. Answer

(6a)

22.

In a parallel circuit the voltages are all _____.



---

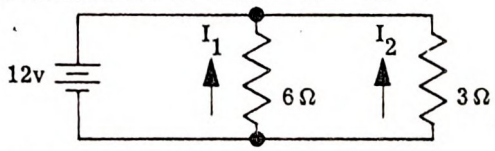
51. Answer

$R_T = \frac{E_T}{I_T} = \frac{8v}{2a} = 4\Omega \qquad R_1 + R_2 = 16\Omega$

52.

I_T = ( )

R_T = ( )



Remember: in a parallel circuit R_T is not the sum of the resistors.

---

81. Answer

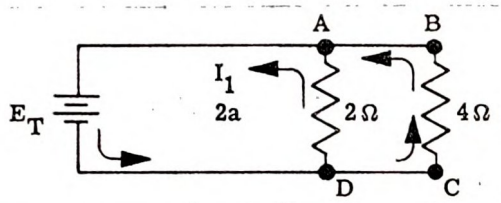
(8v) (8v)

82.

E_T = ( )

E_{BC} = ( )

I_2 = ( )



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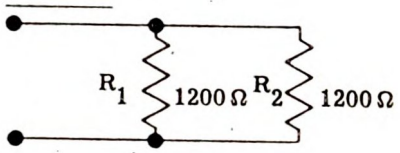
111. Answer

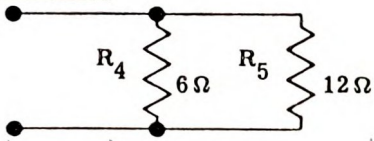
(2Ω) (3Ω)

112.

Is R_T 1/2 of R_1? _____



Is R_T 1/2 of R_4? _____



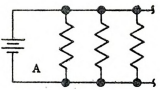
9. Answer

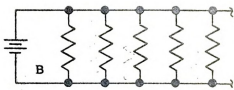
(B)

10.

Circuit A is a parallel circuit.

Circuit B is a _____ circuit.



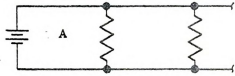


39. Answer

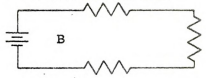
(5a)

40.

Circuit A is a _____ _____.



Circuit B is a _____ _____.



69. Answer

(4Ω)

(4a)

70.

In figure 1: In figure 2:

$R_T = \frac{(6)(3)}{6+3} = \frac{18}{9} = 2\Omega$ $R_T = (\quad)$

$E_T = R_T I_T = 2(3) = 6v$ $E_T = I_T R_T = (\quad)$

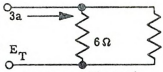


Figure 1

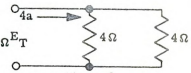
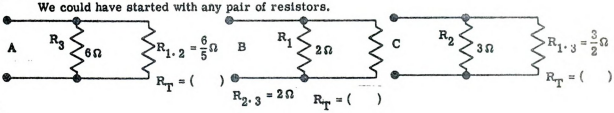


Figure 2

99. Answer

100.

We could have started with any pair of resistors.

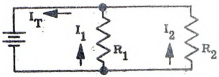


20. Answer

(6a)

21.

If I_1 = 2a and I_2 = 4a, I_T = ( ).



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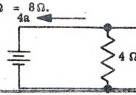
50. Answer

(6Ω) (3Ω) (2Ω)

---

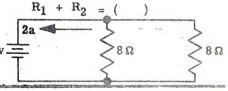
51. In parallel, $R_T = \frac{E_T}{I_T} = \frac{8v}{4a} = 2\Omega$. This is not the sum of the resistors,

which would be 4Ω + 4Ω = 8Ω.



R_T = ( )

$R_1 + R_2$ = ( )



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80. Answer

I_T = 2a + 6a = 8a $E_{AC} = E$ $R_T = \frac{E_T}{I_T} = \frac{16v}{8a} = 2\Omega$ E_{AC} = 16v

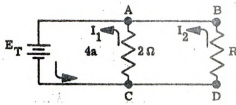
---

81.

$E_T = E_{AC} = E_{BD}$

E_{AC} = (4a) (2Ω) = 8v

E_{BD} = ( ) E_T = ( )



---

110. Answer

(2Ω)

111.

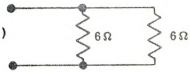
If the resistors are not equal, then the R_T is not 1/2 of their value.

R_T = ( )



R_T is not 1/2 of their value.

R_T = ( )



R_T is 1/2 of their value.

10. Answer

parallel

11.

Ohms Law may be expressed three ways:

I = ( ) R = ( ) E = ( )



---

40. Answer

parallel circuit series circuit

41.

The separate paths for current flow in a parallel circuit are called "BRANCHES."
There are two branches in figure 1.
How many branches are there in figure 2?



Fig 1

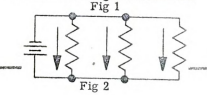


Fig 2

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70. Answer

(2Ω) (8v)

71.

In both series and parallel circuits $R_T = \frac{E_T}{I_T}$, but in a series circuit, $R_T = R_1 + R_2$, and in a parallel circuit, $R_T = (\quad)$.

---

100. Answer

A. $R_T = \frac{(6)(6/5)}{6 + 6/5} = \frac{36/5}{36/5} = 1\Omega$

B. $R_T = \frac{(2)(2)}{2 + 2} = \frac{4}{4} = 1\Omega$

C. $R_T = \frac{(3)(3/2)}{3 + 3/2} = \frac{9/2}{9/2} = 1\Omega$

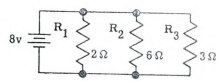
See, they all give R_T of 1Ω.

101.

$R_{2,3} = \frac{(6)(3)}{6 + 3} = \frac{18}{9} = 2\Omega$

$R_T = \frac{(2)(2)}{2 + 2} = (\quad)$

$I_T = (\quad)$



19. Answer

(6v)

(6v)

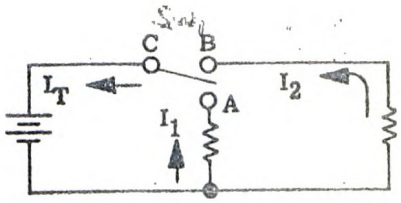
20.

In parallel, the currents add. $I_T = I_1 + I_2$

If Sw_1 is in position A, I_1 = 3a.

If Sw_1 is in position B, I_2 = 3a.

If both A and B are connected to C, I_T = ( ). $I_T = I_1 + I_2$



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49. Answer

Any of these are correct. $R_T = \frac{E_T}{I_T} = \frac{8v}{6a} = \frac{8}{6}\Omega = \frac{4}{3}\Omega = 1\frac{1}{3}\Omega = 1.33\Omega$

50.

	AB	CD	Total
R	4Ω	4Ω	2Ω
I	2a	2a	4a
E	8v	8v	8v

$R_T = \frac{E_T}{I_T}$

so $R_T = \frac{8v}{4a} = 2\Omega.$

Finish this table

	AB	CD	Total
R	( )	( )	( )
I	2a	4a	6a
E	12v	12v	12v

---

79. Answer

add same

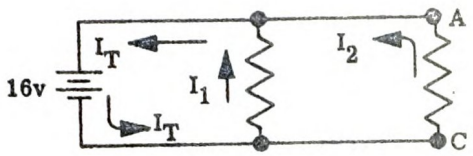
same add

80.

I_1 = 2a I_2 = 6a

R_T = ( ) E_{AC} = ( )

Make a table if you need it.



---

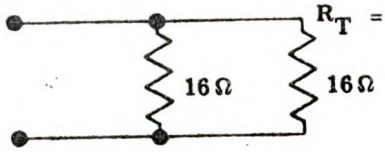
109. Answer

1/2 or .5

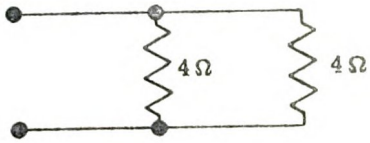
110.

$R_T = \frac{1}{2}$ of two equal resistors

$R_T = \frac{1}{2}(16) = 8\Omega$



R_T = ( )



11. Answer

$(\frac{E}{R})$ $(\frac{E}{I})$ (IR)

12.

A resistor and a lamp are connected in parallel across a 100v battery.

Draw the circuit. _____

---

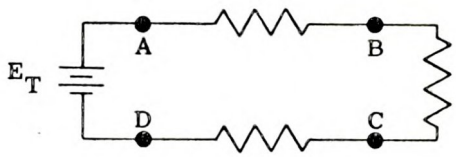
41. Answer

(3)

42.

In a series circuit, the voltages around the circuit add and the current flow is always the same through each resistor.

$E_T = E_{AB} + (\quad) + (\quad)$



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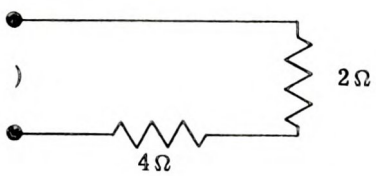
71. Answer

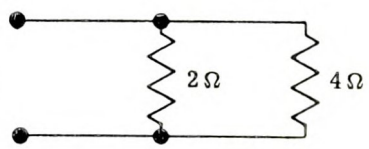
$$\frac{R_1 \quad R_2}{R_1 + R_2}$$

72.

$R_T = (\quad)$



$R_T = (\quad)$



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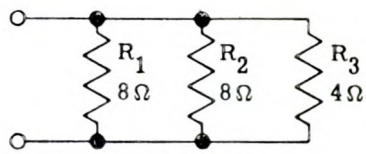
101. Answer

(1Ω)

(8a)

102.

To solve any parallel circuit, take any two resistors and put an equivalent resistance in their place. Redraw this circuit with the $R_{1.2}$ of the two 8Ω resistors.



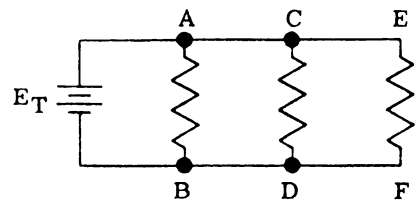
18. Answer

3. $R_T = R_1 + R_2 + R_3$

19.

E_T = 6v $\qquad$ E_{CD} = ( )

E_{AB} = 6v $\qquad$ E_{EF} = ( )



---

48. Answer

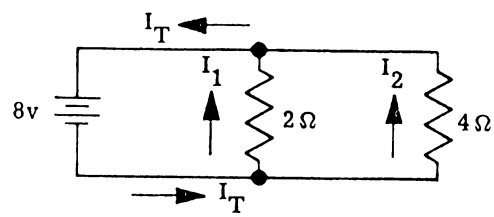
(8Ω) $\qquad$ (8Ω)

49.

In a parallel circuit R_T is not the sum of all the resistors.

$I_T = I_1 + I_2 = \frac{8v}{2\Omega} + \frac{8v}{4\Omega} = 4a + 2a = 6a$

$R_T = \frac{E_T}{I_T} = \frac{8v}{6a} = ($ $)$



---

78. Answer

TEST

---

79. In a series circuit, the voltages _____ around the circuit, and the current is the _____ through each resistor.

In a parallel circuit, the voltage across each branch is the _____ and the currents through each branch _____.

---

108. Answer

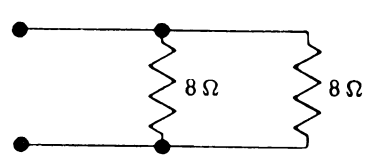
TEST

109.

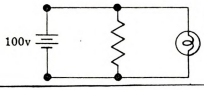
If two resistors are in parallel and are equal, the R_T is 1/2 of their value.

$R_T = \frac{(8)(8)}{8 + 8} = \frac{64}{16} = 4\Omega$

8 × ( ) = 4



12. Answer



13.

In a circuit, the total power (P_T) is the sum of the power across each component. Which formula says the same thing as the sentence? ( )

1. $P_T = I_T E_T$ 2. $P_T = I_T{}^2 R_T$ 3. $P_T = P_1 + P_2 + P_3$

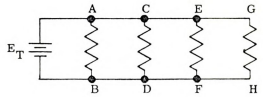
42. Answer

$E_{BC} + E_{CD}$

43.

In a parallel circuit, the currents through each branch add and the voltage across each branch is the same.

$E_T = E_{AB} = E_{CD} = (\quad) = (\quad)$



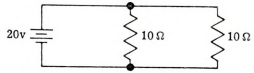
72. Answer

(6Ω) $\frac{8}{6}$ or $\frac{4}{3}$ or 1.33Ω

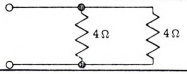
73.

$I_T = (\quad)$

Hint: first find R_T, then find I_T.



102. Answer

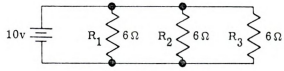


103.

$R_{2,3} = \frac{(6)(6)}{6+6} = \frac{36}{12} = 3\Omega$

$R_T = (\quad)$

$I_T = (\quad)$



17. Answer

A, B, and C, or all

---

18. In a series circuit of 3 resistors, the total resistance (R_T) is equal to the sum of the individual resistances.

Which formula says the same thing as the sentence?

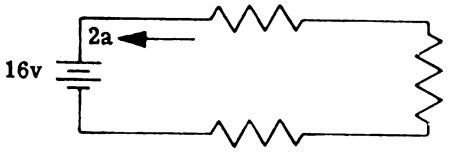
1. $R_T = \frac{E_T}{I_T}$ 2. $R_T = R_1 - R_2 - R_3$ 3. $R_T = R_1 + R_2 + R_3$

---

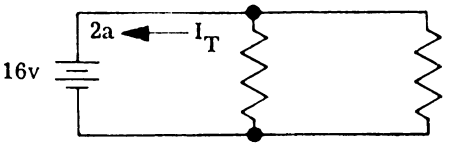
47. Answer

$R_T = \frac{E_T}{I_T} = \frac{8v}{2a} = 4\Omega$

48.



$R_T = (\quad)$



$R_T = (\quad)$

---

77. Answer

$R_T = \frac{(10)(8)}{10+8} = \frac{80}{18} = \frac{40}{9} = 4\frac{4}{9} = 4.44\Omega$

78.

$I_T = 5a$ $E_T = 20v$

$R_T = (\quad)$

---

107. Answer

(1Ω)

(8a)

108.

A 4Ω toaster, an 8Ω iron, and an 8Ω heater are in parallel across an 80v line.

$R_T = (\quad)$

$I_T = (\quad)$

13. Answer

3. $P_T = P_1 + P_2 + P_3$

14.

Write three forms of Ohm's Law.

1. ( )
2. ( )
3. ( )

---

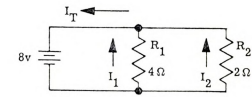
43. Answer

E_{EF} E_{GH}

44.

I_2 = ( )

I_T = ( )



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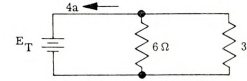
73. Answer

$R_T = \frac{(10)(10)}{10 + 10} = \frac{100}{20} = 5\Omega$ $I_T = \frac{E_T}{R_T} = \frac{20v}{5\Omega} = 4a$

74.

E_T = ( )



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103. Answer

(2Ω)

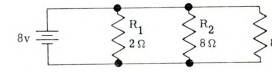
(5a)

104.

$R_{2.3}$ = ( )

R_T = ( )

I_T = ( )

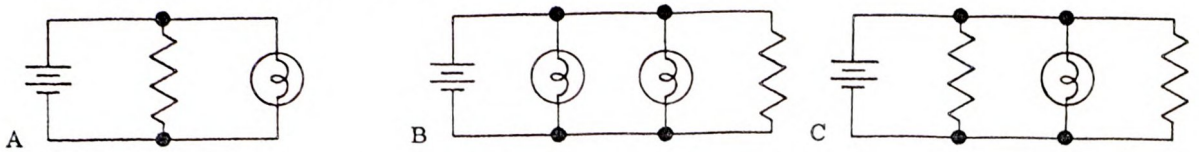


16. Answer

(PR) $(\frac{E^2}{P})$ $(\frac{P}{R})$ $(\frac{P}{I^2})$

17.

Which circuits show elements in parallel? ( )



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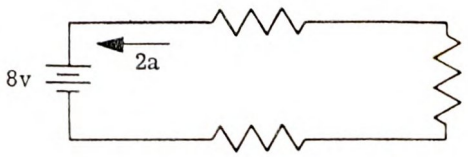
46. Answer

TEST

47.

We know that R_T is the total resistance and that $R_T = \frac{E_T}{I_T}$.

What is the total resistance of this circuit? ( )



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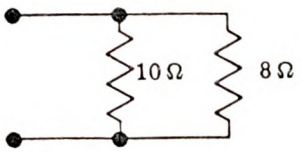
76. Answer

(24)

77.

R_T = ( )



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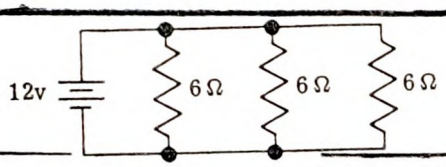
106. Answer

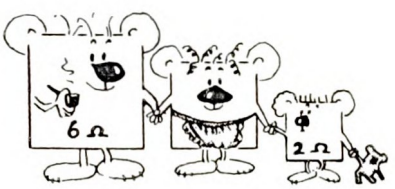


107.

A 2Ω, a 6Ω, and a 3Ω resistor are all in parallel across an 8v battery.

R_T = ( )

I_T = ( )



14. Answer

1. $E = IR$ 2. $I = \frac{E}{R}$ 3. $R = \frac{E}{I}$ (any order)

15.

In a parallel circuit there is (one/more than one/no) path for current to flow.

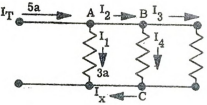
41. Answer $I_T = I_1 + I_2$

$I_1 = \frac{E_T}{R_1} = \frac{8v}{4\Omega} = 2a$ $I_2 = \frac{E_T}{R_2} = \frac{8v}{2\Omega} = 4a$ $I_T = 6a$

$I_T = 2a + 4a$

45.

I_T splits up at A into I_1 and I_2.
I_2 splits up at B into I_3 and I_4.
I_3 and I_4 join up at C and produce I_x.
So, $I_x = I_2$. $I_x = (\quad)$.

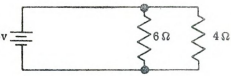


74. Answer

$R_T = \frac{(6)(3)}{6+3} = \frac{18}{9} = 2\Omega$ $E_T = I_T R_T = (4a)(2\Omega) = 8v$

75.

$I_T = (\quad)$



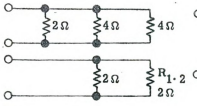
104. Answer $R_{2,3} = \frac{(8)(8)}{8+8} = \frac{64}{16} = 4\Omega$ $I_T = \frac{E_T}{R_T} = \frac{8v}{4/3\Omega} = 6a$

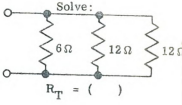
$R_T = \frac{(R_1)(R_{2,3})}{R_1 + R_2} = \frac{(2)(4)}{2+4} = \frac{8}{6} = \frac{4}{3} = 1\frac{1}{3}\Omega$

105.

$R_{1,2} = \frac{(4)(4)}{4+4} = \frac{16}{8} = 2\Omega$ First

$R_T = \frac{(2)(2)}{2+2} = \frac{4}{4} = 1\Omega$ Then





15. Answer

TEST

16.

If $P = \frac{E^2}{R}$, $E^2 =$ ( ) and $R =$ ( ).

If $P = I^2R$, $I^2 =$ ( ) and $R +$ ( ).

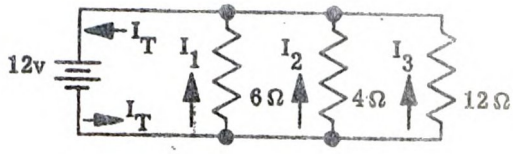
---

45. Answer

(2a)

46.

$I_T =$ ( )



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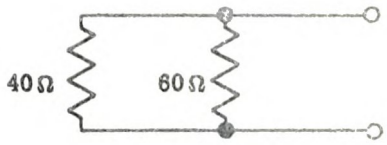
75. Answer

$I_1 = \frac{4.8v}{6\Omega} = .8a$ $I_2 = \frac{4.8v}{4\Omega} = 1.2a$ $I_T = I_1 + I_2 = .8 + 1.2 = 2a$

76.

$R_T =$ ( ).

Remember: in parallel circuits R_T is always smaller than either R_1 or R_2.



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105. Answer

(3Ω)

106.

Three 6Ω resistors are placed in parallel across a 12v battery.

Draw the circuit.

APPENDIX C

CROWDER PROGRAM

OHM'S LAW AND POWERS OF TEN

1-C



NAVAL AIR TECHNICAL TRAINING COMMAND

Acknowledgements

This program was adapted by the Naval Air Technical Training Center, Memphis, Tennessee, from a larger one developed under contract No. AF 33 (616)-6983 CPFF between the U.S. Air Force and Western Design and Electronics. In a letter dated 27 July, 1961 from the Aeronautical Systems Division, Air Force Systems Command, United States Air Force, use of these materials by other governmental agencies was confirmed. Appreciation is expressed to the Aeronautical Systems Division and to Western Design and Electronics for assistance in making the original program available.

In this course you do not go from page 1 to page 2 to page 3 etc, but after reading the material given, a question will be asked and your answer will determine the page you go to next.

You advance at your normal rate of learning. You cannot advance until you are right.

We will start out with Ohm's Law and Powers of Ten and go on to simple series circuits in the next lesson, and then to simple parallel circuits in the third lesson.

Ohm's law can be summed up: Voltage (EMF) equals amperage times resistance. In mathematical shorthand, E is the symbol used for voltage, I stands for amperage, and R for resistance. The formula for Ohm's law is expressed as follows:

$$E = I \times R \quad \text{or} \quad E = IR$$

That means electromotive force (in volts) equals current (in amperes) times resistance (in ohms).

Now, if I equals .5 and R equals 12 ohms, what does E equal?

6 volts	Page 3
24 volts	Page 5
60 volts	Page 7

YOUR ANSWER: The unit in which I is measured is the ohm.

No. And since you are apparently still uncertain about what unit measures which quantity, or which letter is the symbol for which quantity, here they are again.

Resistance (denoted by the letter R) is measured in ohms.

Voltage (denoted by the letter E) is measured in volts.

Current (denoted by the letter I) is measured in amperes.

Return to Page 3 for the correct answer.

YOUR ANSWER: 6 volts.

$$E = IR = .5 \times 12 = 6 \text{ volts.}$$

Right. What is the unit in which I is measured?

The ohm	Page 2
The ampere	Page 6
The volt	Page 11

YOUR ANSWER: An ampere is equal to the electrons that will flow through a resistance of one ohm.

No.

You have begun to say something. But you have not finished.

Amperes denote coulombs-per-second. Your answer is an incomplete statement because it contains no mention of the time involved or the quantity of electrons.

You can't just splash around with words and hope they come out right -- not in electronics, at any rate.

One of the alternative statements is much more precise. Return to **Page 6** and select that one for your answer.

YOUR ANSWER: 24 volts.

Wrong.

This is the problem again: If I equals .5 amps and R equals 12 ohms, what does E equal?

Here is the formula once more: E = IR.

You seem to have divided I into R, instead of multiplying as the formula indicates.

The calculation you should have made is:

E = IR = .5 amps x 12 ohms = ? volts.

Complete the calculation and then return to Page 1 for the correct answer.

YOUR ANSWER: The ampere.

Right. Current is measured in amperes.

What is an ampere equal to?

The electrons that will flow through a resistance of one ohm. Page 4

Resistance times voltage. Page 8

One coulomb of electrons per second. Page 14

YOUR ANSWER: 60 volts.

No. You apparently got a little careless about the placing of the decimal point. The decimal point is important, to say the least.

The problem: If I equals .5 amps and R equals 12 ohms, what does E equal?

The formula: $E = IR$

The calculation: $E = IR = .5 \text{ amps} \times 12 \text{ ohms} = ? \text{ volts}$.

Taking care to be a shade less reckless with the decimal point this time, return to Page 1 for the accurate answer.

YOUR ANSWER: An ampere is equal to resistance times voltage.

No.

This is a wild attempt at rendering Ohm's Law in different form. In addition it is a hopelessly imprecise statement.

If expressing any scientific law, you have to be precise about the quantities involved. "An" ampere means "one" ampere. Your answer seems to say, "One ampere is equal to an indefinite amount of resistance multiplied by an indefinite amount of voltage".

To make matters worse, the form in which you have met Ohm's Law so far is $E = I/R$, current (in amperes) equals voltage divided by resistance. That's something we'll come to shortly.

To get back to the question: Do you recall what an ampere is? It is another way of saying electrons are flowing at the rate of one coulomb per second, isn't it?

Bear that in mind as you return to Page 6 to select another answer.

YOUR ANSWER: E stands for resistance.

Oh, come now!

E is the symbol for voltage, or, if you like, electromotive force.

As you have just seen, I is the symbol for current, and R is the symbol for resistance.

Return to Page 14 , vowing never to forget that I stands for current, E for voltage and R for resistance.

YOUR ANSWER: .25a

If you got that answer right the first time, you did well because you discovered one of the two variations of Ohm's Law. We began with this: E = IR. The variation is written:

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

It is used when E and R are known and you need to find I.

Of course, both the original statement and the variation are the same thing. If E = IR, then

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

It is perfectly legitimate to perform the same mathematical operation to both sides of an equation. To change Ohm's Law for purposes of discovering amperage, we merely divided both sides of the equation by R.

If E and I are known but not R, how would we vary the formula?

$R = \frac{E}{I}$ Page 12

$R = \frac{I}{E}$ Page 21

You can't find R from the other two factors. Page 23

YOUR ANSWER: The unit in which I is measured is the volt.

No. And since you are apparently still uncertain about what unit measures which quantity, or which letter is the symbol for which quantity, here they are again.

Resistance (denoted by the letter R) is measured in ohms.

Voltage (denoted by the letter E) is measured in volts.

Current (denoted by the letter I) is measured in amperes.

Return to Page 3 for the correct answer.

YOUR ANSWER: $R = \frac{E}{I}$

Right. In this case, both sides of the equation are divided by I.

So, Ohm's Law can be written in three different ways, depending on which variable is unknown. The three ways are:

$$E = IR$$

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

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

Now, if you are given E = 6 and I = .3a, what is R?

.05Ω	Page 19
2Ω	Page 24
20Ω	Page 26

YOUR ANSWER: Voltage.

Good for you. E stands for voltage. This is not as hard to remember as it may seem. Voltage is the unit in which we measure electromotive force (EMF, as it is called).

Which of the following would be an accurate statement about voltage?

Voltage is the electrical pressure needed to move a coulomb through one ohm of resistance. Page 15

Voltage can be found by multiplying resistance times current. Page 19

Voltage is the electromotive force of a resistance of one ohm. Page 22

YOUR ANSWER: One coulomb of electrons per second.

Correct. One of the wrong answers, "The electrons that will flow through a resistance of one ohm " is not a complete statement. If it had been stated as: "The number of electrons that will flow through a resistance of one ohm. in one second when one volt of electrical pressure is being applied", it would have been accurate.

Now, what does E stand for?

Resistance Page 9

Voltage Page 13

Current Page 17

YOUR ANSWER: Voltage is the electrical pressure needed to move a coulomb through one ohm of resistance.

Almost, but not quite.

Somewhere in that statement you need a reference to time. You can say, for instance, that a volt is the electrical pressure needed to move one coulomb through one ohm of resistance in one second.

You could say that voltage is electromotive force and that it is measured in volts.

Unfortunately, neither of these complete answers is available to you.

There is another way of arriving at voltage, and that is through Ohm's Law. If you know the resistance and the current present in a circuit you can calculate voltage.

And that should be enough of a hint for you to return to Page 13 and select the correct answer.

YOUR ANSWER: 4a

Wrong.

Here is the problem again: If E = 24v and R = 96Ω, what is the value of I?

Ohm's Law as we have considered it so far says: E = IR. Obviously we need it in different form since I is the unknown quantity.

To isolate I, divide both sides of the equation by R. This gives you:

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

Thus I = E/R = 24 volts/96 ohms = ? amperes.

Return to Page 18 with the correct answer.

YOUR ANSWER: E stands for current.

No. No. And again, no. You've seen enough of these symbols by now to be able to recognize them.

E is the symbol for voltage, or, if you like, electromotive force.

As we saw just a moment ago, the symbol for current is I. And R is the symbol for resistance.

Return to Page 14 , vowing never to forget that I stands for current, E for voltage and R for resistance.

YOUR ANSWER: Voltage can be found by multiplying resistance times current flow.

Ohm's law, E = IR. Right you are. The statement that voltage is the electrical pressure needed to move a coulomb through one ohm of resistance, was almost correct as a definition of one volt. But it lacked a time factor. If it had been modified in either of two ways, it would have been correct:

1. A volt is the amount of electrical pressure needed to move one coulomb through one ohm in one second, or

2. A volt is the amount of electrical pressure needed to move one ampere through one ohm.

The Greek letter omega, which looks like this Ω, is the abbreviation for ohm. The shorthand for volt is simply v or V; that for amperes is a. We could say:

$$v = a\Omega .$$

That statement is true. It is Ohm's law written in different symbols. However, it is not proper usage. Now, here is a problem which illustrates the proper usage:

If E = 24v and R = 96Ω, what is I?

I = .25a Page 10

I = 4a Page 16

I = 2304a Page 20

YOUR ANSWER: .05Ω

Wrong.

You've got things topsy-turvy.

The equation you should be working with says:

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

The equation you seem to have used says:

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

Go back to the version you should have used and when you have the answer, return to Page 12

YOUR ANSWER: 2304a.

Wrong.

Here is the problem again: If E = 24v and R = 96Ω, what is the value of I?

Ohm's Law as we have considered it so far says: $E = IR$. Obviously we need it in different form since I is the unknown quantity.

To isolate I, divide both sides of the equation by R. This gives you:

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

Thus I = E/R = 24 volts/96 ohms = ? amperes.

Return to Page 18 with the correct answer.

YOUR ANSWER: $R = \frac{I}{E}$.

No. You're getting tangled up in transposing this equation.

We know that Ohm's Law can be expressed $E = IR$.

In a case where we do not know the value of R the equation can be adjusted to isolate R by dividing both sides by I, like this:

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

You see that the top and bottom I in the right-hand group cancel each other, leaving the final equation:

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

Work it over once more for yourself and then return to Page 10 for another answer.

YOUR ANSWER: Voltage is the electromotive force of a resistance of one ohm.

No. This is one of those answers that doesn't really say anything. It would be as sensible to say that voltage is the electromotive force of a stick of licorice.

A resistance of one ohm got into the conversation because it was possible to pass a current of one ampere through it by applying a voltage of one volt.

And, you may recall, that led us to Ohm's Law in the form E = IR -- voltage equals current times resistance.

You should now be well enough informed to return to Page 13 and select the correct answer.

YOUR ANSWER: You can't find R from the other two factors.

Your mathematics is coming unstuck.

In an equation involving three factors, if you know any two you can find the third.

You have an example in Ohm's Law when it is expressed E = IR. If you do not know E but have values for I and R, then multiplying together the known values will give you the value of E. That is what the equation tells us.

And if we divide both sides of the original equation by I, we can obtain an equation which isolates R and expresses it in terms of the other values, like this:

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

If you have trouble in following this, substitute simple numbers for the factors in the original equation, thus: Instead of E = IR, write 12 = 3 x 4. If you want to isolate the factor 4, divide both sides of the equation by 3, like this:

$$\frac{12}{3} = \frac{3 \times 4}{3} \text{ leaving } 4 = \frac{12}{3}$$

This method of substituting simple figures for factors within a formula is useful as a check in many cases.

And with that, return to Page 10 and select the correct answer.

YOUR ANSWER: 2Ω

No.

Decimals can be a nuisance, but ignoring them won't make them go 'way.

The equation you need is the version of Ohm's Law with which we began the last page, R = E/I.

If we apply that to the present problem, in which E = 6v and I = .3a, we get:

R = E/I = 6 volts/.3 amperes = ? ohms.

Complete the calculation, this time allowing for the decimal point, and return with your answer to Page 12

YOUR ANSWER: .2 volt.

Wrong.

Obviously you needed prompting after all on the form of Ohm's Law to be used.

You should have been back with the first version of the formula, the one you should have committed to memory. Here it is again. Memorize it.

$$E = IR$$

In this case we know that R = 10 ohms and I = 2 amperes.

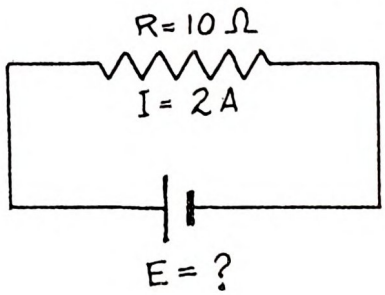
$$E = IR = 2 \text{ amperes} \times 10 \text{ ohms} = ? \text{ volts.}$$

Return to Page 26 with the correct answer.

YOUR ANSWER: 20Ω

Correct. R = E/I = 6/.3 = 20Ω.

Now without any prompting on the form of Ohm's Law you're to use, what is the value of E in this circuit?



2 volts	Page 25
5 volts	Page 28
20 volts	Page 30

YOUR ANSWER: 1.2 volts.

Wrong.

This looks like a guess that was guided by the form of the other answers. And if it wasn't then your arithmetic isn't working too well today.

Let's go over the simple calculation: The resistance is 6 ohms, the current is .02 amperes. The equation you need to find the voltage is E = IR.

E = IR = .02 amperes x 6 ohms = ? volts.

When you have the answer, return to **Page 30.**

YOUR ANSWER: 5 volts.

Wrong.

Obviously you needed prompting after all on the form of Ohm's Law to be used.

You should have been back with the first version of the formula, the one you should have committed to memory. Here it is again. Memorize it.

$$E = IR$$

In this case we know that R = 10 ohms and I = 2 amperes.

E = IR = 2 amperes x 10 ohms = ? volts.

Return to Page 26 with the correct answer.

YOUR ANSWER: Not 1.2 volts

Correct.

This is the calculation:

E = IR .02 x 6 = .12 volts.

This form of Ohm's Law, E = IR, is the most important and most often used version. In addition, it has the advantage that it is the easiest version to convert to the other forms. Merely dividing both sides by the unwanted quantity will leave you a desired quantity at the right. You should memorize the law in this form.

Now lets check your understanding of Ohm's Law in the next four questions. Just choose one of the distractors and keep going. These will be checked at the end of the last period. Just put down a, b, c, or d for your answer.

In using Ohm's Law, if R is 20 ohms and E is 100 volts, what will I be?

- a. .2 amps
- b. .5 amps
- c. 2 amps
- d. 5 amps

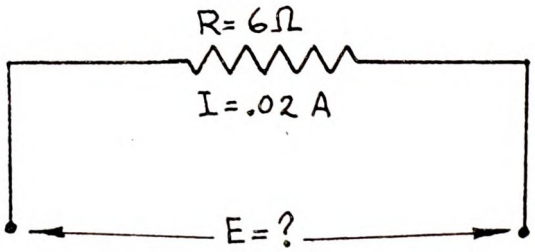
After selecting an answer go on to page 31.

YOUR ANSWER: 20 volts.

Correct. E = IR = 2 x 10 = 20 volts.

Keep in mind what the letter E stands for: It is voltage, the unit of measurement for electromotive force. Voltage is really a measurement of the difference in electrical pressure between two points. It is this difference in pressure that exerts the force to make electrons move from one point (the point of higher pressure) to another point (the point of lower pressure).

What is the EMF of this circuit?



1. 2 volts Page 27
Not 1. 2 volts Page 29
I don't know. Page 32

What is the resistance of an electric soldering iron if it operates on 120 volts d-c and draws 3 amps.

a. 360 ohms

b. 40 ohms

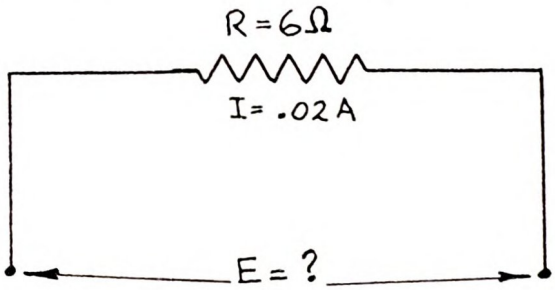
c. 25 ohms

d. .025 ohms

After selecting an answer go on to page 33.

YOUR ANSWER: I don't know.

There's nothing new in the text at this point. Is it the diagram that bothers you? Here it is again:

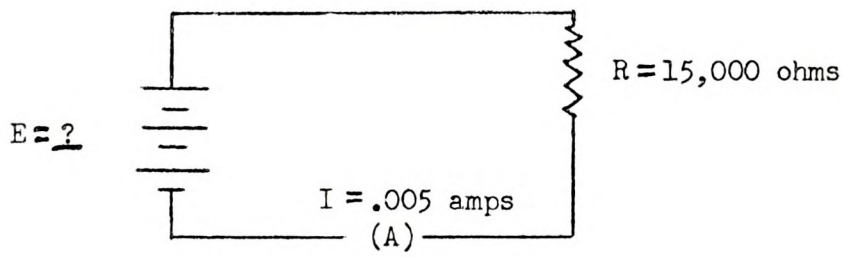


And the only thing that is new about this diagram is the method of showing the voltage source. This is the reason for the reminder that preceded it: "Voltage is a measurement of the difference in electrical pressure between two points. It is this difference in pressure that makes electrons move from one point (the point of higher pressure) to another point (the point of lower pressure)."

In this diagram we are showing a voltage source without indicating just what form that source takes -- it might be a battery, it might be a generator, it could be that this is an offshoot of some larger circuit. You are not told what it is and it doesn't matter what it is, as far as the problem is concerned. The important thing is that voltage is being imposed on this circuit and that it is causing a current of .02 amperes.

Once again the voltage can be found by using the E = IR form of the Ohm's Law formula. When you have a value of E, return to Page 30 and select the correct answer.

Solve for the unknown in the diagram below.



a. 3,000,000 volts

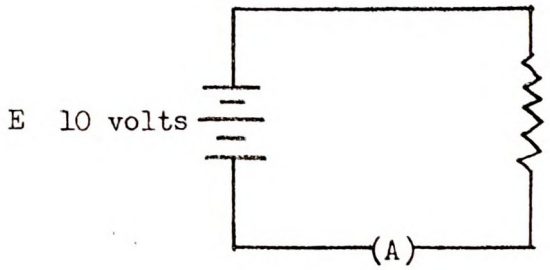
b. 3,000 volts

c. 750 volts

d. 75 volts

After selecting an answer go on to page 34.

If the resistance of the resistor in the circuit below decreases in value, what will happen to the current in the circuit.



a. it increases

b. it decreases

c. it stays the same

After selecting an answer go on to page 55 and continue with Power's of Ten.

YOUR ANSWER: $8 \times 10^3\Omega$ would be 800 amperes.

No, this answer is wrong twice. The omega (Ω) is the Greek letter that is used for ohms, not amperes. You will find amperes shown: A, a, or amp.

Also, you have chosen the wrong power of ten. Remember that 10^3 is the same thing as 10 cubed, 10 x 10 x 10 or 1000. You must move the decimal point three places to the right when you multiply a number by 10^3.

Now return to Page 38 and choose the correct answer.

YOUR ANSWER: $8 \times 10^3 \Omega$ is 8000 amperes.

No, the Greek letter omega (Ω) is used for ohms, not amperes. You will find amperes indicated: A, a, or amp.

However, you did choose the correct numerical value for 8×10^3. You move the decimal point three places to the right to multiply by 10^3.

Now return to page 38 and choose the correct answer.

YOUR ANSWER: 2.5×10^4v means 2500 volts.

No. When you multiply by 10^4 you must move the decimal point four places to the right, as you would to multiply by 10,000.

The thing to remember is: The exponent tells you how many places to move the decimal point.

If you feel you need a more detailed explanation of powers of ten, please go to Page 55

If this was just a slip and you think you understand, return to Page 43 and select the correct answer.

How would you translate $8 \times 10^3 \Omega$?

800 amperes	Page 35
8000 amperes	Page 36
800 ohms	Page 39
8000 ohms	Page 43

YOUR ANSWER: $8 \times 10^3 \Omega$ is 800 ohms.

No, you've multiplied by the wrong power of 10. Remember that 10^3 is 10 multiplied by itself three times ($10 \times 10 \times 10 = 1000$). To multiply by 10^3 you must move the decimal point three places to the right, so that you multiply by 1000.

Now return to Page 38 and choose the correct answer.

YOUR ANSWER: 2.5×10^4v = 25,000 volts.

Right. Since the decimal point is before the 5, moving it four places to the right yields 25,000.

If you came here by the direct route and now find this isn't completely clear, spend a few minutes reviewing powers of ten by going immediately to Page 55.

If it is plain, let's consider powers of ten with negative exponents.

To multiply powers of ten, you add the exponents. Or, to put it more precisely than we have done until now, you add the exponents algebraically. We introduce that word "algebraically" to take care of the instances in which negative numbers are concerned.

To divide powers of ten, you change the sign of the number you are dividing by and then proceed as in multiplication, adding the exponents algebraically.

An example will make this plainer. Say you want to divide 100 by 10,000. You know the answer is going to be 0.01. Let's do it with powers of ten:

$$\frac{100}{10,000} = \frac{10^2}{10^4} = 10^{2-4} = 10^{-2} = 0.01$$

You see what's happened? In dividing, we arrived at an answer that was less than 1. Our answer is 1×10^{-2}, which is 0.01. To increase 0.01 to 1, the decimal point moves two places, but this time it moves to the right.

To arrive at a positive exponent, we moved the decimal point to the left. This time, by moving the decimal point in the opposite direction, we have an exponent with the opposite sign -- a negative sign.

Now you try it. How would you express 0.000001 as a power of ten?

1×10^5 Page 42

1×10^{-5} Page 47

1×10^{-6} Page 59

I don't get it Page 71

YOUR ANSWER: 9.8×10^{-4}A means 0.0098 amperes.

Well, it looks as if you have four decimal places in your answer, but you have actually moved the decimal point only three places to the left.

To multiply by 10^{-4} you must move the point four places to the left. Pay no attention to the presence or absence of digits on either side of the decimal point when you multiply by exponents. Simply reproduce the figures in the same order they were in, and move the decimal point the proper number of spaces.

Now return to Page 44 and choose another answer.

YOUR ANSWER: 1×10^5

Wrong.

Just as 1×10^2 is equal to $1 \times 10 \times 10$ (using 10 as a factor two times) and 1×10^3 is equal to $1 \times 10 \times 10 \times 10$ (using 10 as a factor three times), so 1×10^5 is equal to $1 \times 10 \times 10 \times 10 \times 10 \times 10$ (using 10 as a factor five times), which equals 100,000.

But we asked you to express 0.000001 as a power of ten.

How would you write 0.000001 as a fraction?

$$\frac{1}{1,000,000}$$

Then express 1 as a power of ten: 10^0 (If you don't know why $10^0 = 1$, please refer to the question on Page 143 before proceeding)

And express 1,000,000 as a power of ten: 10^6

So you have $\frac{10^0}{10^6}$.

Remember the rule for dividing powers of ten: You change the sign of the number you are dividing by and then proceed as in multiplication, adding the exponents algebraically.

Think of it like this: $10^0/10^6 = 10^0 \times 10^{-6} = 10^{0-6} = ?$

Now return to Page 40 for the correct answer.

YOUR ANSWER: $8 \times 10^3 \Omega$ = 8000 ohms.

Right. When the exponent (the number above the line) is positive, we add to the left of the decimal point the number of places indicated by the exponent. In the expression 8×10^3, the 8 is read as 8.0; that is, the decimal point is at the right of the 8, and the 10^3 ("10 cubed", as it is read) has the effect of shifting this decimal point 3 more places to the right. And, Ω (omega) is the symbol used for ohms.

Now, try this:

$$2.5 \times 10^4 v =$$

2500 volts	Page 37
25000 volts	Page 40
250000 volts	Page 45
I don't understand	Page 55

YOUR ANSWER: 0.00007 amperes.

Good. The rule with negative exponents is add to the left of the decimal the number of places shown by the exponent. Since the decimal point was to the right of the seven and the exponent was minus five, we count off five places to the left to locate the decimal point of the product.

Now, try this one:

9.8×10^{-4} a is . . .

0.0098 amperes Page 41

0.00098 amperes Page 49

0.000098 amperes Page 52

YOUR ANSWER: 2.5×10^4v means 250,000 volts.

Whoops, you went a little too far! True enough you have four zeros in your answer, but multiplying by 10^4 means move the decimal point four places to the right. You have actually multiplied by 10^5 to get this answer.

Multiplying by 10^4 is the same thing as multiplying by 10,000. This multiplier may have four zeros, but your answer may not have any zeros at all. For instance, you could miltiply 3.897645 by 10^6 and you still wouldn't have any zeros in your answer. It would just be 3,897,645. The exponent, remember, tells you how many places to move the decimal point.

If you feel you need a more detailed explanation of powers of ten, please go to Page 55

If this was just a slip and you think you understand, please return to Page 43 and select the correct answer.

YOUR ANSWER: 0.0025

Good.

You multiplied $2.5 \times \frac{10^2}{10^5}$ to get 2.5×10^{-3}.

To complete the multiplication, you move the decimal point three places to the left.

What is 7×10^{-5}a ?

0.00007 amperes Page 44

0.000007 amperes Page 48

YOUR ANSWER: 10^{-5}.

Not quite.

It is true that your answer will contain a negative exponent -- it must if you are expressing a quantity that is less than one.

We asked you to express 0.000001 as a power of ten.

This will be ten to the minus something.

Here's a clue: The first place to the right of the decimal point is $\frac{1}{10}$. The second place to the right of the decimal point is $\frac{1}{100}$. The third place to the right of the decimal point is $\frac{1}{1000}$, etc.

So 0.000001, written as a fraction, is $\frac{1}{1,000,000}$.

Translating this into powers of ten: $1 = 10^0$. (If you don't understand this, please refer to the question on Page 143 before proceeding)

$1,000,000 = 10^6$.

So the fraction $\frac{1}{1,000,000}$ becomes $\frac{10^0}{10^6}$.

Divide them: $10^0/10^6 = 10^0 \times 10^{-6} = 10^{0-6}$. All you have to do now is to add the exponents algebraically.

Return to Page 40 and try it out.

YOUR ANSWER: 7×10^{-5}a means 0.000007 amperes.

You're too enthusiastic. Be careful when you multiply by powers of 10, negative or positive, that you don't count zeros. True enough, you have five zeros in front of your 7 above. But when you multiply by 10^{-5}, you are supposed to move the decimal point five places to the left.

To begin with, the decimal point is on the right of the number, 7.0. The first place moved to the left just puts the decimal point on the other side of the number, 0.7, and this is the same thing as multiplying 7.0 by 10^{-1}.

The exponent, remember, tells you how many places to move the decimal point. The sign of the exponent tells you which way to move the decimal point.

Now return to Page 46 and choose the correct answer.

YOUR ANSWER: 9.8×10^{-4}a is 0.00098 amperes.

Exactly. The exponent is -4. That means that the decimal point must be moved four places to the left.

Let's restate the rules again before moving on:

POSITIVE EXPONENTS

To express a large number as a smaller number multiplied by a power of ten, move the decimal point to the left and count the number of places moved. The number of places counted is the proper positive power of ten.

NEGATIVE EXPONENTS

To express a decimal as a whole number times a power of ten, move the decimal point to the right and count the number of places moved. The number of places counted is the proper negative power of ten.

These are important rules. Make sure you understand them before going on. Once it is plain to you that the exponent is an instruction about how many places and in which direction the decimal point is to be moved, you should have no trouble.

Here's some practice in using powers of ten, this time involving a more practical use. Complete the calculation:

$$(2.5 \times 10^{3}\Omega) \times (2 \times 10^{-2}\text{a}) = ?$$

5 watts Page 54

50 watts Page 56

50 volts Page 58

500 volts Page 60

YOUR ANSWER: 300 volts becomes 3×10^3v, and 2400 ohms becomes 24×10^3 ohms.

No, both numbers are off a little. 10^3 is 1000, so 3×10^3 would be 3000. Likewise, 24×10^3 would be 24,000.

Now return to Page 58 and choose numbers that express the values given.

YOUR ANSWER: 0.00025

Wrong. You're getting zero-happy.

Here's how you should have worked the problem:

$$2.5 \times \frac{10^2}{10^5} = 2.5 \times 10^{-3}$$

10^{-3} tells you that you must move the decimal point three places to the left.

Study the following table, and you'll see why:

$$1.0 = \frac{1}{1} = \frac{1 \times 10^0}{1 \times 10^0} = 1 \times 10^{(0-0)} = 1 \times 10^0$$

$$0.1 = \frac{1}{10} = \frac{1 \times 10^0}{1 \times 10^1} = 1 \times 10^{(0-1)} = 1 \times 10^{-1}$$

$$0.01 = \frac{1}{100} = \frac{1 \times 10^0}{1 \times 10^2} = 1 \times 10^{(0-2)} = 1 \times 10^{-2}$$

$$0.001 = \frac{1}{1000} = \frac{1 \times 10^0}{1 \times 10^3} = 1 \times 10^{(0-3)} = 1 \times 10^{-3}$$

Return to Page 59 for the correct answer.

YOUR ANSWER: 9.8×10^{-4}A means 0.000098 amperes.

No, it looks as if you are counting the number of zeros instead of decimal places. To multiply by 10^{-4} you should move the decimal point four places to the left. The first place to the left will give you 0.98 which is the same as multiplying by 10^{-1}. There are no zeros at all.

Count the decimal places in your answer again, and you will see that you have actually multiplied by 10^{-5}.

Now return to Page 44 and choose another answer.

YOUR ANSWER: 300 volts becomes 3×10^2v, and 2400 ohms becomes 2.4×10^4 ohms.

Well, you're half right. You have the right expression for the volts, but the number of ohms is wrong.

When you multiply by 10^4, you are really multiplying by 10,000. 2.4×10^4 would be 24,000. To convert a large number to a pow of 10, be sure to count your decimal places very carefully The exponent tells you how many places to move the decimal point, remember.

Now return to Page 58 and choose another answer.

YOUR ANSWER: $(2.5 \times 10^{3}\Omega) \times (2 \times 10^{-2}$ amp) = 5 watts.

No, this shouldn't come out to 5 of anything. When you multiply 2 x 2.5 you get 5, but you have to figure out your exponents. As you remember, you must add them algebraically. When you do this, you come out with 10^{1} or just 10. To get the correct answer you must now multiply by this.

And where did you get watts for your answer?

You should recognize that ohms times amperes comes directly out of the Ohm's Law relationship. Something = IR. What is it?

Return to Page 49 and choose another answer.

In electronics we work with numbers which go from one extreme to the other. Numbers in the millions are used in equations with numbers in the millionths.

Numbers mount into the millions when you're speaking of resistance and dealing with ohms. It can get very cumbersome if you don't use a short cut.

For example, say you want to multiply 250,000 by 2,000. In long-hand multiplication, your problem looks like this:

```
  250000
    2000
  ------
  000000
 000000
000000
500000
------
500000000
```

But it isn't necessary to cope with all these zeros. You can get the same result another way.

The first step is to take each number concerned and keep on dividing it by 10 until there is a single whole number between 1 and 9 to the left of the decimal point.

For instance, if 500 is our number, divide it by 10 (which reduces it to 50) and again by 10 so that you are left with the number 5.

We'll take care of the vanishing zeros in the second step. Before we go any further, what is the result of applying to the number 4000 this first step of repeated division by 10?

YOUR ANSWER: $(2.5 \times 10^{3}\Omega) \times (2 \times 10^{-2}$ amp) = 50 watts.

Your number 50 is O.K., but how did watts get in here? You should recognize ohms times amperes as something right out of Ohm's Law.

Something = IR. What is it?

Return to Page 49 and choose another answer.

Ohm's Law can be stated in three forms:

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

Since we want to find amperage -- we know the other two factors -- we choose the middle form of the law as shown above.

Once again, the resistance is $2.4 \times 10^{3}\Omega$ and E is 3×10^{2}v. How will the answer be expressed in powers of 10?

1.25×10^{-1}a Page 64

1.25×10^{1}a Page 68

7.2×10^{1}a Page 70

7.2×10^{5}a Page 73

YOUR ANSWER: 50 volts.

Correct. Here are the steps:

$(2.5 \times 10^{3}\Omega) \times (2 \times 10^{-2}$ amp)

Since the order of multiplication doesn't make any difference, we rearrange the problem to:

$(2.5 \times 2) \times (10^{3} \times 10^{-2})$

$(2.5 \times 2 = 5)$ and $(10^{3} \times 10^{-2} = 10^{1})$

S O

$(5) \times (10^{1})$, which is 5×10, and that equals 50.

The answer, of course, comes out in volts since this was actually a problem involving Ohm's Law: Ohms times amperes equals volts.

Now, let's try another one using Ohm's Law.

We are given 300v and a resistance of 2400 ohms, and have to find the amperage. Which of the following translates these figures into powers of ten?

3×10^{3}v and 24×10^{3} Page 50

3×10^{2}v and 2.4×10^{4} Page 53

3×10^{2}v and 2.4×10^{3} Page 61

YOUR ANSWER: 10^{-6}.

Correct.

When you write 0.000001 as a fraction, it becomes $\frac{1}{1,000,000}$ or $\frac{10^0}{10^6}$.

You add exponents to multiply powers of ten. When you divide powers of ten, you change the sign of the number you are dividing by, then you go ahead as in multiplication -- adding exponents algebraically.

$$10^0/10^6 = 10^0 \times 10^{-6} = 10^{(0-6)} = 10^{-6}.$$

In division as well as in multiplication of large numbers, we rely on this short cut. Here is a problem in long division:

$$\frac{200,000}{4,000} = \frac{200,\emptyset\emptyset\emptyset}{4,\emptyset\emptyset\emptyset} = \frac{200}{4} = 50$$

Now look at the same problem expressed in powers of ten:

$$\frac{2 \times 10^5}{4 \times 10^3} = \frac{2}{4} \times 10^{(5-3)} = 0.5 \times 10^2.$$

Multiplying by 10^2 means moving the decimal point two places to the right. So 0.5×10^2 becomes 50. This time let's make our larger number the divisor:

$$\frac{25,000}{5,000,000} = 0.005$$

Here's the same problem expressed in powers of ten. When you change the sign of 10^6, you get a negative exponent. Adding algebraically, you end up with a negative exponent for your answer:

$$\frac{25 \times 10^3}{5 \times 10^6} = \frac{25}{5} \times 10^{(3-6)} = 5 \times 10^{-3}$$

Multiplying by 10^{-3} means moving the decimal point three places to the left. So 5×10^{-3} becomes 0.005.

(Note: For simplicity, we didn't reduce 25,000 any lower than 25 to start with, since it was to be divided further within the problem.)

What does $2.5 \times \frac{10^2}{10^5}$ equal?

0.0025	Page 46
0.00025	Page 51
0.025	Page 62

YOUR ANSWER: $(2.5 \times 10^{3}\Omega) \times (2 \times 10^{-2}$ amp) = 500 volts.

You must not have added your exponents correctly. Add 3 and -2 together algebraically and you get 1, so you must multiply your answer by 10^{1}, which is just plain 10.

Now return to Page 49 and choose the correct answer.

YOUR ANSWER: 3×10^2 V and 2.4×10^3

Right. You just use the same process backwards. The exponents indicate how many places the decimal point was moved.

In using Ohm's Law if $E = 3 \times 10^2$ volts and $R = 2.4 \times 10^3$ ohms, what will I be?

a. 1.25×10^1

b. 1.25×10^{-1}

c. 8×10^0

d. 8×10^1

After selecting an answer go on to page 65.

YOUR ANSWER: 0.025

No. You're trying to give back more than you got!

If someone had a coin that wasn't even worth one cent, why give them two and a half cents for it?

When you put only one zero to the left of the decimal point before writing the number, you are indicating $\frac{2.5}{100}$. This is not the right answer. Look at the problem:

$$2.5 \times \frac{10^2}{10^5} = 2.5 \times 10^{(2-5)} = 2.5 \times 10^{-3}$$

Ten to the minus third power tells you that to complete this multiplication you must move the decimal point three places to the left.

Study the following table, and you'll see why:

$$1.0 = \frac{1}{1} = \frac{1 \times 10^0}{1 \times 10^0} = 1 \times 10^{(0-0)} = 1 \times 10^0$$

$$0.1 = \frac{1}{10} = \frac{1 \times 10^0}{1 \times 10^1} = 1 \times 10^{(0-1)} = 1 \times 10^{-1}$$

$$0.01 = \frac{1}{100} = \frac{1 \times 10^0}{1 \times 10^2} = 1 \times 10^{(0-2)} = 1 \times 10^{-2}$$

$$0.001 = \frac{1}{1000} = \frac{1 \times 10^0}{1 \times 10^3} = 1 \times 10^{(0-3)} = 1 \times 10^{-3}$$

Return to Page 59 for the correct answer.

YOUR ANSWER: 4

Of course. If you repeatedly divide 4000 by 10 until you are left with a single whole number to the left of the decimal point, you come down to 4.

And now for the case of the vanishing zeros, in which, via an explanation and a question, we'll lead up to step two.

$$4000 = 4 \times 10 \times 10 \times 10$$

The figure 4 is a factor once; the figure 10 is a factor 3 times. (It's possible to factor even further, of course, but this is the end of the road for using powers of ten.)

Using the first step already described (repeated division by 10 until you have a single whole number remaining to the left of the decimal point), split the number 100 into factors.

10×10	Page 75
$1 \times 10 \times 10$	Page 87
10^2	Page 94

YOUR ANSWER: 1.25×10^{-1}a.

Right. Let's go through the problem.

$I = E/R$, $E = 3 \times 10^{2}$v, $R = 2.4 \times 10^{3}\Omega$

So, the problem is expressed this way:

$$I = \frac{3 \times 10^{2}}{2.4 \times 10^{3}}$$

Now, a positive exponent below the line of a division problem is handled as if it were a negative exponent above. So, the problem can also be expressed as:

$$I = \frac{3 \times 10^{2} \times 10^{-3}}{2.4} \quad \text{or,} \quad I = \frac{3 \times 10^{-1}}{2.4} \quad \text{or,} \quad I = \frac{3}{2.4} \times 10^{-1}$$

Since 3 divided by 2.4 equals 1.25, the result is 1.25×10^{-1}a.

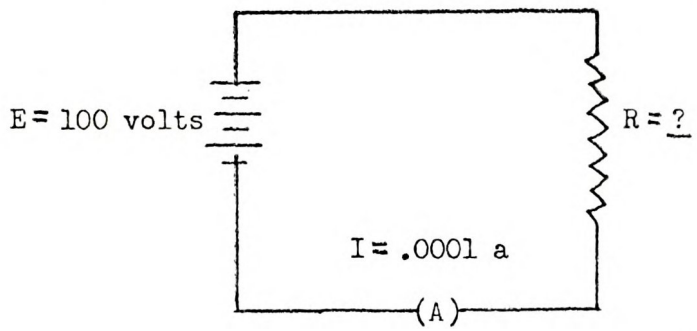
Now, express the result in common terms.

0.0125 amperes Page 66

0.125 amperes Page 74

12.5 amperes Page 76

Using Power's of Ten solve for the unknown value in the circuit below.



a. 1×10^{6}

b. 1×10^{2}

c. 1×10^{-2}

d. 1×10^{-6}

After selecting an answer go on to page 57 and continue on.

YOUR ANSWER: 1.25×10^{-1} amp means 0.0125 amperes.

You moved your decimal point too far. When you multiply by 10^{-1} you are really just moving the decimal point one place to the left. This is the same as multiplying by 0.1 .

Return to Page 64 and try again.

YOUR ANSWER: 40.

You're holding back!

We asked you to go all the way -- to a single whole number which is nine or less. So it could hardly be 40.

Think of it this way: 4000 is the same as 1000 multiplied by what?

Return to Page 55 and select the obvious answer.

YOUR ANSWER: 3×10^2 v divided by 2.4×10^3 ohms is 1.25×10^1 amp.

No, the exponent in your answer is incorrect.

Your division was fine, but then you reached the point where something had to be done with the exponents.

Apparently you subtracted the 2 from the 3. This would have been correct if you had been dividing 2.4×10^3 by 3×10^2.

But, of course, you weren't. As the problem stands, you should have subtracted the 3 from the 2.

If you do that, what will the resulting exponent be?

When you think you know, return to Page 57 and choose another answer.

YOUR ANSWER: $I = 2.5 \times 10^{0}$a, $R = 4 \times 10^{4}\Omega$, so $E = 0.625 \times 10^{4}$v.

It looks as if you tried to divide instead of multiply. You shouldn't have done it. Your formula is E = IR.

Besides, if you had really divided, you should have subtracted your exponent 4.

Now return to Page 82 multiply the two numbers, and add the exponents.

YOUR ANSWER: Given 2.4×10^3 ohms and 3×10^2 volts, the current is 7.2×10^1 amperes.

You've got yourself all turned around.

First of all, you multiplied the two numbers when you should have divided. Remember, $I = E/R$, so you must divide the resistance into the voltage.

And then, how did you get "1" for an exponent? Did you guess? If you multiplied to get part of your answer you would have multiplied the rest. And when you multiply, you should add the exponents.

However, in this problem there is no question of multiplying. The formula to be used is, once more, $I = E/R$. You have to divide voltage by resistance.

And remember that when you divide using powers of ten, you divide the actual numbers but use subtraction on the exponents.

Now return to Page 57 and figure it out again.

YOUR ANSWER: I don't get it.

All right. You know that you add exponents of ten when you multiply:

$$2 \times 10^2 \times 4 \times 10^4 = (2 \times 4) \times (10^2 \times 10^4) = 8 \times 10^6.$$

When you divide, you change the sign of the number you are dividing by. For example:

$$\frac{4 \times 10^4}{2 \times 10^2} = \frac{4}{2} \times 10^4 \times 10^{-2} = 2 \times 10^{4-2} = 2 \times 10^2.$$

In algebra, when you add a positive number and a negative number and the positive number is larger, you get a positive answer:

$$(+4) + (-2) = +2$$

This is what we did with the exponents in the problem above. But when the negative number is larger, your answer will be negative:

$$(-4) + (+2) = -2$$

Now we'll change the problem:

$$\frac{2 \times 10^2}{4 \times 10^4} = \frac{2}{4} \times 10^2 \times 10^{-4} = \frac{1}{2} \times 10^{2-4} = \frac{1}{2} \times 10^{-2}.$$

You added the exponents algebraically: $(+2) + (-4) = 2 - 4 = -2$.

10^0 equals 1. 10^{-1} equals 0.1 or $\frac{1}{10}$. 10^{-2} equals 0.01 or $\frac{1}{100}$. 0.001 is $\frac{1}{1000}$. This is 10^{-3}.

Notice that to increase 0.001 to 1, we would have to multiply by 10 x 10 x 10. We would move the decimal point 3 places, this time to the right. We say this is a negative direction and it gives us an exponent of -3.

How many places to the right must we move the decimal point to do the same thing with 0.000001? 0. 0 0 0 0 0 1

So two steps will give you the answer: (1) Count the number of places you must move the decimal point. (2) Express your answer with a minus exponent. You will have ten to a minus power.

Return to Page 40 for the correct answer.

YOUR ANSWER: $I = 2.5 \times 10^{0}a$, $R = 4 \times 10^{4}\Omega$, so $E = 10 \times 10^{4}v$.

Your answer is correct, but it can be simplified a little further.

The number 10^{4} is "shorthand" for 10 x 10 x 10 x 10, four tens multiplied together. When you multiply 10^{4} by 10, as in your answer, you are just adding another 10 to the string of multipliers shown above.

Now return to Page 82 and choose the answer that expresses five tens multiplied together.

YOUR ANSWER: Given 2.4×10^3 ohms and 3×10^2 volts, the current would be 7.2×10^5 amperes.

Well, you multiplied the two numbers correctly; this would be 720,000 amperes, and that would be a lot of current!

Actually you should have divided the resistance into the voltage. The formula is $I = \frac{E}{R}$. This will give you a much smaller figure for amperage.

Now return to Page 57 and choose another answer.

YOUR ANSWER: 0.125 amperes.

Right.

Here is another problem. You are asked to find voltage when you are given:

$$I = 0.004a, \text{ and } R = 4500\Omega$$

Use powers of ten in your calculation. It will be much simpler.

Given the above, the voltage is:

0.18	Page 77
1.8	Page 80
18	Page 82

YOUR ANSWER: 10 x 10

You're not being as specific as we want you to be.

It may seem superfluous to insist on a more precise answer since it is obvious that 10 x 10 = 100.

The method you're following is to divide the number by 10 as many times as necessary to leave a single figure to the left of the decimal point. Don't just ignore that single figure. It should show up in your answer.

The reason is very plain if you express 200 in powers of ten. Here you divide by 10 and then by 10 again. That leaves you with a single figure to the left of the decimal point.

$$2 . 0 0$$

And the factors of 200 are 2 x 10 x 10.

Return to Page 63 for a more complete answer.

YOUR ANSWER: 1.25×10^{-1} amp means 12.5 amperes.

You moved the decimal place the wrong way. If you started with 1.25×10^{1}, your answer would have been correct. When you have a negative exponent, you have to move your decimal point to the left and make your number "smaller."

Return to Page 64 and try again.

YOUR ANSWER: I = 0.004, R = 4500, so E = 0.18 volts.

Your decimal point is astray. Put 0.004 and 4500 in powers of ten. Then you will have I = 4.0 x 10 to some power, and R = 4.5 x 10 to a certain power. Multiply 4 x 4.5 and add the exponents algebraically.

Take care of the details and then return to Page 74 for an answer that corresponds to your result.

YOUR ANSWER: 10^5v.

Right you are. 10×10^4 is a correct answer, but, since 10 is 10^1, we can express 10×10^4 as 10^5. Clearly, 10^5 is the simpler answer to deal with.

Now, 10^5 is how many volts?

10,000 volts Page 81

100,000 volts Page 86

YOUR ANSWER: 30×10^6.

Only half right.

You worked the multiplication correctly: $3.75 \times 4 \times 2 = 30$.

But evidently you multiplied the exponents, too. That's about the only way you could have handled $10^6 \times 10^0 \times 10^1$ to come up with 10^6.

You had better back track to Page 116 and go over this again.

YOUR ANSWER: I = 0.004 amp, R = 4500Ω, so E = 1.8 volts.

Your decimal point is astray. First express the two numbers as powers of 10. Then you will have I = 4.0 x 10 to a certain power, and R = 4.5 x 10 to a certain power. To multiply these two numbers you will combine the 4.0 and 4.5 in ordinary multiplication, but you must add the exponents algebraically.

Now return to Page 74 and choose another answer.

YOUR ANSWER: 10^5 volts is 10,000 volts.

No, you seem to have forgotten just what 10^5 means. It is the expression for five tens multiplied together -- 10 x 10 x 10 x 10 x 10. Start multiplying tens in your head, and you will see that the answer always has the same number of zeros as there were tens multiplied together. Two tens make 100, and there are two zeros in the answer. In your answer above there are four zeros, so this is the product of four tens or 10^4.

Now return to **Page 78** and choose the answer that expresses five tens multiplied together.

YOUR ANSWER: 18.0

Correct. The solution is as follows:

$E = IR$,

$I = 0.004a$, which is $4 \times 10^{-3}a$,

and $R = 4500\ \Omega$, which is $4.5 \times 10^{3}\Omega$.

So, $E = 4 \times 10^{-3} \times 4.5 \times 10^{3}$,

or, $E = 4 \times 4.5 \times 10^{-3} \times 10^{3}$.

That means $E = 18 \times 10^{0}$.

Remember that 10^{0} (or any number to the zero power) equals 1. That was proved in this manner:

$100/100 = 1$.

Now, 100 is 10^{2}, so $10^{2}/10^{2} = 1$.

But, 10^{2} over 10^{2} is the same as $10^{2} \times 10^{-2}$, so

$10^{2} \times 10^{-2} = 1$, or $10^{0} = 1$.

Now, if $10^{0} = 1$, the answer to our original problem is 18×1 or 18.

Let's try one more problem. Given $I = 2.5 \times 10^{0}A$ and $R = 4 \times 10^{4}\Omega$, what does E equal?

$0.625 \times 10^{4}v$	Page 69
$10 \times 10^{4}v$	Page 72
$10^{5}v$	Page 78

YOUR ANSWER: 300×10^6.

Wrong.

You're not sticking to the rules. Don't try to mix in too much ordinary arithmetic. There are several manipulations you might have gone through to get this answer.

Look at the problem:

$$(3.75 \times 10^6) \times (4 \times 10^0) \times (2 \times 10^1) = ?$$

Did you take 10^0 as being equal to one and 10^1 as being equal to ten and figure it this way?

$$(3.75 \times 10^6) \times (4 \times 1) \times (2 \times 10)$$

If you did something like this, you would have multiplied 3.75 by 80 to get 300 -- then you had 10^6 left over, so you put down 300×10^6.

This kind of monkeying around will get you no place.

It is true that 10^0 equals 1 and 10^1 equals 10, but when you're working a problem, always handle the powers of ten as exponents, not as their equivalents.

Return to Page 116 and follow the rules.

YOUR ANSWER: One thousand volts is 1 kv.

Correct, but you didn't read far enough down the list. It's always a good idea to glance down the whole list of answers given. Sometimes it gives you an idea as to what the right answer will be, and sometimes you'll be surprised at what you find.

As we said, there are many different abbreviations used in electronics. Often there is more than one way of saying something. Now return to Page 91 and look over the answer list again.

YOUR ANSWER: 6ma would be 6×10^6 amperes.

No, the abbreviation "ma" means milliamperes or one-one thousandth of an ampere. The answer you've chosen would be a monster, 6,000,000 amperes.

Return to Page 97 and choose an answer that means 6 milliamperes.

YOUR ANSWER: 100,000 volts

Correct.

Powers of ten are a great help in expressing figures of many digits. You may have noticed as you went through the last few examples that powers of ten also provide a simple and convenient way for calculating with many digit numbers. It is much easier to keep track of the zeros this way than it is to compute by longhand.

There is an even more convenient way of eliminating zeros when writing out figures, although it doesn't help much in calculating. This is a system of prefixes. Probably the most familiar of these prefixes is Kilo, as used in kilowatt. It is in kilowatt-hours that electrical bills are measured. We will learn more about watts later on. For the moment, we are interested in the prefix, kilo. Kilo means one thousand. So, kilowatt means 1000 watts and one kilowatt-hour is 1000 watt-hours.

You should develop the habit of eliminating zeros in expressing quantities by using this and several other prefixes, and translate such numbers into powers of ten for convenient computation.

See if you can translate this figure: 5 kilovolts.

That means:

500 volts or 5×10^3v	Page 89
5000 volts or 5×10^3v	Page 91
5000 volts or 5×10^4v	Page 93

YOUR ANSWER: 1 x 10 x 10.

Exactly.

Just as 400 is 4 x 10 x 10, and 40 is 4 x 10, so 100 is 1 x 10 x 10.

And this brings us to the second step which is to show how many times 10 has been used as a factor (as a multiplier, if you like). There is a "shorthand" way of doing this. For instance:

4000	= 4 x 10 x 10 x 10	or 4×10^3
400	= 4 x 10 x 10	or 4×10^2
40	= 4 x 10	or 4×10^1

The raised 1, 2, 3, etc., used to indicate the number of times 10 is used as a factor (multiplier), are called exponents. It is usual in mathematics to omit the exponent 1 since it is understood.

10^3 is called ten cubed, or ten to the third power.

10^2 is called ten squared or ten to the second power.

10 (which is really 10^1) has the numerical value of 10.

Numbers written using this notation, are said to be expressed as powers of ten.

In writing 3,000,000 as a power of ten, which answer is <u>incorrect</u>?

3×10^6	Page 103
$3 \times 10 \times 10^5$	Page 113
300×10^4	Page 115
None of the above is incorrect.	Page 117

YOUR ANSWER: 1000 volts is 1×10^0 kv.

Correct, but you didn't look closely enough at the answer list. Often there is more than one way of saying something. Be sure that you look at all of the possible answers before you choose one.

Now return to **Page 91** and study the answers again.

YOUR ANSWER: 5 kilovolts means 500 volts or 5×10^3 volts.

No, the prefix "Kilo" means 1000, so a kilovolt would be 1000 volts.

There's something else wrong with the answer you've chosen. It isn't consistent in itself. The expression 5×10^3 doesn't mean 500. If you have 10^3, you have 10 x 10 x 10 or 1000.

Now return to Page 86 and choose an answer that defines 5 kilovolts.

YOUR ANSWER: 6×10^{-3} amperes.

Right. The small m means milli, and milli is 1/1000 or, 0.001. Six ma is 0.006, which is 6×10^{-3}

The table below summarizes the information on prefixes and abbreviations. You should have paper and pencil with you. Make a copy of the table to use for reference until you get it down pat.

NUMBER	PREFIX	ABBREVIATION	POWER OF 10
1,000,000	Meg	M	10^6
1,000	kilo	k	10^3
0.001	milli	m	10^{-3}
0.000001	micro	μ	10^{-6}
0.000000000001	pico*	p	10^{-12}

*The alternate prefix for pico is micromicro and you may hear micromicro used some times in place of pico, so don't let it throw you. The symbol for micromicro is μμ.

Is the following true or false?

Both mf and μf mean the same thing, one-millionth of a farad.

True Page 99

False Page 101

YOUR ANSWER: 5000 volts or 5×10^3 v

Right. Now, kilo can be further shortened to k. An example of using the symbol k is kv (1,000 volts), kw (1,000 watts), and etc.

You will find as you go along that abbreviations sometimes vary slightly from book to book or from engineer to engineer. It should not concern you -- and won't once you get used to seeing a small letter where you might have expected a capital, or vice versa.

Although this course will be consistent in usage where possible, it will also try to give alternative forms, such as might be found in data sheets from different manufacturers.

One thousand volts equals:

1 kv	Page 84
1×10^0 kv	Page 88
1 Kv	Page 95
All of the above	Page 97

YOUR ANSWER: 6ma in powers of 10 would be 6×10^{-6}.

Too small. Remember that 6ma means 6 milliamperes, and a milliampere is one-one thousandth of an ampere.

The power of ten you have chosen, 10^{-6}, would show millionths.

Return to Page 97 and choose an answer that corresponds to 6 milliampere.

YOUR ANSWER: 5 kilovolts means 5000 volts or 5×10^4v.

Not quite correct. The first part is O.K. A kilovolt is equal to 1000 volts; the prefix "Kilo" means thousand.

But when it came to powers of ten, your thinking began to wobble. When you say 10^4, you mean $10 \times 10 \times 10 \times 10$, four tens multiplied together. This is 10,000, so 5×10^4 would be 50,000. Note that when you have a number multiplied by 10^4, you move the decimal point <u>four</u> places to the right. You begin with 5.0, and after you move the point four places to the right, you have 50,000.

Now return to Page 86 and choose the correct answer.

YOUR ANSWER: 10^2

You didn't follow directions.

We illustrated that 4000 is equal to 4 x 10 x 10 x 10, and asked you to express 100 in the same way.

While it is true that 10 squared is equal to 100, that is not the way we want you to write it -- yet.

Later on, it will be helpful for you to remember that even in the figure 100, 10 x 10 is being multiplied by another number, a number arrived at by dividing the large figure by 10 until you come down to a single number to the left of the decimal point.

Please return to Page 63 and choose a more precise answer.

YOUR ANSWER: All of the above.

That is correct. All, including 1×10^0 kv mean 1000 volts.

There are three other quantity abbreviations besides kilo All four come from the Greek language. Mega or Meg means million. Megohm can be written meg Ω or M Ω.

There are also abbreviations for one-one thousandth and one-one millionth. Milli is the prefix for 1/1000; Micro is the prefix for 1/1,000,000.

You will notice that all three prefixes begin with m.

M means mega. (It may help to recall that mega stands for million, and, as the abbreviation for the largest amount, normally gets a capital letter.)

m means milli.

μ means micro. (Micro is the smallest amount and the symbol μ is the Greek equivalent of the letter m. It is called mu in English and pronounced "mew".)

Now, how would 6ma be written in powers of ten?

6×10^6 amperes	Page 85
6×10^{-3} amperes	Page 90
6×10^{-6} amperes	Page 92
10^{-6} amperes	Page 100

YOUR ANSWER: 30×10^7.

Correct.

You multiplied the significant numbers, 3.75 x 4 x 2, to get 30, then you added the exponents, $10^{(6+0+1)}$, to get 10^7.

Again we will check your understanding of this material. What is your answer to this one.

$$(1.25 \times 10^2) \quad (2 \times 10^8) \quad (1.5 \times 10^0)$$

a. 2.50×10^{10}

b. 3.75×10^{10}

c. 2.50×10^6

d. 3.75×10^6.

After selecting an answer go on to page 38 and continue on with Power's of Ten.

YOUR ANSWER: True

Right you are. Both mf and uf mean the same thing, one-millionth of a farad.

Now, here are three groups of abbreviations with translations. In one group, one translation is incorrect. Pick the group that has an incorrect translation.

12mv = 0.012 volts
216μa = 2.16×10^{-4} amperes
37kw = 37,000 watts

Page 102

800kΩ = 8×10^{5} ohms
1μw = 0.0000001 watt
120kv = 120,000 volts

Page 104

1ma = 1×10^{-3} amperes
17MΩ = 1700 ohms
1100kwh = 1,100,000 watt hours

Page 106

YOUR ANSWER: 6ma as a power of 10 would be 10^{-6} amperes.

No, keep in mind that 6ma means 6 milliamperes, and a milliampere is one-one thousandth of an ampere.

You seem to be confusing the number of milliamperes with the exponent. If you use -6 for an exponent, you are saying that the decimal point must move six places to the left. Your answer would then be 0.000001 ampere. This is one microampere or one-one millionth of an ampere, and this isn't what you wanted to say.

Now return to Page 97 and choose an answer that means the same as 6 milliamperes.

YOUR ANSWER: False, mf and μf do not mean the same thing.

No, this is incorrect. Ordinarily you must distinguish between m for milli or one-thousandth and μ for micro or one-millionth. However, with farads, the units of capacitance that you will study later, we seldom need to use any unit larger than microfarads. So we use uf to stand for microfarads. And for a unit still smaller, we use the picofarad (one millionth of a microfarad) which is abbreviated pf or μμf.

Now return to Page 90 and choose the correct answer.

YOUR ANSWER: One of these is incorrect:

12mv = 0.012 volts

216ua = 2.16×10^{-4} amperes

37 kw = 37,000 watts

No, these are all correct.

To convert millivolts to volts, you multiply by 1000, and that is shown in the first example.

Take 2.16 and move the decimal point four places to the left, and you will have 0.000216. This is 216 microamperes.

To convert kilowatts to watts you would multiply by 1000. So 37 kw is 37,000 watts.

Return to Page 99 and find a group with a false conversion

YOUR ANSWER: 3×10^6.

You must have misunderstood the question.

We asked you to indicate which answer was incorrect. This answer is a most concise way of writing the number 3,000,000.

Return to Page 87 read the question again, then consider all the answers more thoughtfully.

YOUR ANSWER: One of these is incorrect:

800 k $\Omega = 8 \times 10^5$ ohms

1μw = 0.0000001 watt

120kv = 120,000 volts

No, these are correct.

The quantity 800 k Ω would be 800,000 ohms, and this is shown correctly as a power of ten above.

A microwatt is one-one millionth of a watt, and the decimal fraction above is correct.

There are 1000 volts in a kilovolt, so the last conversion is all right, too.

Now return to Page 99 and choose a group that has a false conversion.

YOUR ANSWER: 1v

Yes, one ohm is the amount of resistance that will limit current to one ampere when the electrical pressure is one volt. This statement can be turned around to define all three of our units of measure:

> One volt is the amount of electrical pressure that will push one ampere of current through one ohm of resistance.
>
> One ampere is the amount of current that will flow through one ohm of resistance when the electrical pressure is one volt.

Each of these expresses one of the three forms of Ohm's Law.

Which of the following statements is <u>in</u>correct?

a. 80 k ohms is the same as 8×10^4 ohms.

b. .000056 volts is the same as 5.6×10^{-5}.

c. .0008 amps is the same as 80 micro amps.

d. 98,000,000 ohms is the same as 98 Meg ohms.

After selecting an answer go on to page 133.

YOUR ANSWER: 1ma = 1 x 10^{-3} amperes
17MΩ = 1700 ohms
1100kwh = 1,100,000 watt hours

That's right, there is a mistake among those three translations. Let's see if we can find it.

One milliampere equals 0.001 ampere, and 0.001 equals 10^{-3}, so that one is correct.

And, of course, 1100kwh is 1,100,000 watt hours. One megohm is equal to 1,000,000 ohms, so 17MΩ is equal to 17,000,000 ohms.

When you are given problems with prefixes attached to the units, the values will have to be translated into the basic units before you begin calculation. Thus, if you have a resistance given in MΩ and a current in ma's, you will have to translate to ohms and amperes before you can calculate voltage.

Here is a problem. Work it with powers of ten.

Given, R = 12 k (often k is used alone for k Ω or 1000 ohms), and I 15 ma, what does E equal?

125 volts	Page 108
180 volts	Page 109
1250 volts	Page 112
1.8 kv	Page 114

YOUR ANSWER: One ohm limits the current to one ampere when the electrical pressure is 1kv.

No, with one kilovolt, or 1000 volts, you would have 1000 amperes of current through just one ohm of resistance.

Remember that you must translate all of your electrical quantities into the basic units before using Ohm's law.

Now return to Page 110 and choose the correct answer.

YOUR ANSWER: R = 12k , I = 15ma, so E = 125 volts.

No, you must have divided. The proper form of Ohm's law is E = IR, so you must multiply.

Now return to Page 106 and choose another answer.

YOUR ANSWER: 180 volts.

Correct. If you worked it out by powers of ten, the problem went something like this:

$$R = 12\text{k} = 1.2 \times 10^{4} \text{ ohms}$$

$$I = 15\text{ma} = 0.015 \text{ amps} = 1.5 \times 10^{-2} \text{ amps}$$

Since $E = IR$, $E = 1.5 \times 10^{-2} \times 1.2 \times 10^{4}$, or

$$E = 1.5 \times 1.2 \times 10^{-2} \times 10^{4}$$

$$= 1.8 \times 10^{2}$$

$$= 180\text{v}$$

There's just one more thing we want to add about powers of ten. So far, we have encouraged you to reduce a large number by moving the decimal point to the left until there was a single figure to the left of the decimal point. We followed a smililar method for negative exponents.

In practice, it is often more convenient to move the decimal point fewer places than this. For example, if you are given a value of 256 milliamperes and you have to use it in a formula for Ohm's law where a value in amperes is called for, you may find it less trouble to use 256×10^{-3} amperes rather than 2.56×10^{-1} amperes. Or again, you may have to figure a resistance value of .17k. Properly expressed in powers of ten, this is 1.7×10^{4} ohms, but it's usually more convenient to use 17×10^{3} ohms.

You should have a copy of the table showing these and similar abbreviations and their equivalent powers of ten. If you neglected to copy the table, return to Page 90 and make a note of them now.

When all this is taken care of, please go ahead to Page 110

Now, let us go on to resistance.

Do you remember the definition of an ohm? See if you can complete the sentence below.

The ohm may be defined as the amount of resistance that will limit current to one ampere when the electrical pressure is:

1mv	Page 96
1v	Page 105
1kv	Page 107

YOUR ANSWER: $10^0 = 0$.

You're still having trouble. So let's go over it slowly:

This is a problem in division. When we divide one power of a number by another power of the same number, we subtract the exponent of the second from the exponent of the first.

And when you tried a case in which the exponents were equal, you got

$$10^3/10^3 = 10^{(3-3)} = 10^0$$

Now look at it this way: When you divided a power of ten by itself, you got 10^0. But you also know that any number divided by itself equals one.

Thus you see that $10^3/10^3$ is equal to 10^0 by our rule for working with exponents -- and is equal to one by ordinary arithmetic.

That tells you how to define 10^0, doesn't it?

Return to page 120. The right answer is the logical one.

YOUR ANSWER: R = 12k , I = 15ma, so E = 1250 volts.

No, it looks as if you divided the two numbers. The proper form of Ohm's Law for this problem is E = IR, so you must multiply.

Also, before you leap at another answer, take a second look at your powers of 10. You must have assigned one or both of them incorrectly. For12k -ohms you should have 1.2×10^{4}, and for 15 milliamperes you should have 1.5×10^{-2} (because 15ma is 0.015 amperes). Now multiply these two numbers, and return to Page 106 to choose the correct answer.

YOUR ANSWER: $3 \times 10 \times 10^5$.

It just looks wrong.

But it isn't. It would not be incorrect to write 3,000,000 this way -- merely awkward. You are using powers of ten, but obviously, you can condense the notation to a more concise form since

$$10 \times 10^5 = 10 \times 10 \cdot 10 \cdot 10 \cdot 10 \cdot 10 = 10^6$$

Please return to Page 87 and this time give more consideration to each answer.

YOUR ANSWER: R = 12k , I = 15ma, so E = 1.8kv.

You multiplied the two numbers together as you should have, but your decimal point has wandered. Your answer gives E as 1800 volts.

In powers of ten, $R = 1.2 \times 10^{4}$ and $I = 1.5 \times 10^{-2}$ (because 15 milliamperes would be 0.015 amperes, and this is just <u>two</u> decimal places removed from 1.5). Now multiply these two numbers and you get 1.8×10^{2}.

Return to Page 106 and choose the answer that corresponds to this power of ten.

YOUR ANSWER: 300×10^4.

Why do you think that's wrong?

You can write 3,000,000 this way, although it's awkward and doesn't follow the rules we've given you.

The whole point of using powers of ten is to be as concise as possible. You're defeating yourself when you stop short of the short cut.

$300 \times 10^4 = 3 \cdot 10 \cdot 10 \cdot \times 10 \cdot 10 \cdot 10 \cdot 10 = 3 \times 10^6$

For our purposes, the shortest notation is 3×10^6. Any other combination is unsatisfactory -- but it isn't necessarily incorrect.

Return to **Page 87** for another look at the question -- then study the possible answers thoroughly.

YOUR ANSWER: $10^0 = 1$.

Correct.

Dividing any number by itself gives you a result of 1, and this is as true of a power of ten as of any other number.

And we'll toss in one other little piece of information which may come in handy some day: Just as the base 10 to the zero power (10^0) is equal to 1, so any number to the zero power is equal to 1.

Just to give you a little practice in working with 10^0, try this problem:

$$(3.75 \times 10^6) \times (4 \times 10^0) \times (2 \times 10^1) = ?$$

What is your answer:

30×10^6	Page 79
300×10^6	Page 83
30×10^7	Page 98

YOUR ANSWER: None of the answers is incorrect.

Fine. Each of the choices offered

$$3 \times 10^6$$
$$3 \times 10 \times 10^5$$
$$300 \times 10^4$$

is a method of writing 3,000,000 using powers of ten. There are, of course, many ways of writing 3,000,000 in this notation. However, the idea is to express it as conveniently as possible and there is no point in dragging in unwanted zeros or extra tens.

In reducing 3,000,000 to powers of ten, we used two steps applicable to any number greater than 10:

1. Using repeated division by 10, reduce the number until there is a single figure to the left of the decimal point.
2. Indicate how many times 10 has been used as a factor.

Thus 3,000,000 becomes 3×10^6, or, in words, three times ten to the sixth power. "Ten to the sixth power" means that we multiply 10 by itself six times, which makes one million. In the expression 10^6, the number 10 is called the <u>base</u> and the number six is called the <u>exponent</u>.

$$10 \times 10 \times 10 \times 10 = \underbrace{\overset{\boxed{\text{base}}}{10}}_{\boxed{\text{power of ten}}}{}^{4} \leftarrow \boxed{\text{exponent}}$$

And for a little practice, what does 8×10^4 equal?

8,000	Page 119
80,000	Page 121
800,000	Page 123

YOUR ANSWER: $10^3/10^3 = 1000/1000 = 0$.

Now you're letting yourself get carried away with this zero idea.

It's just a matter of dividing one number by itself. Any number divided by itself equals one -- so don't look for tricks. Just go ahead and work the obvious, ordinary arithmetic.

Return to Page 122 and try again.

YOUR ANSWER: 8,000

Wrong.

When you started multiplying 10 by 10, you stopped too soon. The number 8,000 can be factored as 8 x 10x10x10, which is 8×10^3, not 8×10^4.

If you simply made an error in multiplication, you know what to do. But if you were counting digits, and figured that 10^4 is the same as a number with four figures, then you've forgotten the two steps to be taken.

1. Using repeated division by 10, reduce the number until there is a single figure to the left of the decimal point.

2. Indicate how many times 10 has been used as a factor.

So, in 8×10^4, you multiply 8 by 10^4 which is 10 times 10 times 10 times 10.

This means that your answer will contain the figure 8 plus the four zeros that stand for 10^4.

Now return to Page 117 for the correct answer.

YOUR ANSWER: $10^3/10^3 = 1000/1000 = 1$.

Naturally.

Solving the problem by ordinary arithmetic, we get one for an answer. But when we solved the problem using powers of ten, we got this answer:

$$10^3/10^3 = 10^{(3 - 3)} = 10^0$$

What conclusions can you draw from this:

$10^0 = 0$ Page 111

$10^0 = 1$ Page 116

YOUR ANSWER: 80,000.

Correct.

10^4 is 1 x 10 x 10 x 10 x 10 -- or 10,000. You multiplied 10,000 by eight.

Now, just to fix the picture in your mind before we go on, study this table:

$10,000 = 1 \times 10 \times 10 \times 10 \times 10 = 10^4$ (ten as a factor 4 times)
$1,000 = 1 \times 10 \times 10 \times 10 = 10^3$ (ten as a factor 3 times)
$100 = 1 \times 10 \times 10 = 10^2$ (ten as a factor 2 times)
$10 = 1 \times 10 = 10^1$ (ten as a factor 1 time)

Apply these principles to the problem with which we began:

$$250,000 \times 2,000 = 500,000,000$$

First, reduce each number until you come down to a single number to the left of the decimal point.

What two numbers do you get?

0.25 and 2 Page 125

2.5 and 2 Page 127

25 and 2 Page 131

YOUR ANSWER: $10^3/10^3 = 10^{(3 - 3)} = 10^0$.

Right.

But now that you have 10^0 -- what can you do with it?

Hold on a minute and let's figure this same problem by ordinary arithmetic, without using powers, and see what you get.

Using ordinary arithmetic, which answer is right?

$10^3/10^3 = 1000/1000 = 0$ Page 118

$10^3/10^3 = 1000/1000 = 1$ Page 120

YOUR ANSWER: 800,000.

A stab in the dark?

You can't go on this way for long. Sooner or later you'll need more light. It might as well be now.

If this was just an error in multiplication, return to Page 117 **and select the right answer.**

However, if the whole idea is still giving you trouble, you may have been skimming. Go back to Page 55 **and make a new beginning.**

YOUR ANSWER: $10^3/10^3 = 1000/1000 = 1$

It is true that 1000 divided by 1000 equals one.

But we didn't ask for an answer in ordinary numbers. We asked you to give the result in exponent form -- as some power of ten.

In division of values expressed as numbers with exponents, you just saw that we subtracted the second exponent from the first.

So, return to Page 126 and do likewise.

YOUR ANSWER: 0. 25 and 2.

Wrong.

Did you forget that we want you to come up with a single whole number to the left of the decimal point? Your answer, 0. 25, is less than one.

When you divided your large number (250,000) by 10, you went too far. Remember to quit while you're still ahead -- one whole number ahead. In this case, your decimal point will be followed by a fraction, so that you have a whole number and a tenth.

Now return to Page 121 and select the right answer.

YOUR ANSWER: 10.

Of course.

10^2 is 100. 10^1 is ten. 100/10 equals 10.

Simple enough. But do you see what happened to the powers of ten?

You subtracted the second exponent from the first.

$$10^2 \div 10^1 = 10^{(2 - 1)} = 10^1$$

Now, following the same method, let's see what happens when you divide a power of a number by itself.

We'll divide ten to the third power by ten to the third power.

$$10^3/10^3 = ?$$

How would you write the result as a power of ten?

$10^3/10^3 = 10^{(3-3)} = 10^0$ Page 122

$10^3/10^3 = 1000/1000 = 1$ Page 124

YOUR ANSWER: 2.5 and 2.

Correct.

If you had selected 25 as your answer, you wouldn't have been reducing 250,000 the way we asked you to -- you'd just be lopping off zeros. This could get you into trouble. Besides, we wanted only one whole number to the left of the decimal point.

To select 0.25 is to go too far. You would have a value that is less than a whole number.

Our calculations won't require accuracy beyond one or two parts in a hundred, so you don't have to worry about more than three non-zero digits in a large number. To put it in the proper language: You don't need to go further than three significant figures. This will give you a whole number plus at most a decimal fraction rounded out to the hundredth.

So now you have the number 2.5 to multiply by a power of ten and the number 2 to multiply by a power of ten. What powers of ten do you use?

Count to the left until you have moved the decimal point to the correct position:

2.5 0 0 0 0	x	2. 0 0 0
5 places		3 places

The number of places moved to the left tells how many times you divided by 10. So, five places means 10^5 (ten to the fifth power); and three places means 10^3 (ten to the third power).

You would write it like this: $2.5 \times 10^5 \times 2 \times 10^3$

How would you state this problem: 375,000,000 x 400,000 ?

$3.75 \times 10^6 \times 4 \times 10^5$ Page 129

$37.5 \times 10^7 \times 4 \times 10^5$ Page 130

NEITHER CORRECT Page 132

YOUR ANSWER: 100.

How did you do that?

You made an error which indicates too much speed or too little thought.

Perhaps you mistook 10^1 for one and divided 100 (10^2) by one to get the answer. Of course this is wrong. 10^1 is ten. What does 100 divided by ten equal?

Return to Page 143 for the obvious answer.

YOUR ANSWER: $3.75 \times 10^6 \times 4 \times 10^5$.

Too hasty.

Study this problem again:

$$375,000,000 \times 400,000$$

Reduce the first figure as far as you can to arrive at a single whole number to the left of the decimal point. You get 3.75.

But what happened when you started counting the number of places you moved the decimal point? Count again. Were you counting only zeros?

Return to Page 127 and consider all the answers carefully. You must count every place you move the decimal point to the left -- not just the zeros.

YOUR ANSWER: $37.5 \times 10^7 \times 4 \times 10^5$.

No. Take another look. This is simply a matter of counting.

$$375,000,000 \times 400,000$$

In the first amount, you didn't move the decimal point far enough to the left. In order to arrive at a single whole number to the left of the decimal point, you must divide by 10 once more. And that means you will have moved the decimal point how many places to the left?

Return to Page 127 and don't settle for a wrong answer.

YOUR ANSWER: 25 and 2.

No.

For our calculations, we want to reduce each number down until a single whole number remains to the left of the decimal point.

The figure 25 doesn't fall into this category, since it is comprised of two whole numbers.

We want you to divide 250,000 by 10 until you come to a single whole number and, in this case, a decimal fraction. Don't let the fraction stop you. Remember that you're still after one whole number to the left of the decimal point.

Return to Page 121 and find it.

YOUR ANSWER: Neither answer was correct.

Right.

The problem, 375,000,000 x 400,000, multiplied as powers of ten, was, in both cases, stated incorrectly.

Each time the error was in the first half of the problem -- involving the figure 375,000,000. The last half was stated accurately:

400,000 is written 4×10^5

The figure 375,000,000, written correctly in powers of ten, would be 3.75×10^8 -- not 10^7 or 10^6. (The decimal point has to be moved eight places to the left.)

So the first half of the problem is expressed: 3.75×10^8. You are going to multiply this by 4×10^5 (400,000).

The answer should have been: $3.75 \times 10^8 \times 4 \times 10^5$.

Once more, let's pick up our problem:

250,000 x 2,000 = 500,000,000

What is 500,000,000 expressed in powers of ten?

5×10^8 Page 134

5×100^8 Page 135

Solve:

$$\frac{(8 \times 10^{-3}) (2 \times 10^{2}) (2.5 \times 10^{6}) (6 \times 10^{-1})}{(5 \times 10^{4}) (1.6 \times 10^{2}) (3 \times 10^{-7})}$$

a. 1×10^{4}

b. 1×10^{5}

c. 1×10^{6}

d. 1×10^{-6}

After selecting an answer go on to page 136.

YOUR ANSWER: $500,000,000 = 5 \times 10^8$.

Correct.

Let's pick up the rest of the problem now. Expressing it in powers of ten:

$$250,000 \times 2,000 \text{ is } 2.5 \times 10^5 \times 2 \times 10^3$$

And we've just figured out that

$$500,000,000 \text{ is } 5 \times 10^8$$

We can put these two parts together and say that

$$250,000 \times 2,000 = 500,000,000$$

can be expressed in powers of ten as

$$2.5 \times 10^5 \times 2 \times 10^3 = 5 \times 10^8$$

We're on the verge of something important now and it'll be plainer if we turn that equation around a little.

$$2.5 \times 2 \times 10^5 \times 10^3 = 5 \times 10^8$$

A careful look should show you the procedure for multiplying in powers of ten: Multiply the significant figures, add the exponents. In this case, 2.5×2 gives you 5; $10^5 \times 10^3 = 10^{5+3} = 10^8$

Now try this: Given $I = 3 \times 10^3$ amps, and $R = 4.25 \times 10^6$ ohms, we find that $E = 12.75 \times 10^9$ volts.

Using Ohm's law and expressing this in ordinary numbers, how would the problem look?

3000a x 4,250,000Ω = 12,750,000,000v Page 137

3000a x 425,000Ω = 1,275,000,000v Page 138

3000a x 42,500,000Ω = 127,500,000,000v Page 140

YOUR ANSWER: $500,000,000 = 5 \times 100^{8}$.

What!

You've got enough goose eggs there to start a hatchery!

You reduced 500,000,000 to a single number to the left of the decimal point. But to arrive at

5.00000000

how many places did you move the decimal point? Or, to put it another way, how many times did you divide by 10?

The answer is 8, as you're probably aware. But remember, you're dividing by 10. That 8 is going to be the exponent for the base 10. You're working in powers of 10, not of 100.

Incidentally, have you paused to figure what number your answer represents?

50,000,000,000,000,000

Return to Page 132 for a logical solution.

How much current will flow through a 680 K ohm resistor that is connected across a 34 volt battery ?

a. 5 milli amps.

b. 50 micro amps.

c. 2 milli amps.

d. 200 micro amps.

After selecting an answer go on to page 139.

YOUR ANSWER: 3000a x 4,250,000Ω = 12,750,000,000 volts.

Correct.

If I equals 3×10^3a, then I equals 3000a.

$$3 \times 10 \times 10 \times 10 = 3 \times 1000 = 3000$$

And if R equals 4.25×10^6 ohms -- then R equals 4,250,000 ohms.

When you're in the millions, multiplying 10 by 10 by 10, etc. gets to be a nuisance. It's easier to move the decimal point to the right as many places as are indicated by the exponent of ten. In this case, the value of R is multiplied by ten to the sixth power, so you move the decimal point six places to the right. Thus, 4.25×10^6 becomes 4,250,000.

Now look at it from the other direction, changing 4,250,000 back to 4.25×10^6. The number of places you move the decimal point (the number of times you divide by 10, in other words) to reduce 4,250,000 to the point where there is a single digit to the left of the decimal point will give you the figure for the exponent. You arrive at the power of ten.

Expressed in powers of ten, your problem looks like this:

$$3 \times 10^3 \text{ amps} \times 4.25 \times 10^6 \text{ ohms} = 12.75 \times 10^9 \text{ volts.}$$

How would you work that problem using powers of ten?

Multiply the first two factors, add the last two. Page 141

Multiply 3 x 4.25, add the exponents of ten. Page 143

Multiply 3 x 4.25, multiply the exponents of ten. Page 144

YOUR ANSWER: 3000a x 425,000Ω = 1,275,000,000 volts.

Wrong.

It is true that if $I = 3 \times 10^3 a$, then $I = 3000a$.

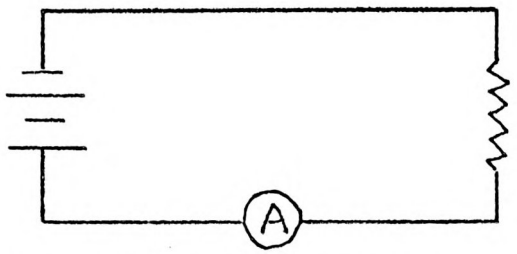
$$3 \times 10 \times 10 \times 10 = 3 \times 1000 = 3000$$

But something went wrong when you tried to translate 4.25×10^6 into ordinary numbers.

To multiply 4.25 by 10^6, you must move the decimal point <u>six</u> places to the right.

Return to Page 134 and start counting.

If the current in the diagram below decreased in value, which of the following could have happened to cause it to decrease.



a. The voltage from the battery increased.

b. The resistor increased in value.

c. None of the above could cause it to increase .

After selecting an answer go on to page 142.

YOUR ANSWER: 3000a x 42,500,000Ω = 127,500,000,000 volts.

Wrong.

It is true that if $I = 3 \times 10^3$, then I = 3000a.

$$3 \times 10 \times 10 \times 10 = 3 \times 1000 = 3000$$

But when you tried to translate 4.25×10^6 into ordinary numbers, you lost count someplace.

To multiply 4.25 by 10^6, you must move the decimal point **six places** to the right.

Return to Page 134 and this time count slowly.

YOUR ANSWER: Multiply the first two factors, add the last two.

Impossible.

You may be thinking the right answer, but it's coming through wrong.

In this problem, $3 \times 10^3 \times 4.25 \times 10^6$, the first two factors are 3 and 10^3. So far so good. Multiplying them isn't the right way to solve the problem, but it is still a recognizable operation.

The second two factors are 4.25 and 10^6. You certainly don't add them. That's clearly a multiplication problem, too.

It is true that you multiply and add in order to solve the problem. But your terminology is incorrect. What do you multiply, and what do you add?

We'll answer part of that for you: To multiply powers of ten, you add the exponents.

Return to Page 137 for the correct answer.

This is the end of the lesson. Please write the length of time it took you to complete this lesson on your answer sheet.

YOUR ANSWER: Multiply 3 x 4.25, add the exponents of ten.

Correct.

To multiply with powers of ten:

1. Reduce each number in your problem until you have a single whole number remaining to the left of the decimal point.

   (a) 2,000 x 25,000

   (b) 2.ØØØ x 2.5ØØØ

2. Determine how many places you moved the decimal point:

   2.ØØØ x 2.5ØØØ

   3 places 4 places

   This gives you the power of ten for each number: $10^3 \times 10^4$.

3. Multiply the significant numbers in the usual way:

   $(2. \times 10^3) \times (2.5 \times 10^4)$

   $2. \times 2.5 = 5$

   Add the powers of ten of each number multiplied:

   $10^3 \times 10^4 = 10^{3+4} = 10^7$

4. Your answer is expressed as two factors: 5×10^7.

The first factor is the product of your multiplication.

The second factor is 10 with an exponent which is the sum of your addition. But note that the 10 remains 10.

You should feel easy about working with powers of ten now. So let's pursue the subject a little further.

You know what 10^2 equals and what 10^1 equals. So what do you think 10^2 divided by 10^1 would equal?

10 Page 126

100 Page 128

YOUR ANSWER: Multiply 3 x 4.25, multiply the exponents of ten.

No!

You do not multiply and multiply. You multiply and add!

Using another example, here's what happens if we follow your method:

$$(2 \times 10^2) \times (2 \times 10^4) = 4 \times 10^8$$

Now let's check this by doing it the long way :

$10^2 = 10 \times 10 = 100$ $\quad\}\quad 2 \times 100 = 200$

$10^4 = 10 \times 10 \times 10 \times 10 = 10,000$ $\quad\}\quad 2 \times 10,000 = 20,000$

$$\begin{array}{r} 20000 \\ \underline{\quad 200} \\ 00000 \\ 00000 \\ \underline{40000\quad} \\ 4000000 \end{array}$$

Your answer is 4,000,000. Now if you reduce this to a single whole number to the left of the decimal point, you get 4. How many places must you move the decimal point? Six, isn't it? So your answer may be expressed in powers of ten:

$$4 \times 10^6 \text{ -- not } 4 \times 10^8$$

Return to Page 137 for the accurate statement.

SERIES CIRCUITS

2-C



NAVAL AIR TECHNICAL TRAINING COMMAND

Acknowledgements

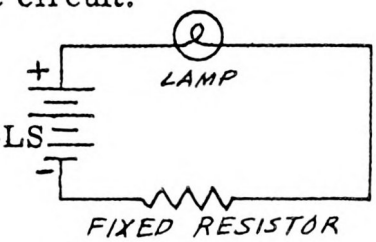
This program was adapted by the Naval Air Technical Training Center, Memphis, Tennessee, from a larger one developed under contract No. AF 33 (616)-6983 CPFF between the U.S. Air Force and Western Design and Electronics. In a letter dated 27 July, 1961 from the Aeronautical Systems Division, Air Force Systems Command, United States Air Force, use of these materials by other governmental agencies was confirmed. Appreciation is expressed to the Aeronautical Systems Division and to Western Design and Electronics for assistance in making the original program available.

INTRODUCTION TO CIRCUITS

An electrical circuit is made by connecting with conductors a source of electrical potential and one or more electrical devices, light bulbs or motors, for instance. The word circuit comes from the same root as the word circle. Its use in electricity emphasizes the need for a continuous path for electron flow.

Until now, we have drawn pictures of the electrical equipment in our circuits. This is inconvenient. There are standard symbols that are used to represent this equipment in circuit diagrams.

Here is a diagram of a simple circuit.



Two electrical devices are connected to the battery. The connecting lines represent conductors. Three standard electrical symbols are employed. Here they are labeled, but most circuits are not. You will need to remember what the symbols stand for. Don't worry, it's not difficult. A complete chart is available in your Basic Electronics Text Book.

Current actually starts to flow in all parts of a complete circuit at the same instant. Let us consider those electrons starting at the battery.

Which is the correct statement about the circuit diagram?

The direction of electron flow is from the battery through the fixed resistor and through the lamp. Page 4

The direction of electron flow is from the battery through the lamp and through the fixed resistor. Page 6

The direction of electron flow is not indicated. Page 9

YOUR ANSWER: The voltage across lamp A is higher.

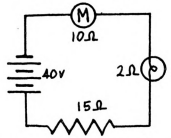
It's difficult to see how you reached this conclusion if you looked carefully at the two diagrams.

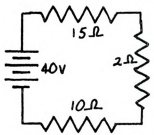
Chemical sources of voltage are usually indicated as if they were three-cell batteries, even though the voltage is greater than could be generated by three cells. This is done for convenience, since it would be impractical to draw the number of cells needed to generate 90v or even 22-1/2v. After all, the most common cells generate only 1.3v to 2v.

It is usual to indicate on an electrical diagram the actual voltage being generated by the seat of EMF so that the three-cell diagram will not mislead. Actual voltage may be written either right next to the battery symbol or in a footnote or table. Normally, in this course you will find the voltage right next to the symbol, as it is on the examples on Page 7. Return not to that image and select the circuit with the highest voltage.

YOUR ANSWER: Yes, the two circuits are electrically identical.

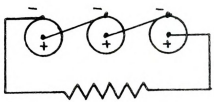
Correct. In the diagram on the left, the negative pole of the battery





is at the top. The direction of current is from the negative pole to the motor, to the lamp, and then to the fixed resistor and back to the battery. In the diagram on the right, the negative pole is at the bottom. The current flows through three resistances of the same value as those in the diagram on the left and in the same sequence. These diagrams are called electrically equivalent because analysis by Ohm's law would show the same relationship in both between voltage, current and resistance.

Remember when you learned about batteries, you were shown two ways in which batteries could be hooked up? One of those ways was called series, one parallel. Here is an illustration of one of the two ways. Which is it?



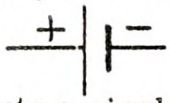
Series Page 8

Parallel Page 15

YOUR ANSWER: The direction of electron flow is from the battery through the fixed resistor and through the lamp.

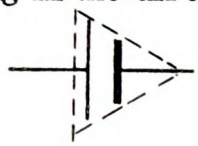
Correct. We can think of current as an instantaneous flow of electrons moving from the negative side of the battery, around the circuit and back to the positive side of the battery.

The symbol for the battery is composed of pairs of lines like this:

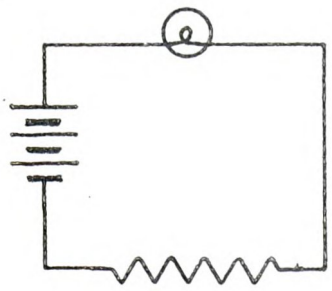


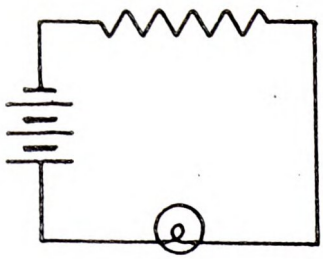
Each such pair represents a single cell. The short line is the negative pole, the long line the positive pole. Sometimes the negative line is drawn thicker as above.

Electrical diagrams do not normally label the polarity of the cell, so you will need to remember which side is which. It may be helpful to think of the symbol for a cell as an arrowhead pointing in the direction of electron flow. That makes the point end negative.



Now look at these circuits:





In each case, is the direction of electron flow through the fixed resistor and then through the lamp?

Yes Page

No Page 10

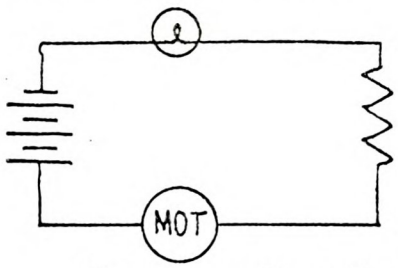
I don't know Page 1

YOUR ANSWER: The voltage across Lamp B is higher.

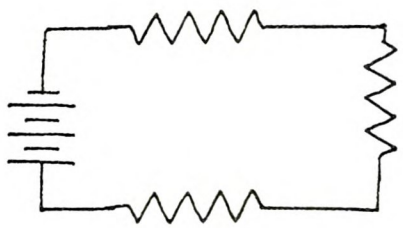
Yes, the power supply in circuit B was labeled "60 volts" and that in A "50 volts". The three-cell battery symbol was used in each diagram simply for convenience. If this device weren't used, a 60-volt source composed of 2-volt cells would require drawing in 30 cells.

So far we have used the special symbol —(ℓ)— for a lamp. Sometimes the only electrical importance of the lamp is the resistance it offers and we'll sometimes find that lamps and other circuit components are shown simply by resistor symbols (—/\/\/\—). Whole circuits will be drawn looking as if nothing was being done but the pumping of electrons through resistances.

For example, the standard symbol for a motor is —(MOT)— We can specifically include a motor, a lamp, and a fixed resistor in a circuit, or we can show the electrical equivalent with three resistors.

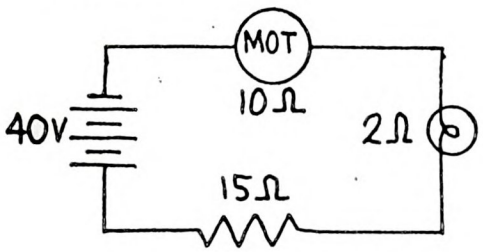


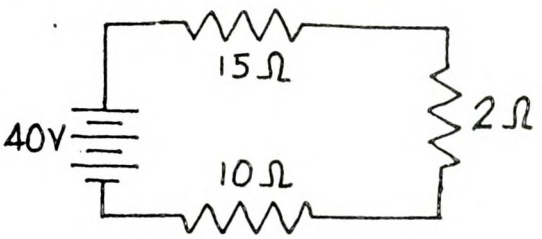
or



If we are primarily interested in the resistance offered by each device, the second diagram is just as good as the first and, in addition, it's a little easier to draw. What kind of a device each resistance represents may or may not be indicated but the resistance of each will be given in ohms (Ω).

Look at these two circuits. Do you think they are electrically identical?





Yes — Page 3

No — Page 13

YOUR ANSWER: The direction of electron flow is from the battery through the lamp and through the fixed resistor.

Sorry, but you seem to have forgotten one of those really basic points, or else you didn't look closely at the diagram.

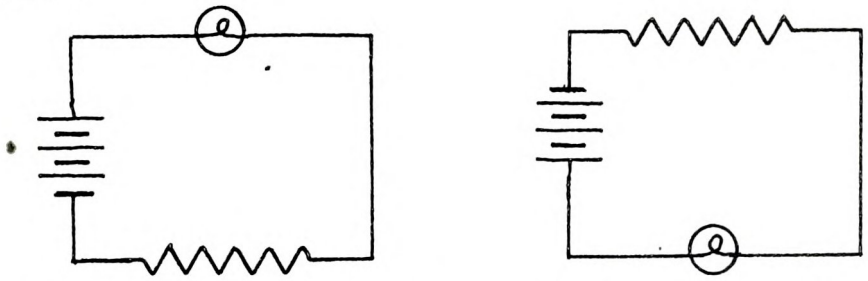
Electrons flow away from the negative pole of a battery or cell. They do so because like charges repel. Both an electron and a negative pole are negatively charged.

If you remembered that but just failed to notice which side of the battery was marked negative, look more closely when you go back.

Now, return Page 1 and select the correct answer.

YOUR ANSWER: Yes, in each case the direction of electron flow is through the fixed resistor and then through the lamp.

Correct. The two circuits are identical. It's just that one has been turned over.



There is no standard position for a battery. In most simple circuits, we try to show the power supply on the left side of the diagram, but you will have to check each time whether negative is on the top or the bottom.

In both circuits you saw three pairs of parallel lines in the battery symbol. Occasionally this form may be used to show a battery that actually has three cells in series. In those cases, the total battery voltage is found by adding the voltage of each cell. Three dry cells would be 4.5 volts, three lead cells 6 volts, and three Edison cells about 3.9 volts.

In most circuits the three-cell symbol will be used to represent larger voltages, however. The actual voltage will be indicated beside the symbol.

Which of these two circuits has the higher voltage?



The voltage across Lamp A is higher. Page 2

The voltage across Lamp B is higher. Page 5

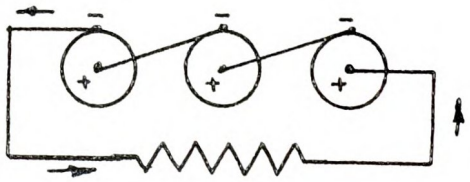
I can't tell without knowing what type of cell is shown. Page 12

The voltage is the same in each circuit. Page 16

YOUR ANSWER: Series.

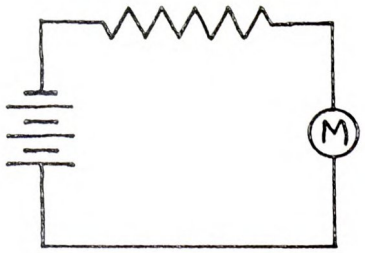
That is correct.

And all of the circuits used so far in this section have been series circuits. The series connection of electrical cells looked like this:



An equal number of electrons flows in each cell. And, as we saw earlier, in a series circuit the total current flows through each component. This is the distinguishing feature of the series circuit. There is no alternative path for current. It can go nowhere but 'round and 'round the circuit.

Now, here is a diagram of another simple series circuit. Notice that it has both a motor and a resistor. If we take out the resistor and put nothing back in to bridge the gap, will the motor run better?



Yes Page 11

No Page 18

YOUR ANSWER: The direction of electron flow is not indicated.

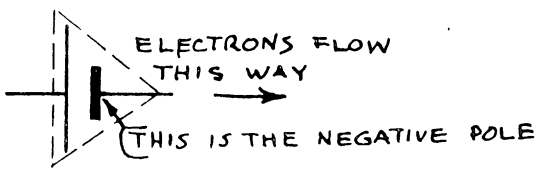
Oh, but it is. True, there is no arrow to show which way electrons are flowing, but you should know because the poles of the battery are marked.

Electrons can only flow away from a like charge and toward an unlike charge. Electrons have a negative charge. They will flow away from the negative pole. You should certainly know that by now.

Now, return to **Page 1** and select the correct answer.

YOUR ANSWER: No.

You couldn't have looked very closely at the two diagrams. To tell the direction of electron flow in a battery, imagine that the combination of lines used to indicate a single cell is really an arrowhead pointing in the direction of electron flow, like this:



If you have that clearly in mind, you can look at the diagrams again and figure out the direction of electron flow.

Now, return to Page 4 and select the correct answer.

YOUR ANSWER: Yes, it will run better.

It might seem that if there is less resistance in the line, the motor will run better. That is not necessarily true, since you might have a motor that would burn out if too much current reached it.

But that is not really the point. The sneaky, key phrase in the question was, "and put nothing back in to bridge the gap". If nothing was put back in to bridge the gap, the motor will not run at all. What we have then is called an open or open circuit. Remember, you recently used an ohmmeter to test for opens. Well, an open is what you've got here.

Now, return to **Page 8** and select the correct answer.

YOUR ANSWER: I can't tell without knowing what type of cell is shown.

You missed the point.

Chemical sources of voltage are indicated as if they were three-cell batteries, even though the voltage is greater than could be generated by three cells. This is done for convenience since it would be impractical to draw the number of cells needed to generate 90v or even 22-1/2v. After all, the most common cells generate between 1.3v and 2v.

It is usual to indicate on an electrical diagram the actual voltage being generated by the seat of EMF so that the three-cell diagram will not be misleading. Actual voltage may be written right next to the battery symbol or in a footnote or table. Normally, in this course you will find the voltage right next to the symbol. Only if the voltage were not written in would you need to know the type of cells used in order to compute the voltage.

In these diagrams the voltage generated by the batteries in both diagrams is clearly indicated right next to the battery symbols. Return to Page 7 and select the right answer.

YOUR ANSWER: No, the circuits are not electrically identical.

You must have lost something, somewhere along the line.

The last image was devoted to explaining that for some purposes it is sufficient to show all the components of a circuit as resistances. Any appliance or electrical device -- a toaster, a light, a motor, a radio set, or what you will -- offers a resistance to electron flow, no matter what kind of work it does. For purposes of discovering current flow or voltage requirements, the only important thing about the device is how much resistance it offers. So, sometimes we simply diagram a circuit as if it were a series of resistances. That is simple enough and should not have misled you.

The other thing that may have tripped you is that the components, though they are shown to have the same resistance, appear to be in different order. Perhaps you failed to check the polarity of the battery. If you check, you will find that in one illustration the negative pole is up, in the other down.

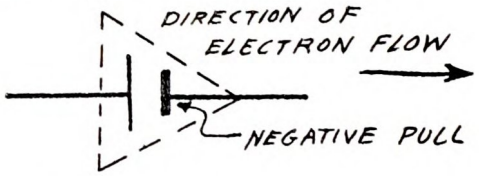
Now, go back and follow the electron flow of the two circuits starting from the negative pole of the battery. See if the flow isn't through the same resistances in the same order in both circuits. The page was 5.

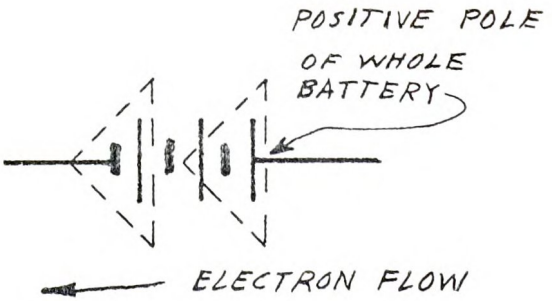
YOUR ANSWER: I don't know.

That's honest, at least.

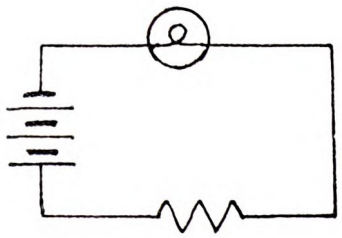
Current starts flowing at once in all parts of a complete circuit. We'll consider a portion of the current starting at the battery.

First, let's get it clear how to tell the direction of current from looking at the battery or cell symbol. The symbol for a single cell can be thought of as an arrowhead, as at the right, pointing in the direction of current flow. If you had trouble with the symbol for a battery (which is just a collection of cells), begin at either end of the battery symbol and take the first two lines as the cell that forms the arrowhead, like this:





Now, let's look at one of the schematic diagrams and figure out the direction in which electrons will go through its components.



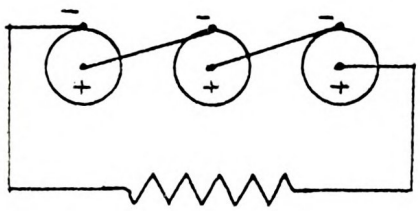
The arrowhead points upward in this diagram, so that's where electrons leave the battery. Electrons move toward the lamp. The direction of electron movement from the lamp is along the conductor toward the next component, the fixed resistor. From the fixed resistor, the direction of movement is toward the positive side of the battery.

Now, return to Page 4 analyze both illustrations in this manner, and select the correct answer.

YOUR ANSWER: Parallel.

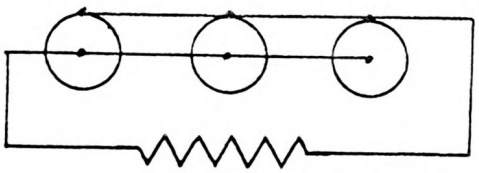
Afraid not.

If you stop to consider what parallel means, you will see that this illustration could not be a parallel circuit.



Parallel means running along beside each other without ever touching, like railroad tracks.

Here is an illustration of a parallel arrangement of cells:



Now, return to Page 3 and select the correct answer.

YOUR ANSWER: The voltage is the same in each circuit.

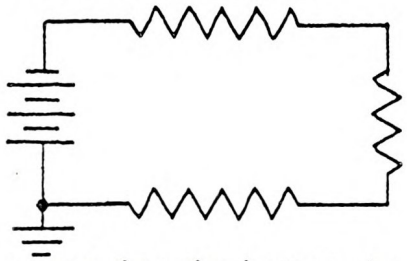
You missed the point. The fact that each battery is shown to have three cells does not indicate that they have the same output.

Chemical sources of voltage are indicated as if they were three cell batteries, even though the voltage is greater than could be generated by three cells. This is done for convenience since it would be impractical to draw the number of cells needed to generate, for instance, 90v or even 22-1/2v. After all, the most common cells generate between 1.3v and 2v.

It is usual to indicate on an electrical diagram the actual voltage being generated by the seat of EMF so that the three cell diagram will not be misleading. Actual voltage may be written right next to the battery symbol or in a footnote or table. Normally, in this course you will find the voltage right next to the symbol, as it is in the two examples on Page 7 Return now to that image and select the circuit with the highest voltage.

YOUR ANSWER: Yes. The battery alone is grounded.

Here is the illustration once more.



Why would you say that the battery is connected to ground but that the resistor is not connected?

Return to **Page 20** and select the correct answer.

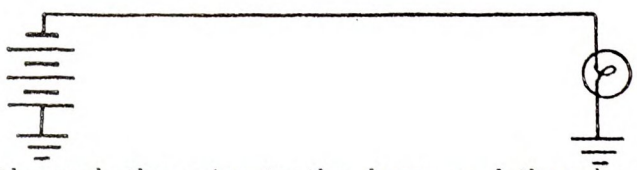
YOUR ANSWER: No, it won't run better.

Correct. It won't run at all. If, as the question has it, "we take out the resistor and put nothing back in to bridge the gap", we have made an open circuit, so no current can flow.

All the series circuits studied so far have been closed circuits, because they had wires running from one component to the next. Sometimes a circuit is completed (closed) by grounding it.

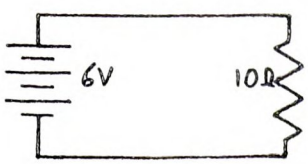
And here's a statement you can preserve: Ground doesn't necessarily mean ground of the dirt type. The term ground is used to mean a path other than a wire conductor for returning electrons or current to the power source. For instance, in the circuit for an automobile tail light, the car's steel frame might be used as the return. One pole of the battery and one side of the light bulb are attached to the frame. When this is done, the frame is called the ground and the battery and bulb are said to be grounded. Here is the symbol for ground and the circuit of an auto tail light.

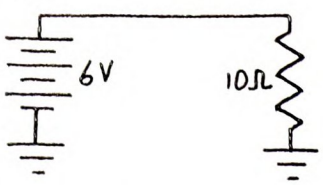




The current is through the wire to the lamp and then back to the battery through the frame. It is necessary to run only one wire the length of the car. This is a closed circuit. The chief advantage of a circuit of this sort is that it saves wire and makes for simplicity.

Are the circuits below electrically equivalent?





Yes — Page 20

No — Page 23

YOUR ANSWER: Part of the current is flowing through the ground.

That, frankly, is a rather improbable answer.

Remember these two principles:

1. In a series circuit, the current is the same in all parts of the circuit.

2. It it necessary to have a conducting loop for current to flow.

The ground forms one section of the conducting loop. There is no point in this circuit where current can split up and go in different directions. That means it is a series circuit. Since it is a series circuit, the amount of current going through the ground has to be exactly equal to the amount of current flowing in any other part of the circuit.

If different amounts of current were flowing in different parts of a series circuit, electrons would be piling up somewhere along the circuit.

Now, return to **Page 21** and select the correct answer.

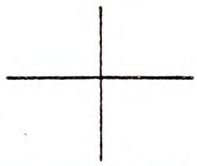
YOUR ANSWER: Yes, they are electrically equivalent.

Right. Both are complete or closed circuits, and both have equal voltage and resistance.

When wires cross each other in a circuit, it is necessary to show whether they are actually in electrical contact. When there is such a connection, it is indicated by a dot, like this:



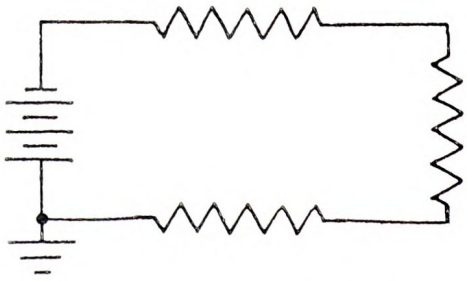
CONNECTED WIRES



CROSSED-OVER WIRES
NO CONNECTION

Wires that cross without electrical contact do not have a dot. The symbol for crossed-over wires with no connection, means that the two wires are insulated from each other at that point. In an actual circuit they may not even cross, though they do so in the diagram because the drawing of a complicated wire arrangement makes it unavoidable.

In the circuit below, is the battery alone grounded?



Yes Page 17

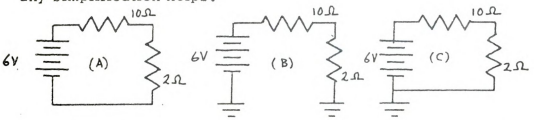
No Page 21

YOUR ANSWER: No. The battery is not the only component that is grounded.

Correct. The positive side of the battery was connected to the resistor at the bottom of the diagram and both were connected to ground.

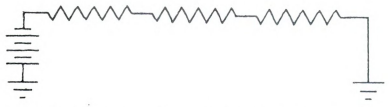
In drawing circuits, simplicity is important. Look at the three drawings below. Diagram A represents the basic circuit. Diagram B shows an equivalent circuit which uses ground for the return. Diagram C, which looks rather like the circuit on the last image, is electrically identical to Diagram B.

In C we have dispensed with one drawing of the symbol for earth. This may not seem much, but in more complicated circuits any simplification helps.



Remember that in electrical circuits, "ground" does not often mean a connection to earth itself. It usually means a connection to a conductor to which one side of the power source is also connected. This common conductor could be the chassis of a radio set, a single wire or bar within an electrical apparatus, or something similar, just as the frame is used as ground in the car's electrical system.

Now look at this series circuit, and choose the correct statement below:



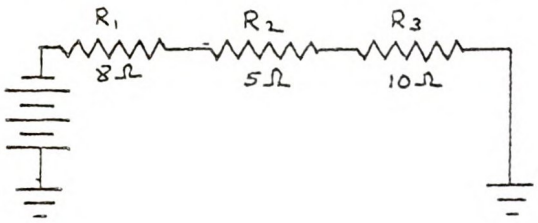
Part of the current is flowing through ground.

All of the current is flowing through ground.

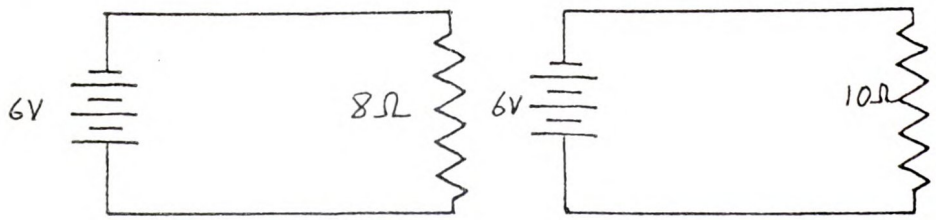
None of the current is flowing through ground.

YOUR ANSWER: More than 2 amperes are flowing through R_1.

You weren't reading very carefully. It may seem at first that because the resistance at R_3 is greater than at R_1, there should be more current flowing through R_1.



If we had two circuits like those below, one with a resistance of 8 ohms and one with a resistance of 10 ohms, it is true that, according to Ohm's Law, the current would be greater in the circuit with the smaller resistance.

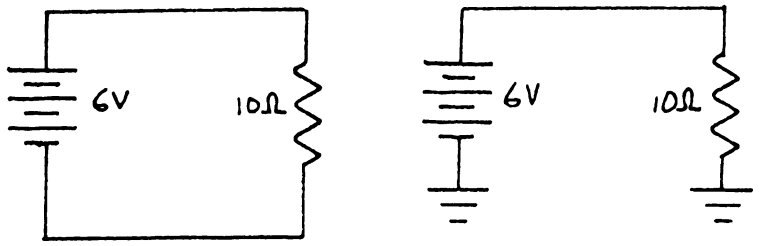


However, in a series circuit the amount of current flowing through any component of the circuit is determined by the total resistance of the circuit. More current cannot possibly flow through one part than another. Think back to the analogy of the water pump and the continuous pipe. The rate of flow through any portion of that pipe cannot be greater than the rate of flow through any other portion.

Now, return to Page 21 and select the correct answer.

YOUR ANSWER: No, they are not electrically equivalent.

Sorry, but they are. Look at the diagrams again. Both have a power source of 6v. Both have a resistance of 10 ohms, too. So, the current should be equal in both circuits, too, if the circuits are closed.



In the left-hand circuit, it is clear that we have continuity, so we have current. To be precise, we have a current of .6 amps, according to Ohm's Law.

The last image tried to point out that a common ground, such as an auto frame, for instance, serves the same function as a conductor, and can be used to complete circuits in such a way as to save wiring. That is the case in the circuit on the right. It, too, is a complete circuit, so there is current. The current in the right-hand circuit is also .6 amps.

Now, return to Page 18 and select the right answer.

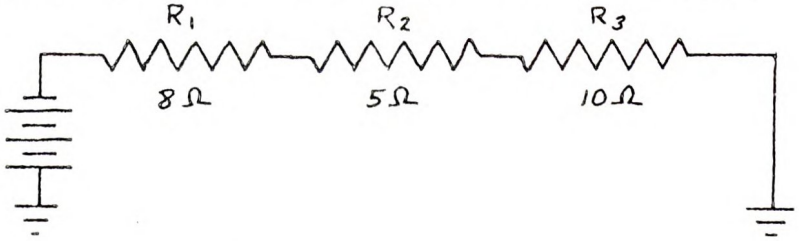
YOUR ANSWER: All of the current is flowing through ground.

Correct. In order to return to the battery after flowing through the three resistances, all of the current must go through ground. This is one characteristic of the series circuit: the total current goes through each device in the circuit. You may think of current as a quantity of electrons. In a series circuit the quantity of electrons flowing per second through any one part of the circuit is the amount that must be flowing through all other parts of the same circuit.



Electric current, you will recall, is measured in amperes, so in a series circuit the amperage will be the same through each component in the circuit.

Look at the circuit below and choose the correct statement. Each resistance in the circuit is given in ohms (Ω).



If 2 amperes are flowing through R_3, then _____.

More than 2 amperes are flowing through R_1. Page 22
Exactly 2 amperes are flowing through R_1. Page 27
Less than 2 amperes are flowing through R_1. Page 29

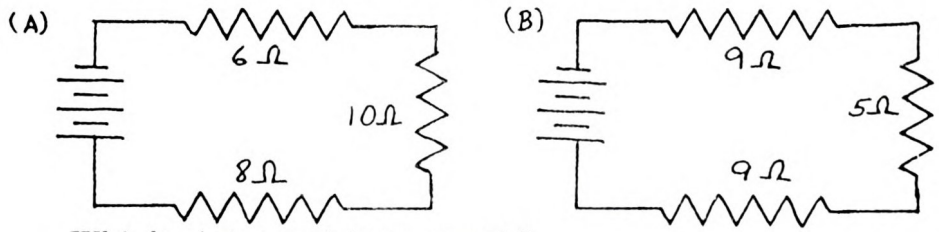
YOUR ANSWER: Exactly 2 amperes are flowing through the battery.

Correct. In a series circuit you find the same amperage at every point in the circuit. If 2 amperes were flowing through one resistance, 2 amperes were also flowing through ground, 2 amperes through the battery, and 2 amperes through each wire in the circuit.

Of course, we can't make 2 amperes flow through a circuit just by wishing for it. We must have a battery strong enough to move that quantity of current through the given resistance. In this circuit, for instance, with resistances of 8 ohms, 5 ohms, and 10 ohms, we couldn't make 2 amperes flow with a flashlight battery or even with a 12-volt car battery. There is too much resistance. We can apply Ohm's Law to determine how many volts would be needed to produce 2 amperes of current in this circuit.

First, you will need to know the total resistance in the circuit. In a series circuit, the total resistance is found simply by adding together all the resistances present. The ground conductor and the wires, themselves, have a slight resistance, but generally you may consider them as having "no resistance." (The battery always has an internal resistance to its own current flow which affects its efficiency and life span, but doesn't affect the application of Ohm's Law to circuit analysis. We will consider internal resistance of power sources later on.)

Look at these two circuits:



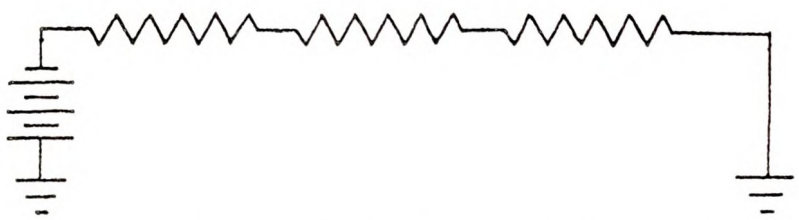
Which statement is correct?

The resistance in circuit A is less than the resistance in circuit B. Page 28

The resistance in circuit B is less than the resistance in circuit A. Page 33

YOUR ANSWER: None of the current is flowing through ground.

Well, let's look at the illustration again:



There is current, improbable as it may seem, and that current is flowing through the ground.

We have a source of electromotive force and a conductor that is at least part of a circuit. The question seems to be, does the ground form the balance of the circuit? Can't it be a conductor? If it is, then the circuit is complete and electrons should flow.

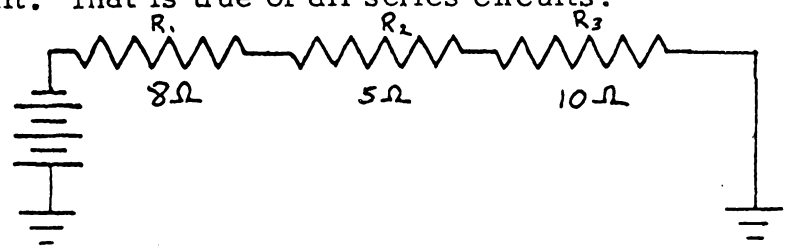
Be sure you understand that both ends of the circuit are grounded to the same piece of material, and that that piece of material is capable of conducting.

So, current can and does flow through ground.

Now, return to Page 21 and select the correct answer.

YOUR ANSWER: Exactly 2 amperes are flowing through R_1.

Yes, the size of the resistors makes no difference in this problem. If 2 amperes are flowing through one component, then 2 amperes are flowing through every component in the circuit. That is true of all series circuits.



Remember that the ampere is a measure of quantity. If we go back to our analogy of the ping-pong balls in the tube, we could think of a series circuit as a circular tube already filled with ping-pong balls. We could cut out a piece of the tube so that we could push additional ping-pong balls into the tube. (Then our hand would represent the battery or electromotive force.) If we push three ping-pong balls into the tube, exactly three will come out the other end, of course. And if we cut a small window in the tube at any point, we would see exactly three ping-pong balls move past our view point.

In the circuit above, how many amperes are flowing through the battery?

Exactly 2 amperes are flowing through the battery. Page 25

About 6 amperes are flowing through the battery. Page 32

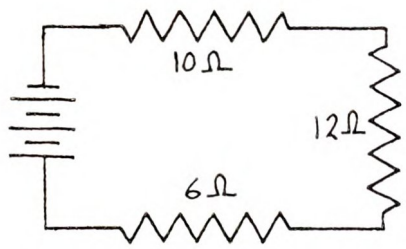
I don't know. Page 34

YOUR ANSWER: The resistance in circuit A is less than the resistance in circuit B.

You didn't add very carefully.

The total resistance of a series circuit is found simply by adding together all the individual resistances in a circuit.

Here is an example. This is a series circuit. To find out the total resistance of this circuit, we add the resistance of all its components. Starting at the top, we have 10 ohms, next down the side, we have 12 ohms, giving us 22. On the bottom we have another 6 ohms, so the total resistance is 28 ohms.



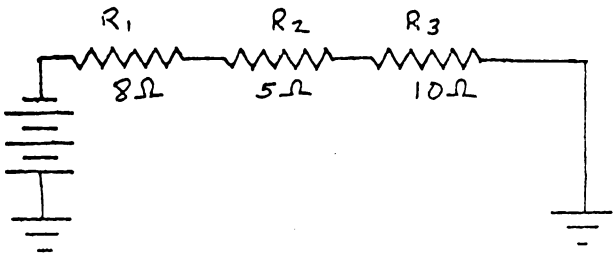
$$\begin{array}{r} 10\Omega \\ 12\Omega \\ +\ 6\Omega \\ \hline 28\Omega \end{array}$$

Now return to Page 25 and calculate the total resistance of both the circuits in the same way.

YOUR ANSWER: Less than 2 amperes are flowing through R_1.

No.

In a series circuit such as the one we are discussing,



the amount of current flowing through any component is determined by the total resistance of the circuit. More current cannot possibly flow through one part than another. The current is the same, whether you measure it in a series circuit.

Now return to **Page 24** and select the correct answer.

YOUR ANSWER: To find electromotive force, use $I = \frac{E}{R}$.

You're not watching very closely. This is the same problem as before.

Electromotive force is E. And the unit of electromotive force is voltage. If you want to solve for voltage, you choose the form of Ohm's Law most convenient for finding E. That form will begin, E equals.....

Now, return to Page 35 and select the correct answer.

YOUR ANSWER: To solve for voltage, you would use the form $I = \frac{E}{R}$.

You could solve for E starting with this form, but you would have to perform an extra mathematical operation to isolate E on one side of the equation. You want to find out what E equals.

The easiest way is to use the equation that starts out E equals..... This way, you will get the answer you want directly. The form you have chosen would be most convenient for finding amperage (I), since I is already isolated on one side of the equation.

Now, go back to Page 33 and select the right answer.

YOUR ANSWER: About 6 amperes are flowing through the battery.

That can't be true.

The battery is just as much a part of the circuit as is the resistance. The current is the same through each component in a series circuit.

To use the ping-pong ball example again, the battery is located in the circular tube where we cut the hole to add more ping-pong balls. The battery collects ping-pong balls at one end (the positive pole) just as fast as it pushes them away from the other end (the negative pole).

The same is true in our electrical circuit. The battery gets back as many electrons as it pushes out at the other side. And at any point in the circuit it is true, too. As many electrons as are forced into the circuit at the negative pole will pass any point in the circuit.

So, the current in the battery is the same as the current in any other part of the circuit.

Now, return to Page 27 and select the correct answer.

YOUR ANSWER: The resistance of circuit B is less than the resistance of circuit A.

Right. In a series circuit, you find the total resistance by adding together the resistance of each part of the circuit.

Ohm's Law tells us the relationship of the electrical units known as amperes, volts, and ohms.

> The ampere (a or amp) is the unit for measuring the quantity of electrons passing any one point in one second. This electron flow is also called current (I).
>
> The volt (v) is the unit of electromotive force (emf or E). It is the measure of the difference in electrical potential, the force that makes electrons move.
>
> The ohm (Ω) is the measurement of resistance (R) to current flow.

The abbreviations, a, v, and Ω, are used in circuit drawings. In Ohm's Law calculations we use:

I = Current flow in amperes.

E = Electromotive force in volts.

R = Resistance in ohms.

The answers are expressed, of course, in volts, ohms, or amperes, or with the appropriate abbreviation or symbol.

If you know the amperage and resistance in a circuit and want to know the voltage, which form of Ohm's Law will you use?

$I = \frac{E}{R}$ Page 31

$E = IR$ Page 35

$R = \frac{E}{I}$ Page 38

YOUR ANSWER: I don't know.

Well, isn't the battery a part of the circuit? The amperage of all parts of a series circuit, including the battery, is exactly the same.

If we look at the function of a cell again, perhaps the matter will become clear. A cell, you will remember, consists of two poles, usually of different materials, that are placed in a chemical solution. The nature of the materials used is such that a potential difference is produced between the two poles. Different combinations of materials produce different amounts of EMF. That is why dry cells, fresh ones, produce 1.5v, lead acid cells 2v, and Edison cells 1.3v. Each uses a different combination of chemicals capable of maintaining a definite voltage.

When electrons flow away from the negative pole of such a cell and return to the positive pole, they tend to neutralize the potential difference. But the battery wants to maintain its natural voltage level, so within the battery just enough electrons move to maintain the cell's normal voltage. The amount of electrons necessary to maintain that voltage is exactly equal to the amount that flowed through the circuit outside the battery.

Now, return to Page 27 and select the correct answer.

YOUR ANSWER: To solve for voltage you would use the form $E = IR$.

Correct.

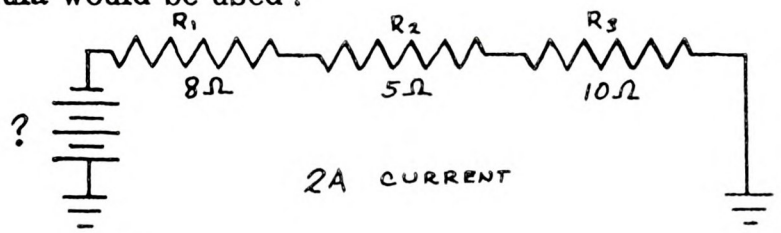
To find voltage, multiply amperes times ohms ($E = IR$).

To find amperes, divide volts by ohms ($I = \frac{E}{R}$).

To find ohms, divide volts by amperes ($R = \frac{E}{I}$).

One volt is agreed to be the potential difference that will force one ampere through one ohm of resistance. If we double the voltage and keep the resistance the same, the current (amperage) will double. If we double the resistance and keep the voltage the same, the current will be just half as great. Ohm's Law is derived from this relationship. The above formulas are three ways of expressing this same law; any one may be converted to the others by multiplication or division.

Earlier, we showed the circuit diagram below and said that 2 amperes of current were flowing in the circuit. We said that a 12 volt car battery would not be big enough to cause 2 amperes of current in this circuit. To find out what electromotive force would be required to obtain two amperes, which formula would be used?



$I = \frac{E}{R}$ Page 30

$E = IR$ Page 39

$R = \frac{E}{I}$ Page 41

YOUR ANSWER: .8 amperes.

You divided the wrong things.

There were three resistors with a total of 16 ohms.

The EMF was given as 20 volts.

The formula was agreed to be $I = \frac{E}{R}$, since we want to find amperage.

If we substitute the known values in this formula, we have:

$$I = \frac{20}{16}, \text{ since } R = 16 \text{ and } E = 20.$$

Apparently you divided 16 by 20 instead of 20 by 16. Now, return to Page 40 and select the correct answer.

YOUR ANSWER: $R = \frac{E}{I}$ is the correct formula.

Yes, that's the correct formula. Cover the R in the triangle and you find E over I, volts divided by amperes.

It may help to keep the triangle in mind if you remember that the E is always on the top and that the three letters are in alphabetical order.



Let's review the three forms of Ohm's Law. It's important to learn them by heart. Memorize at least one of them, preferably the equation for voltage, E = IR. You can discover the other forms mathematically from any one form.

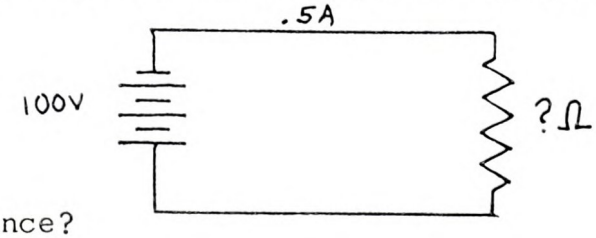
Here they are again with their meanings:

$I = \frac{E}{R}$ Amperes = $\frac{\text{Volts}}{\text{Resistance}}$

$E = IR$ Volts = Amperes x Resistance

$R = \frac{E}{I}$ Resistance = $\frac{\text{Volts}}{\text{Amperes}}$

Now use the correct formula to solve the problem in this circuit.



What is the resistance?

.005 ohms	Page 50
50 ohms	Page 53
200 ohms	Page 55

YOUR ANSWER: To solve for voltage, you would use the form $R = \frac{E}{I}$.

You could solve for E starting with this form, but you would have to perform an extra mathematical operation to isolate E on one side of the equation. You want to find out what E equals.

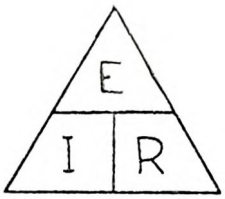
The easiest method is to use the equation that starts out E equals..... This way you get the answer you want directly. The form you have chosen would be most convenient for finding resistance (R), since R is already isolated on one side of the equation.

Now, go back to Page 33 and select the right answer.

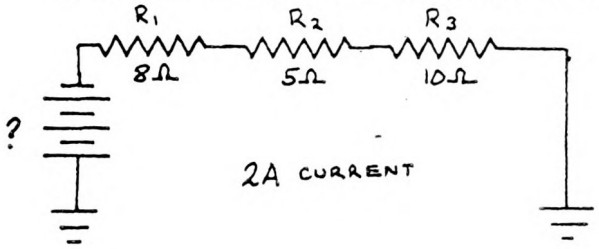
YOUR ANSWER: To find the electromotive force, use E = IR.

Yes, this would be easiest. Actually, you could use any of the three forms, but the arithmetic is easier if you choose the formula arranged with the unknown value isolated on one side of the equation.

It may help you remember the three forms of the equation if you visualize its components in a triangle like this:



Cover up the unknown quantity. What remains shows the operation you must perform. For the problem above, cover up E, because voltage is what you want to determine. Below it you see I times R, the arithmetic necessary to find E. Cover up I, and you find E over R; or cover up R and you find E over I.



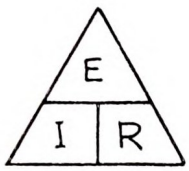
Now see if you can solve the problem of this circuit. What is the EMF of the battery?

11.5 volts	Page 42
23 volts	Page 44
46 volts	Page 47

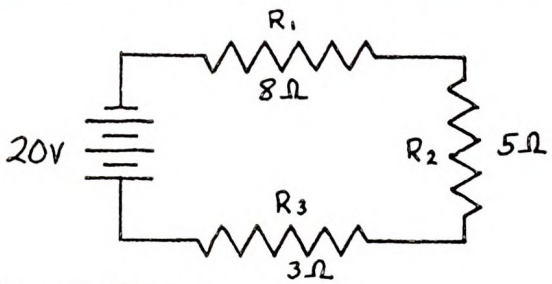
YOUR ANSWER: To solve for amperes, use $I = \frac{E}{R}$.

Yes, divide the voltage by the total resistance, and the result will express the number of amperes in the circuit.

See how this works out with our triangle:



Cover up the letter I (since you want to find the number of amperes), and you see E over R, that is, divide E by R.



Work out this problem now:

What is the strength of the current flow in the circuit above?

.8 ampere Page 36

1.25 amperes Page 43

320 amperes Page 48

YOUR ANSWER: To find electromotive force, use $R = \frac{E}{I}$.

You're not watching very closely. This is the same problem as before.

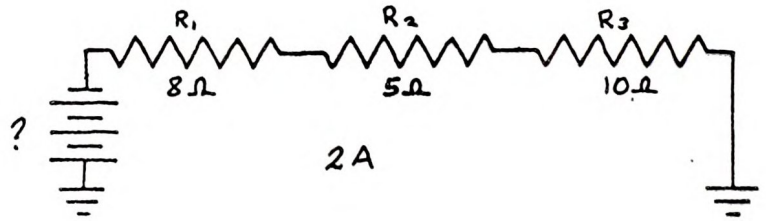
Electromotive force is E. And the unit of electromotive force is voltage. If you want to solve for voltage, you choose the form of Ohm's Law most convenient for finding E. That form will begin, E equals.....

Now, return to Page 35 and select the correct answer.

YOUR ANSWER: It is an 11.5v battery.

No. Let's take a look at the calculation to see where you went wrong. Since we said that a 12-volt car battery was inadequate, this battery must be inadequate, too.

To get to this page, you had to decide that the proper formula for finding voltage is E = IR. That is correct. Here, again, is the circuit:



You agreed that its total resistance is 23 ohms. This you determined by adding the values of the three resistors. So we know that the resistance (R) is 23 ohms and that the current (I) is 2 amperes. This is how the formula should look:

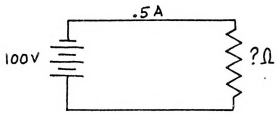
$$E = 2 \times 23$$

Now, return to Page 39 and select the correct answer.

YOUR ANSWER: 1.25 amperes.

Correct. The total resistance was 16 ohms (8 + 5 + 3), and you divided that into the voltage to get $\frac{20}{16}$ = 1.25 amps.

Now let's suppose that the resistance is the unknown factor in the circuit.



The diagram above tells us that 100 volts force just .5 amperes of current through the unknown resistance. Since we know two of the values, we can use Ohm's Law to find the third. We must solve for "R", of course.

Which formula is correct?

$R = \frac{E}{I}$ Page 37

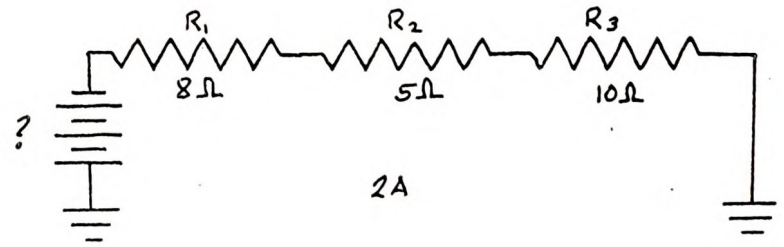
$R = EI$ Page 46

$R = \frac{I}{E}$ Page 52

YOUR ANSWER: It is a 23v battery.

You slipped up somewhere. Let's take a look at the calculation so you can find out where you went wrong.

To get to this page, you had to decide that the formula for finding voltage is E = IR. That is correct. Here again is the circuit:



You agreed that its total resistance is 23 ohms. This you determined by adding the values of the three resistors. So, we know that the resistance (R) is 23 ohms and that the current (I) is 2 amperes. This is how the formula should look:

$$E = 2 \times 23$$

Now, return to Page 39 and select the correct answer.

YOUR ANSWER: To find amperage, use the formula E = IR.

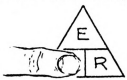
It's hard to believe that you didn't choose this page just to see if we could find yet another way of explaining the same point!

Let's look at the triangle this time.

Here it is:



Now, let's cover up the factor we are seeking, amperage. Remember, I is the symbol used for amperage.



What have we left -- IR , $\frac{E}{I}$, or $\frac{E}{R}$?

Remember, too, that we want a formula that begins with the form I = . . . That will save us the mathematical step necessary to isolate I on one side of the equation.

Now, return to Page 47 and select the correct answer.

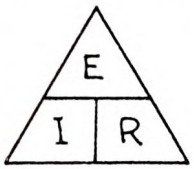
YOUR ANSWER: R = EI is the correct formula.

No, it's not. In fact, that is not even a variation of the correct formula. It says resistance is equal to voltage <u>times</u> amperage. That simply is not the case. Resistance is equal to voltage <u>divided</u> by amperage.

The only form of Ohm's Law in which you multiply rather than divide is that used in solving for E. The formula then is E = IR, voltage is equal to amperage times resistance. This is the basic form of Ohm's Law. The two variations can be derived mathematically from the basic formula.

Since we can perform the same operation on both sides of an equation, to obtain the formula for amperage, you isolate the I by dividing through by R. If you want to check whether a variation of Ohm's Law is correctly put, see if it can be derived from E = IR.

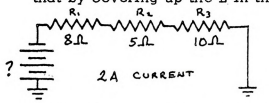
Of course, you can also check with the triangle by covering up the unknown. If you don't remember it, make a copy.



Now, go back to Page 43 and select the correct answer.

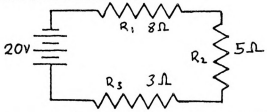
YOUR ANSWER: It is a 46-volt battery.

Correct. To find E, you multiply I times R (you can tell that by covering up the E in the triangle below). The total resistance (R), found by adding the values of the three resistors, was 23 ohms. Multiply 23 times 2, the amperage, and you have solved for E.





Now look at the circuit below:



To find the amperage in the circuit, which formula should you use?

$I = \frac{E}{R}$ Page 40

$E = IR$ Page 45

$R = \frac{E}{I}$ Page 49

YOUR ANSWER: 320 amperes.

Wow! That's about enough to burn whatever you've got to a frazzle! Apparently you multiplied where you should have divided.

There were three resistors with a total of 16 ohms.

The EMF was given as 20 volts.

The formula was agreed to be $I = \frac{E}{R}$, since we want to find amperage.

If we substitute the known values in that formula, we have the following:

$$I = \frac{20}{16}, \text{ since } R = 16 \text{ and } E = 20.$$

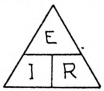
You must have multiplied 16 by 20 instead of dividing 20 by 16. Now, return to Page 40 and select the correct answer.

YOUR ANSWER: To find amperage, use the formula $R = \frac{E}{I}$.

It's hard to believe that you didn't choose the page just to see if we could find another way of explaining the same point'.

Let's look at the triangle this time.

Here it is:



Now, let's cover up the factor we are seeking, amperage. Remember, I is the symbol used for amperage.



What have we left? IR, $\frac{E}{I}$, or $\frac{E}{R}$?

Remember, too, that we want a formula that begins with the form I = . . . That will save us the mathematical step necessary to isolate I on one side of the equation.

Now, return to Page 47 and select the correct answer.

YOUR ANSWER: .005 ohms.

You seem to have divided the wrong things.

Here is the formula we agreed was correct, $R = \frac{E}{I}$.

We also know certain values:

$E = 100v$, and

$I = .5a$.

You apparently divided .5 by 100 instead of the other way around.

Now, return to [illegible] and select the correct answer.

YOUR ANSWER: .20ma.

No, .20 is how many amps it draws.

You evidently arrived at .20 by the correct procedure, dividing the voltage (8v) by the resistance (40 Ω). That gives .20 amperes.

Remember, that milli- is a prefix indicating 1/1000th. A milliamp is .001 amps, just as a millivolt is .001v. Since there are 1000 milliamperes in every ampere, you translate amperes to milliamperes by multiplying amperes by 1000. So, 5 amps is 5000ma, and .5 amps is 500ma.

Now, return to Page 55 and select the correct answer.

YOUR ANSWER: $R = \frac{I}{E}$ is the correct formula.

No, it's not. It's not even a variation of the correct formula. It says resistance is equal to amperage divided by voltage. That's not so. Resistance is equal to voltage divided by amperage.

The basic form of Ohm's Law is E = IR, voltage is equal to amperage times resistance. The two variations can be derived mathematically from the basic formula.

Since we can perform the same operation on both sides of an equation, to obtain the formula for amperage, you isolate the I by dividing through by R. If you want to check whether a variation of Ohm's Law is correctly put, see if it can be derived from E = IR.

Of course, you can also check with the triangle by covering up the unknown. If you don't remember it, make a copy.



Now, go back to Page 43 and select the correct answer.

YOUR ANSWER: 50 ohms.

You seem to have multiplied where you should have divided.

Here is the formula we agreed was correct, $R = \frac{E}{I}$.

We also know certain values:

$E = 100v$, and

$I = .5a$.

If we insert these values in the formula, we have:

$$R = \frac{100}{.5} .$$

Apparently you multiplied .5 times 100 rather than dividing 100 by .5.

Now, return to Pg. 37 and select the correct answer.

YOUR ANSWER: .021 ohms.

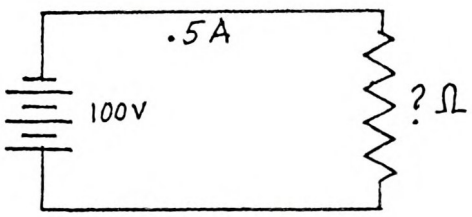
Sorry, but no. You forgot to translate milliamps into amps. When you use Ohm's Law, you must be sure that you have all of the values in comparable units. They can all be milli- units if you choose, or all kilo- units, or, of course, all basic, unhyphenated units, just plain amperes, volts and ohms. As a rule, it is probably simplest to translate all figures into the basic units.

You can, if you want, use powers of ten. Since to translate amps to milliamps, we multiplied by one thousand (moved the decimal three places to the right), to translate back from milliamps to amps, we divide by one thousand (move the decimal three places to the left). So if there are 300ma flowing in the circuit, there is .3 amps.

Now, with that much of a hint, return to Page 59 recalculate the problem, and select the correct answer.

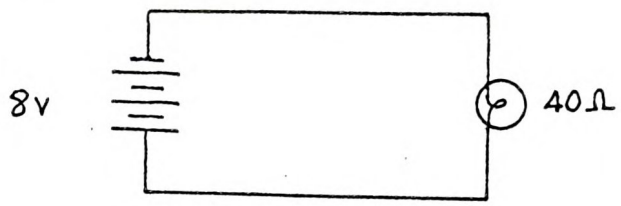
YOUR ANSWER: 200 ohms.

Yes, you found this by dividing 100 by .5; that is, you divided volts by amperes. $R = \frac{E}{I}$. You could have guessed that the resistance was fairly high, since all that electrical pressure could push only one-half ampere.



If one ohm will let one ampere flow with one volt of pressure, it will require 200 ohms to limit current flow to .5 ampere when there is 100 volts applied to the circuit.

In the circuit below, a lamp of 40 ohms resistance is connected to an 8-volt battery. How much current does the lamp draw? Express your answer in milliamperes (ma).



.20 ma.	Page 51
20 ma.	Page 56
200 ma.	Page 59

YOUR ANSWER: 20ma.

You have evidently forgotten that milli- is a prefix meaning 1/1000th. A milliamp is .001 amps, just as a millivolt is .001v.

You arrived at amperage by dividing the voltage (8v) by the resistance (40Ω). That gave you .20 amperes. The problem now is to translate amperes into milliamperes.

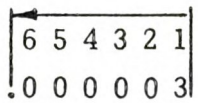
Since a milliampere is 1/1000th of an ampere, there are 1000 milliamperes in every ampere. To translate amperes to milliamperes, therefore, you multiply by 1000. Thus, 5 amps is 5000ma, and .5 amps is 500ma.

Now, return to Page 55 and select the correct answer.

YOUR ANSWER: 3×10^5 amperes.

You have apparently forgotten quite a bit about the use of powers. First of all, since 3 millionths of an ampere is a fraction -- less than one ampere, it will be expressed with a negative exponent. Only whole numbers have positive exponents.

Secondly, since this figure would be written out as .000003, its exponent would be a six, not a five. You determine that by counting off the number of places starting from the right of the first significant figure and moving left toward the decimal point. When there is only one significant figure, as here, that is the first (and last) significant figure. You count like this:



That gives you the exponent.

If the figure had been .0000032, we would have counted off like this:



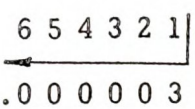
In powers of ten, .0000032 would be expressed 3.2×10^{-6}.

Now, return to Page 61 and select the correct answer.

YOUR ANSWER: 3×10^{-5}.

Well, you're partly right. You got the sign of the exponent as minus, as it should be since we are dealing with a fraction.

However, 3 millionths of an ampere would be written out as .000003, so its exponent would be six, not a five. You determine that by counting off the number of places starting from the right of the first significant figure and moving to the left toward the decimal point. When there is only one significant figure, as here, that is the first (and last) significant figure. You count like this:



That gives you the exponent.

If the figure had been .0000032, we would have counted off like this:

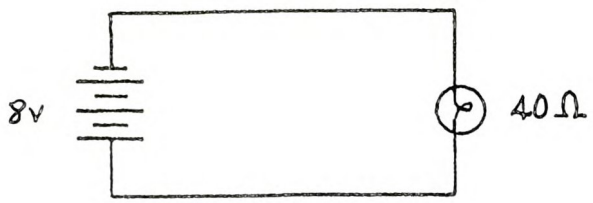


In powers of ten, .0000032 would be expressed 3.2×10^{-6}.

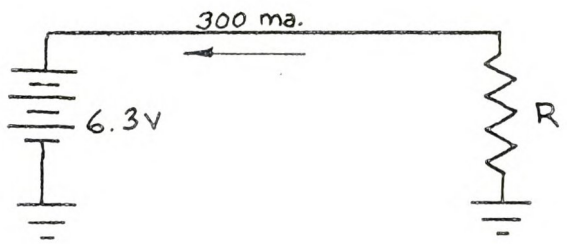
Now, return to Page 61 and select the correct answer.

YOUR ANSWER: 200ma.

Correct. Using the formula $I = \frac{E}{R}$, divide 8 by 40 and you get .20 amperes. Since there are 1000 milliamperes in one ampere, you multiply this answer by 1000, which you can do by moving the decimal point three places to the right, giving 200 milliamperes as the correct answer.



Now let's find the resistance of a light bulb filament which requires 6.3 volts and draws 300ma.



.021	ohms	Page 54
21	ohms	Page 61
21,000	ohms	Page 64

YOUR ANSWER: 3×10^6

You're right in thinking that the exponent is a six, not a five, but you've forgotten about signs. Your answer would be translated back into regular numbers as 3,000,000. But 3 microamperes is .000003.

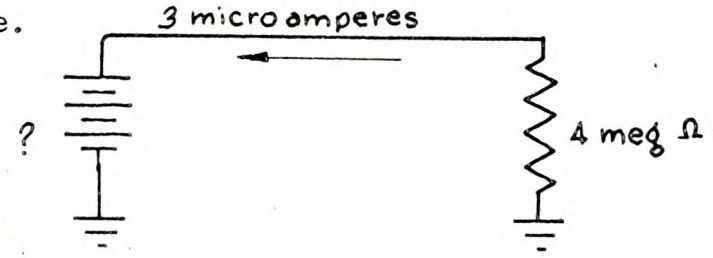
Since 3 millionths of an ampere is a fraction -- less than one ampere -- it will be expressed with a negative exponent. Only whole numbers have positive exponents.

Now, return to Page 61 and select the correct answer.

YOUR ANSWER: 21 ohms.

Yes, it is necessary to change the milliamperes into amperes before calculating so that all values will be in comparable units. To translate milliamperes to amperes, divide by 1000 (move the decimal point three places to the left), changing 300 ma into .3 ampere. Dividing the voltage, 6.3, by .3 amp ($R = \frac{E}{I}$), you get 21 ohms.

In the circuit below, a 4-megohm resistor is passing 3 microamperes of current. Remember, a megohm (meg) is a million ohms, and a microampere is one one-millionth of an ampere.



Let's find the voltage across the resistor. This will be the same as the total voltage produced by the battery since there is just one resistance in the circuit.

Use your knowledge of exponents in solving this problem. Don't mess around with a lot of zeroes when you don't have to. Let's have a brief check-up on powers of ten before tackling the problem.

We will want to translate 3 microamperes (three millionths of an ampere) into powers of ten.

Three microamperes equals _____. (Complete the sentence)

3×10^{5} amperes	Page 57
3×10^{-5} amperes	Page 58
3×10^{6} amperes	Page 60
3×10^{-6} amperes	Page 65

YOUR ANSWER: 4×10^6 ohms.

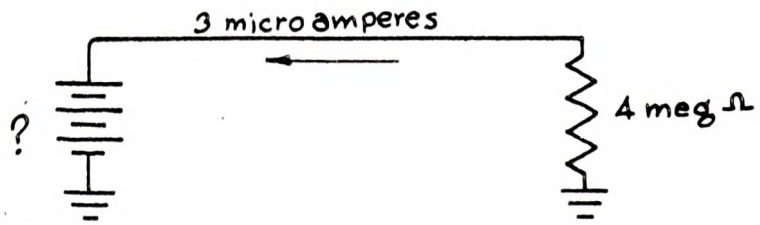
Yes, this is the correct way of expressing 4 million ohms or 4 megohms. The figure "4" is six places from the decimal point so we use 6 for an exponent.

Now, solve the problem below using the values for ohms and amperes that you have just expressed in powers of 10.

$$I = 3 \times 10^{-6}$$

$$R = 4 \times 10^6$$

What is the voltage across the resistor?



12 volts — Page 66

12×10^{-36} volts — Page 67

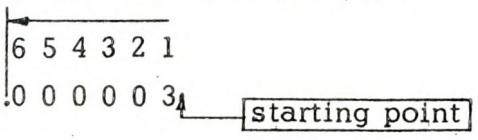
12×10^{12} volts — Page 68

YOUR ANSWER: 4×10^7.

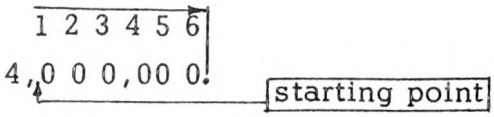
Whoops! When working with positive exponents we count a little differently than when working with negative exponents.

Four megohms is 4,000,000 ohms. When we count off for powers of ten with a whole number, just as we did with a negative power, we start <u>from the right of the first significant figure</u>.

Here is how we counted off the microamps:



Here is how to count off the megohms:



In both cases, counting is started from the right of the significant number that will be the multiplier when the figure is expressed as a power of ten, and from there proceeds toward the decimal point.

Now, return to Page 65 and select the correct answer.

YOUR ANSWER: 21,000 ohms.

Afraid you went all wrong. You could have done a couple of different things to get this answer, so we won't try to track down the error. Here is what you should have done. Figure out for yourself just where you left the track.

When you use Ohm's Law, you must be sure that you have all your values in comparable units. They can all be milli- units if you choose, or all kilo- units, or, of course, all basic, unhyphenated units, just plain amperes, volts and ohms. As a rule, it is probably simplest to translate all figures into the basic units.

You can, if you want, use powers of ten.

Since to translate amps to milliamps, we multiplied by one thousand (moved the decimal three places to the right), to translate back from milliamps to amps, we divide by one thousand (move the decimal point three places to the left). So, if there are 300ma flowing, there is .3 amps.

Now, with that much of a hint, return to Page 59 recalculate the problem, and select the correct answer.

YOUR ANSWER: 3×10^{-6} amperes.

Correct. Since 3 millionths is .000003, you counted six places from the right of the significant figure, and since .000003 is a fraction, the sign of the exponent is negative.

Here is a comparison of some negative exponents:

$$3 = 3 \times 10^{0}$$

$$.3 = 3 \times 10^{-1}$$

$$.03 = 3 \times 10^{-2}$$

$$.003 = 3 \times 10^{-3}$$

$$.0003 = 3 \times 10^{-4}$$

$$.00003 = 3 \times 10^{-5}$$

$$.000003 = 3 \times 10^{-6}$$

Now let's consider the other value given in our problem: 4 megohms. How will you express this as a power of 10?

4×10^{6} ohms Page 62

4×10^{7} ohms Page 63

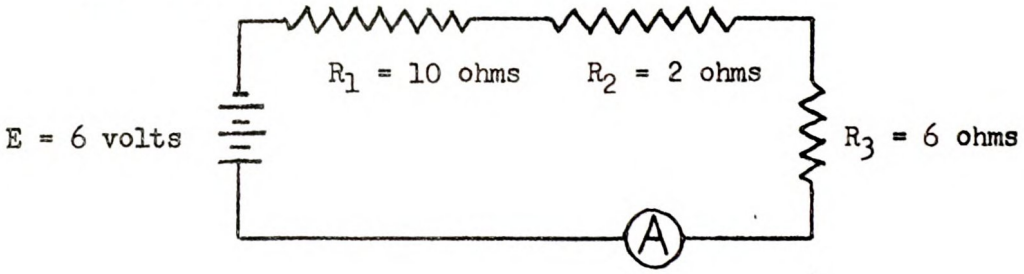
YOUR ANSWER: 12 volts.

Correct. The formula is E = IR, so the problem was computed in this manner:

$E = (3 \times 10^{-6}) \times (4 \times 10^{6})$

$E = 12 \times 10^{0}$, and, since 10^{0} equals 1, E = 12 volts.

How much current is flowing in the diagram below?



a. 3. amps

b. .3 amps

c. .03 amps

d. .003 amps

After selecting an answer go on to page 71 and continue.

YOUR ANSWER: 12×10^{-36}.

That's awful few volts. Remember, you have 4,000,000 ohms of resistance to overcome, even to get 3/1,000,000ths of an amp of current. You went wrong somewhere along the line.

Since E = IR, you were correct in trying to multiply the amperage (3×10^{-6}) by the resistance (4×10^{6}), but you've forgotten how to multiply exponents. You multiply exponents by adding them algebraically. Although in algebra 6 x -6 would be -36, $10^{6} \times 10^{-6}$ gives us 10^{0}, since the negative and the positive powers cancel each other out.

And 10^{0}, remember, is the same as 1.

You do, of course, multiply the 3 x 4 in the normal arithmetic manner. So

$$(3 \times 10^{-6}) \times (4 \times 10^{6}) = 12 \times 10^{0} \text{ or } ?$$

Now, go back and select the correct answer on Page 62

YOUR ANSWER: 12×10^{12} volts.

That's an awful lot of volts. Admittedly, you've got to overcome 4,000,000 ohms resistance, but you're only getting .000003 amps through.

Your mistake came in the process of multiplication by powers of ten. Since E = IR, you were correct in trying to multiply the amperage (3×10^{-6}) by the resistance (4×10^{6}). But when it came to multiplication of the exponents you acted as if you were dividing instead of multiplying. To multiply exponents, you add algebraically. The product of 10^{6} and 10^{-6} is 10^{0}, since the 6 and the -6 cancel each other out.

If you had been dividing 10^{6} by 10^{-6}, you would have performed algebraic subtraction which requires you to change the sign of the divisor and then add algebraically. The result of that process would be 10^{12}. You can see it here:

$$\frac{10^{6}}{10^{-6}} = 10^{6} \times 10^{6} = 10^{12}$$

However, when multiplying; you get the result 10^{0}. Of course, 10^{0} is 1. So,

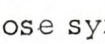
$$(3 \times 10^{-6}) \times (4 \times 10^{6}) = 12 \times 10^{0} \text{ or } ?$$

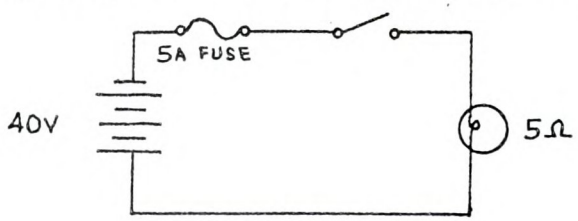
Now, return to Page 62 and select the correct answer.

A common device in an electrical circuit is the switch. The simple on - off switch is called a single pole, single - throw switch. The fancy name means that it can only make or break contact with a single electrical connection. The symbol for such a switch is shown here. Usually, such a switch will be illustrated in this open position in circuit diagrams.



If you are asked how much current flows in a circuit that includes this kind of switch drawn in the open position, you will answer as if the switch were closed. It is drawn in the open position only so it can be easily identified.

Another device used in many electric circuits is the FUSE, whose symbol is  . It is used to protect electrical equipment from damage due to excessive current. Fuses are rated in amperes, according to the amount of current they will pass through the circuit. If amperage rises above the level the fuse is designed to pass, the current will create enough heat to melt the soft metal used as a conductor within the fuse. That, of course, breaks or opens the circuit and completely stops current.



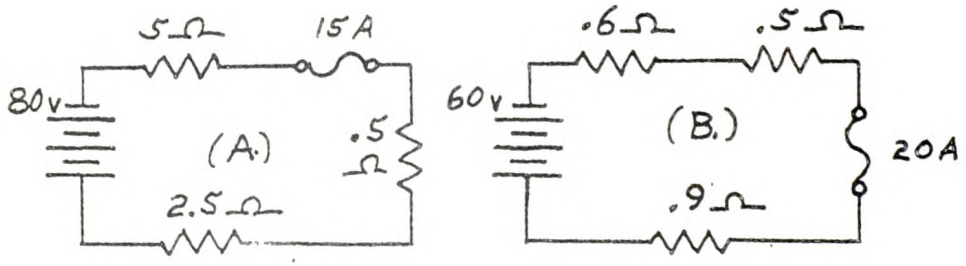
Fuses are not designed to resist current flow, so for practical purposes, we can assume they have no resistance.

Will the lamp in the above circuit stay lit after the switch is closed?

Yes	Page 72
No	Page 74
I don't know	Page 77

YOUR ANSWER: Current will flow in Circuit A only.

You are correct. With 8 ohms resistance, only 10 amperes will flow. Since the fuse will theoretically allow 15 amperes, it will not blow out. Circuit B with only 2 ohms would draw 30 amperes, but the fuse rated at 20 amperes should blow.



Most fuses are not absolutely accurate, so it is usual to select a fuse rated lower than the maximum current that can be tolerated, thus ensuring that the components will be safe.

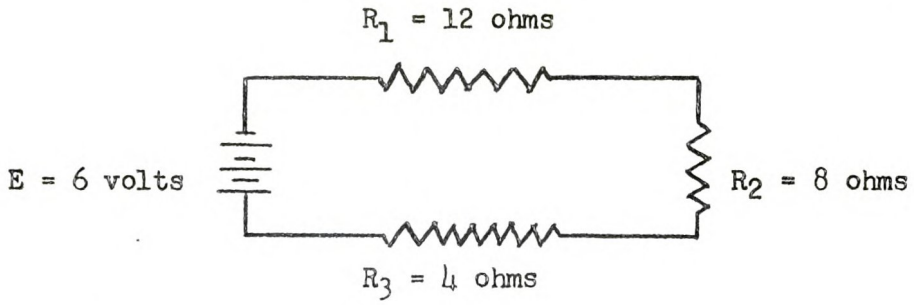
Let's say that a component in Circuit B would be damaged if 25 amperes flowed through it, and we want to change the circuit so it will work. What could we do to it?

Put in a larger fuse. Page 73

Put in another resistor. Page 76

Put in a smaller battery. Page 79

Which resistor has the most current flowing throught it?



a. R_1

b. R_2

c. R_3

d. All resistors have same amount.

After selecting an answer go back to page 69 and continue.

YOUR ANSWER: Yes, the lamp will stay lit.

It may light for an instant -- the time it takes for the fuse to discover just how many amps are going through the circuit -- but it will go right out after that.

The unknown, of course, is the amperage in the problem presented to you. The diagram showed a power source of 40 volts and a resistance of 5 ohms. Since $I = \frac{E}{R}$, or $\frac{40}{5}$, I equals 8 amps. The fuse in the circuit can carry only five amps before blowing, so, when you close the switch you will blow the fuse.

Return to Page 69 and select the right answer.

YOUR ANSWER: Put in a larger fuse.

No, indeed, not unless you were absolutely certain that the fuse already in the circuit was too small. If you put in a larger fuse, you would save the fuse from blowing, but you might damage the components of the circuit. And, you were told in this instance that you do not want in excess of 25 amps.

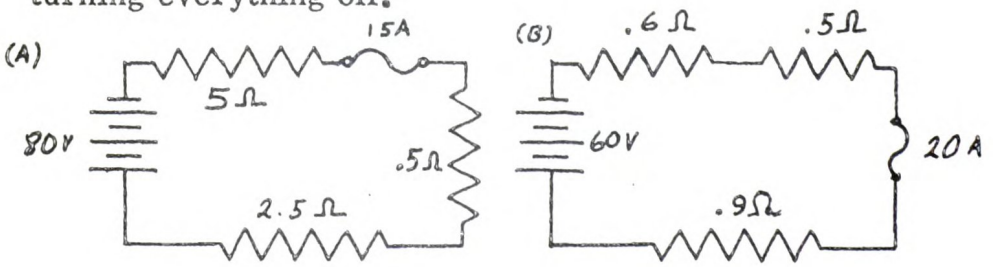
You are not trying to save fuses; you are trying to save circuits.

Now, return to Page 70 and select the correct answer.

YOUR ANSWER: No. The lamp won't stay lit after the switch is closed.

Correct. The only important resistance in the circuit was the 5 ohms of the lamp. Using the formula $I = \frac{E}{R}$ (dividing 40 volts by 5 ohms) showed that 8 amperes will flow in the circuit. The fuse will allow only 5 amperes, so the excessive current will cause the fuse to blow.

It is always irritating to have a fuse blow, but don't try to prevent this by putting in a larger fuse. In the circuit we've been discussing, the lamp might be damaged by excessive current. The fuse warns when something is wrong and prevents damage by turning everything off.



In the circuits above, the fuses will allow current to continue to flow in _____ (complete the sentence).

Circuit A only	Page 70.
Circuit B only	Page 75
Both circuits	Page 78
Neither circuit	Page 80

YOUR ANSWER: Circuit B only.

You've got it wrong. Now, we're not going to work this out for you. We'll just remind you how to do it.

The question that must be answered for both circuits is simple: Will the combination of voltage and resistance produce amperage greater than the capacity of the fuse? The capacity of each fuse is shown.

You have to compute the amperage in each circuit. To do this, you first add up the values of each circuit's resistances to get the total resistance of each circuit.

When you have the total resistance, then you determine the voltage of the power source. In both circuits, the voltage is given next to the battery symbol. Now, you have the total resistance (R) and the voltage (E). You can calculate the amperage with Ohm's Law, the variation that says

$$I\ (\text{amperage}) = \frac{E\ (\text{voltage})}{R\ (\text{resistance})}.$$

When you have found the amperage the circuit is arranged to deliver, compare that with the rated value of the fuse. That rated value tells the amount of current that will cause the fuse to blow and open the circuit. Compare the amperage of the circuit with the rated amperage of the fuse. If the circuit amperage is higher, the fuse will blow.

Now, return to Page 74 and select the correct answer.

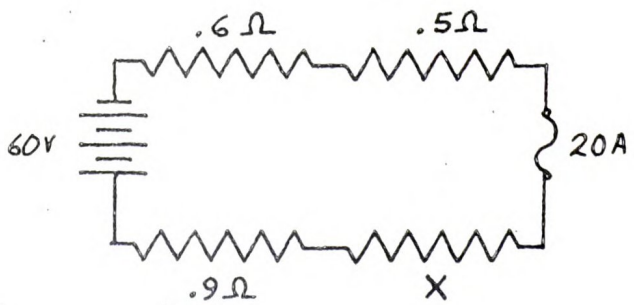
YOUR ANSWER: Put in another resistor.

Yes, that would normally be the easiest, fastest, and safest thing to do.

The situation we now have is this: One device in the circuit will be damaged if 25 amperes should flow through it.

We want to keep the 20 amp fuse in the circuit for protection, but to keep it from blowing, we must add another resistor to reduce the amperage of the circuit.

What is the smallest possible resistance we could insert at "X" to limit current to 20 amperes?



1 ohm Page 81

3 ohms Page 82

YOUR ANSWER: I don't know.

Well, here is how you find out.

The question, really, is whether the fuse will blow out when the switch is thrown. To find out whether it will blow, you must calculate the amperage that will flow when the switch is thrown.

You do this by applying good old Ohm's Law. That law says amperage equals voltage divided by resistance. If we divide voltage (40 volts) by resistance (5 ohms), we discover that 8 amps is the current that will flow through the circuit -- if the fuse will let it.

Now, go back to Page 69 and select the correct answer.

YOUR ANSWER: Both circuits.

Sorry, in one of them the fuse will be blown. We're not going to work this out for you. We'll just remind you how to find in which circuit the fuse will blow.

The question that must be answered for both circuits is simple: Will the combination of voltage and resistance produce amperage greater than the capacity of the fuse? The capacity of each fuse is shown.

You have to compute the amperage in each circuit. To do this, you first add up the values of each circuit's resistances to get the total resistance of each circuit.

When you have the total resistance, then you determine the voltage of the power source. In both circuits, the voltage is given next to the battery symbol. Now, you have the total resistance (R) and the voltage (E). You can calculate the amperage with Ohm's Law, the variation that says

$$I\ (\text{amperage}) = \frac{E\ (\text{voltage})}{R\ (\text{resistance})}.$$

When you have found the amperage the circuit is arranged to deliver, compare that with the rated value of the fuse. That rated value tells the amount of current that will cause the fuse to blow and open the circuit. Compare the amperage of the circuit with the rated amperage of the fuse. If the circuit amperage is higher, the fuse will blow.

Now, return to Page 74 and select the correct answer.

YOUR ANSWER: Put in a smaller battery.

It would certainly reduce amperage if you put in a smaller battery, but it's not the usual approach, and it probably wouldn't be a practical solution.

It's unlikely that you could change the battery, either because you wouldn't have another one handy or because the battery is also needed to power another circuit at the same time.

It would be more practical to seek a safe way of modifying some other part of the circuit.

Now, return to Page 70 and select another answer.

YOUR ANSWER: Neither circuit.

No, the amperage in only one circuit is sufficient to cause the fuse to blow. We're not going to work the problem for you, just review the steps so you can calculate for yourself which is which.

The question that must be answered for both circuits is simple: Will the combination of voltage and resistance produce amperage greater than the capacity of the fuse? The capacity of each fuse is shown.

You have to compute the amperage in each circuit. To do this, you first add up the values of each circuit's resistances to get the total resistance of each circuit.

When you have the total resistance, then you determine the voltage of the power source. In both circuits, the voltage is given next to the battery symbol. Now, you have the total resistance (R) and the voltage (E). You can calculate the amperage with Ohm's Law, the variation that says

$$\text{I (amperage)} = \frac{\text{E (voltage)}}{\text{R (resistance)}}.$$

When you have found the amperage the circuit is arranged to deliver, compare that with the rated value of the fuse. That rated value tells the amount of current that will cause the fuse to blow and open the circuit. Compare the amperage of the circuit with the rated amperage of the fuse. If the circuit amperage is higher, the fuse will blow.

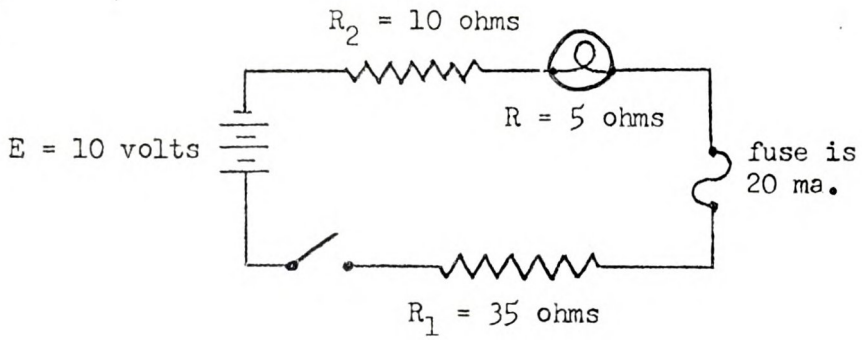
Now, return to Page 74 and select the correct answer.

YOUR ANSWER: A 1 ohm resistance must be added at X.

Yes. This would bring the total resistance of the circuit to 3 ohms, so current would be just 20 amperes.

When a fuse blows, you have an open circuit. The circuit is interrupted, just as when a switch is open, and there is no more current until a new fuse is installed. The circuit would be open, too, if a connecting wire came loose, or if there was a breakdown inside an electrical device. These malfunctions that cut off current are generally called opens.

Would the lamp light when the switch is closed in the diagram below?



a. Yes

b. No

After selecting an answer go to page 85 and continue.

YOUR ANSWER: 3 ohms.

You're probably on the right track, but that's not the right answer. Here's why.

You have a 60 volt output and you want to limit amperage to 20 amps. To determine the amount of resistance necessary to obtain 20 amps with 60 volts output, you divide voltage by amperage ($R = \frac{E}{I}$). The result is 3 ohms. So that is the resistance necessary to limit current to 20 amps. So far, so good.

However, there is already resistance in the circuit, in fact there are three resistors. So, to make a total resistance of 3 ohms, you do not need to add 3 ohms. You must add just enough to make the total resistance 3 ohms.

Now return to Page 76 and select the correct answer.

YOUR ANSWER: None.

No, not none. There will be a voltage drop, since the potential returns to zero. Just because we now have four resistors instead of one doesn't mean that the situation has changed. The positive side of the battery will still be considered to have zero potential, while the negative side has a potential of 40 volts --relative to the positive side, of course.

The voltage expends itself somewhere.

You should know, we hope, that the total voltage to be disposed of in the exterior circuit is 40 volts. It is going to be disposed of in passing through the "working" parts of the circuit -- the resistors. The question is, can you figure out how much of the voltage is disposed of by each resistor?

Now, return to Page 85 and try again.

YOUR ANSWER: 5 volts.

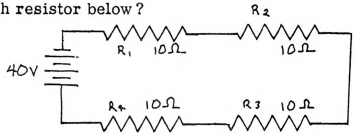
Come now! Stop and think about that answer for a moment. You have four resistors. You say each drops the voltage by 5 volts. That means the total voltage drop around the circuit is 4 x 5 = 20 volts. But, the battery is putting out 40 volts. That means that by the time the current gets around to the positive pole of the battery, it still has 20 volts push behind it! The fact is, as we found not so long ago, the positive pole is at zero potential.

Granted you have lower resistance. But don't be misled into thinking this would produce a smaller voltage drop. The total voltage drop for the circuit is 40 volts. The voltage drop across each resistor is still 10v.

What has changed is the amperage. More current is getting through now. If you calculate the amperage in this circuit, with a total of 32 ohms resistance, against 40 volts EMF, you will find that the amperage is 1.25. With 40 ohms resistance, the amperage was 1.

Now, return to Page 87 and select the correct answer.

Now, let us consider what happens when there is more than one resistance in the circuit. Below, the current flows through each resistor in order, 1 through 4. Each resistor in turn offers an obstacle to current, and each resistor in turn lowers the voltage. We say the voltage drops as current flows in a resistor. What would you guess to be the voltage drop across each resistor below?

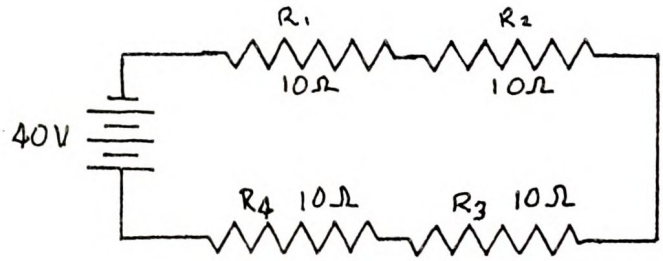


None — Page 83

10 volts — Page 86

40 volts — Page 88

YOUR ANSWER: There should be a 10-volt drop across each resistor.



That's right, and a good guess. Each resistor helps to lower the voltage back to zero. When each resistor has the same ohmage, as here, the voltage drop is equal across each one. Since there are four resistors, you divide the voltage by four.

Let's get a shade more scientific about figuring the voltage drops. There are two things we apply here:

(1) The current is the same at all points in a series circuit.

(2) The voltage drop across a resistor can be found by multiplying the current through the resistor by the value of resistance, $E_1 = I_1 \cdot R_1$.

We know the value of R_1 -- it's given in the diagram. We know that I_1 (the current through resistor R_1) is the same as the current for the circuit. We have to figure the current for the circuit, using Ohm's law $I = E/R$ and the values given for the total circuit.

$$I = E/R = 40 \text{ volts}/10 + 10 + 10 + 10 \text{ ohms} = 40/40 = 1 \text{ ampere.}$$

Is that 1 ampere of current flowing through each of the resistors, or just the one nearest the negative pole of the battery?

Each resistor. Page 87

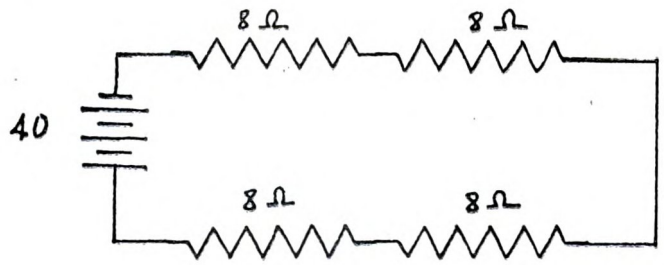
Just the one nearest the negative pole of the battery. Page 89

YOUR ANSWER: The same amount of current is flowing through each resistor.

You are correct. One ampere is flowing through each resistor, for in a series circuit the same amount of current is present at any point in the circuit. The amount the voltage drops across each resistor is found by using Ohm's Law. Since all resistors in this particular circuit have the same value, you need work the problem only once. If the resistors in the circuit are of different values, you must solve for each one.

Using the formula E = IR, we multiply 1 (ampere) times 10 (ohms) and we see that there is a 10-volt drop across each resistor, just as we guessed.

Look at the circuit below. What is the voltage drop across each of these resistors?



5 volts — Page 84

8 volts — Page 90

10 volts — Page 91

YOUR ANSWER: 40 volts.

Whoa, you're overdoing it! If each of the four resistors disposes of 40 volts, we've lost 160 -- four times as many as we had in the first place.

Perhaps you didn't read the question closely. You were not asked for the total voltage drop, you were asked what would be the voltage drop across each resistor.

Now, return to Page 85 and select the correct answer.

YOUR ANSWER: Just the one nearest the negative pole of the battery

Where have you been?

The last page tells you quite plainly: "Current is the same at all points in a series circuit . . . . I_1 (the current through resistor R_1) is the same as the current for the circuit."

Current, remember, is amperes per second. It is a rate of flow. Clearly in a series circuit, which is just like a continuous, one-path pumping system, there cannot be a greater current flow in one part than in another. That is, more electrons cannot be moving past one point than are moving past another.

Now, return to Page 86 and select the correct answer.

YOUR ANSWER: 8 volts.

No.

We'll say it again:

(1) The voltage drop around a series circuit is equal to the total voltage rise within the power source.

(2) The current is the same all the way around a series circuit.

Granted you have lower resistance. But don't be misled into thinking this would produce a smaller voltage drop. The total voltage drop for the circuit is 40 volts. The voltage drop across each resistor is still 10v.

What has changed is the amperage. More current is getting through now. If you calculate the amperage in this circuit, with a total of 32 ohms resistance, against 40 volts EMF, you will find that the amperage is 1.25. With 40 ohms resistance, the amperage was 1.

Now, return to Page 87 and select the correct answer.

YOUR ANSWER: 10 volts.

Correct. There are still four resistors of equal size, so the voltage drop will be equal across each of them. The big difference produced by lowering the resistance is to increase current.

This time $I = \frac{E}{R} = \frac{40}{32} = 1.25$ amps. Last time, with four 10 ohm resistors, the current was 1 amp.

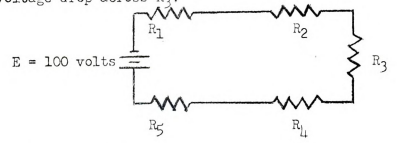
The voltage drop across each resistor, using the new values for current and resistance, is: $E = IR = 1.25 \times 8 = 10$ volts. The voltage drop across each resistor is the same as before, you see.

What we have just demonstrated is the third important fact about series circuits: The sum of the voltage drops across the resistors is equal to the applied voltage. This concept can be stated mathematically:

$$E_t = E_1 + E_2 + E_3 + \ldots E_n.$$

E_t is the total or applied voltage. E_1, E_2, etc., stand for the voltage drops across each of the resistors (which will normally be numbered correspondingly, R_1, R_2, etc.).

In the diagram below the voltage drops are : $E_{R1} = 10$ volts, $E_{R2} = 20$ volts, $E_{R4} = 15$ volts, and $E_{R5} = 25$ volts. What is the voltage drop across R_3?



a. 10 volts

b. 20 volts

c. 30 volts

d. 40 volts

After selecting an answer go on to page 93 and continue.

YOUR ANSWER: $E_1 = 20v$, $E_2 = 20v$, $E_3 = 20v$, and $E_t = 60v$.

The total voltage drop is 60 volts. But the values of the individual resistors are no longer the same. We are now considering a circuit in which the value of resistance varies from resistor to resistor. In this case, the voltage drop varies too. It must, because the current can't change. We have shown many times that current is the same in all parts of a series circuit.

As we have said, the total voltage drop still equals the applied voltage. Varying the resistances, just changes the proportion of the voltage that had to be expended across each resistor.

You can calculate voltage drops in two steps. First, find the circuit current by Ohm's law, $I = \frac{E}{R}$. Since the voltage is 60, and the total resistance 30 ohms, the current is 2 amperes.

Then, you apply the formula $E = IR$, to each resistor. In all cases, the current is 2 amperes. To find the voltage drop across each resistor, multiply the individual resistance by 2 amperes.

Now, return to Page 91 and select the correct answer.

The power in watts is volts times current, or:

P (in watts) = E (in volts) X I (in amperes)

In some situations, you will not always know either the voltage or current. Instead you may know the resistance. By using Ohm's law, the formula for power can be altered.

As an example, how much power is being expended in this circuit?



1.5 watts	Page 94
2 watts	Page 95
18 watts	Page 98

YOUR ANSWER: 1.5 watts are being expended in this circuit.

Correct. Ohm's Law works here, of course. It's simple to find the current in the circuit.

$$I = E/R = 3 \text{ volts}/6 \text{ ohms} = 1/2 \text{ ampere}$$

Then using the given formula for power:

$$P = EI = 3 \times 1/2 = 1.5 \text{ watts}$$

Note that to find current, you used voltage and resistance, then to find power, you multiplied current by volts again.

It seems reasonable that power might be found without ever finding current. Here's the formula for current: $I = E/R$. Suppose instead of $P = EI$, you replace I by E/R. That gives you

$$P = E \times E/R = E^2/R.$$

That gives you power in one calculation without bothering about current.

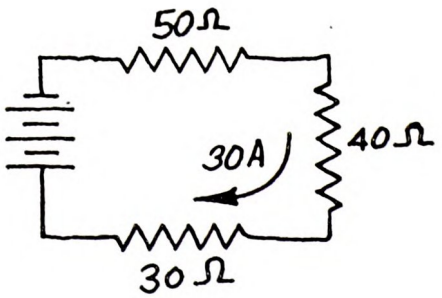
The same kind of approach will enable you to find P when you don't know voltage but do have values for current and resistance.

The formula for voltage is: $E = IR$.

Replacing E by IR in $P = EI$, you get

$$P = IR \times I, \text{ or } P = I^2R.$$

Thus $P = EI = E^2/R = I^2R$.

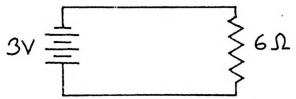


Which one of these formulas is best for finding the number of watts expended in this circuit?

$P = E^2/R$	Page 96
$P = EI$	Page 97
$P = I^2R$	Page 99

YOUR ANSWER: 2 watts of power are being expended in this circuit.

No, but you can soon find out why it's wrong.



The formula for power is:

$$P = EI$$

If P = 2 watts, as you claim then

$$P = EI = 2$$

Since E is given as 3 volts, we have

$$3 \times 1 = 2$$

and I must be 2/3 amperes.

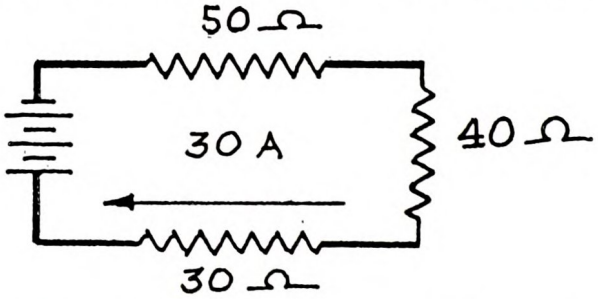
Check this against Ohm's Law for the current in the circuit.

$$I = E/R = 3/6 = 1/2 \text{ amperes.}$$

Clearly the 2/3 ampere must be wrong. Return to **Page 93** and figure it again.

YOUR ANSWER: $P = E^2/R$ is the proper formula to use.

No, it <u>will</u> work, of course, but why figure out the voltage? Look at the circuit again.



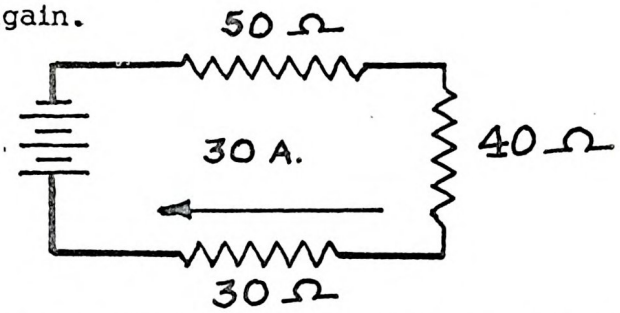
What are the values given? There are three resistances, and the current is specified. You aren't given voltage. Now look again at the formulas for power:

$$P = EI, \quad P = I^2R, \quad P = E^2/R$$

Can't you find one which will give power without knowing voltage? Return to Page 94 and make the correct choice this time.

YOUR ANSWER: P = EI is the correct formula to use.

No, it will work of course, but why figure out the voltage? Look at the circuit again.



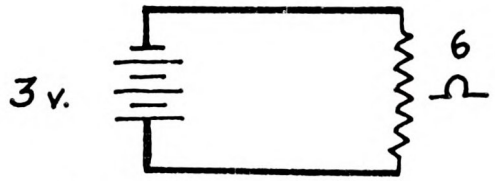
What are the values given? There are three resistances, and the current is specified. You aren't given voltage. Now look again at the formulas for power:

$$P = EI, \quad P = I^2R, \quad P = E^2/R$$

Can't you find one which will give power without knowing voltage? Return to Page 94 and make the correct choice this time.

YOUR ANSWER: 18 watts of power are being expended in this circuit.

No, but you can soon find out why it's wrong.



The formula for power is:

$$P = EI$$

If P = 18 watts, as you claim, then

$$P = EI = 18$$

Since E is 3 volts, we have

$$3 \times I = 18$$

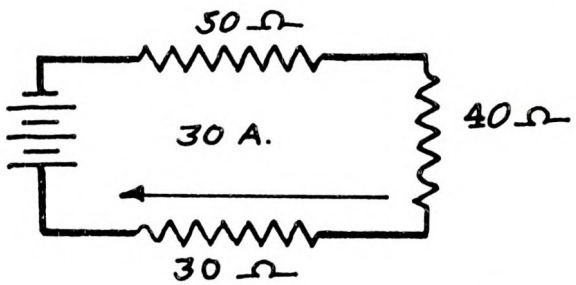
and I must be 6 amperes.

Check this against Ohm's Law for the current in the circuit.

$$I = E/R = 3/6 = 1/2 \text{ ampere}$$

Clearly the figure of 6 amperes must be wrong. Return to Page 93 and figure it again.

YOUR ANSWER: $P = I^2R$



That's right. The resistance and current are given. You could stop and figure out the voltage, too, but by using the correct power formula this isn't needed.

Since the three units, volts, ohms, and amperes, are all related, you may find the number of watts by using any two of them.

For measuring power in larger units, we have the kilowatt (kw) which equals 1000 watts. In low-powered circuits we sometimes use the milliwatt (mw) which is one one-thousandth of a watt.

Now, using the formula you have chosen, solve the problem above and give your answer in kilowatts.

1.08 kw	Page 101
10.8 kw	Page 105
108 kw	Page 111

YOUR ANSWER: 4 ohms is the resistance of a 25-watt bulb for 100 volt operation.

No, but it could be worse, the answer does start with a 4! Since voltage and power are given, and resistance is wanted, the proper equation is:

$P = E^2/R$. Solving for R, you get

$R = E^2P = (100^2)/25 = 10000/25$

Return to Page 111 and check this computation, then choose the correct answer.

YOUR ANSWER: 1.08 kw is being expended in the circuit.

No. Bet you wouldn't have made a mistake here if it were dollars instead of power!

Let's go over this carefully.

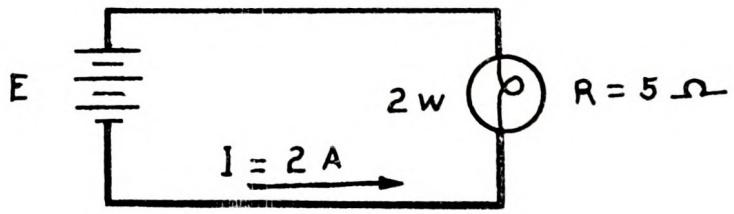
We'll use the formula, $P = I^2R$. The current, I, is given as 30 amperes. The resistance is the sum of 50 ohms, 40 ohms and 30 ohms, a total of 120 ohms.

Then $$P = I^2R = (30)^2 \times 120 = 900 \times 120$$
$$= 108000 \text{ watts}$$

So, if a kilowatt is 1000 watts, then the number of kilowatts in the answer is just 1/1000 of 108000.

Return to Page 99 and select the right answer.

YOUR ANSWER: Yes, the power rating is being exceeded.



It certainly is! Using the formula $P = I^2R$, you should multiply 2^2 x 5 to get 20 watts. The lamp will burn very brightly but only briefly and then burn out, for its power rating is being greatly exceeded.

Let's suppose that you have to make this lamp operate properly. What would be the easiest way to do this?

Increase the voltage. Page 106

Put a resistor in the circuit. Page 112

YOUR ANSWER: Yes, the power rating of the resistor is being exceeded.

No, it isn't. At least this mistake won't burn anything out.

Look at the circuit again.



To check this, all that's necessary is to compute the power being expended in the circuit and compare it with 1/4 watt, the rating of the resistor.

Since voltage and current are given, use

$$P = EI = 60 \text{ kv} \times 3 \text{ } \mu\text{a}$$

$$60 \text{ kv} = 60{,}000 \text{ volts} = 6 \times 10^{4} \text{ volts}$$

$$3 \text{ } \mu\text{a} = 3/1{,}000{,}000 = 3 \times 10^{-6} \text{ amperes}$$

Therefore:

$$P = (6 \times 10^{4}) \times (3 \times 10^{-6})$$
$$= 18 \times 10^{-2} \text{ watts}$$
$$= 0.18 \text{ watts}$$

Clearly, 0.18 watts is less than 1/4, or 0.25 watts. Return to Page 112 for the right answer when you're sure you understand this.

YOUR ANSWER: 400 ohms

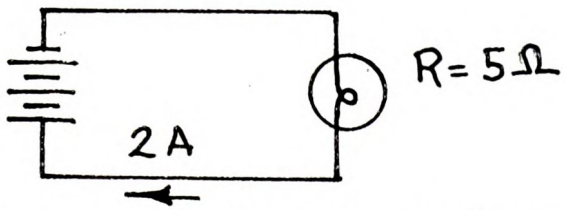
That's correct. Using $P = E^2/R$, and solving for R,

$$R = E^2/P$$
$$= (100^2)/25$$
$$= 400 \text{ ohms}$$

Whenever power is expended in overcoming resistance, heat is generated. For a given resistor, the more power expended, the more heat generated. The limit a resistor, or lamp can withstand before it is damaged is given by the maximum power it can tolerate. Thus a 4-watt resistor of 25 ohms cannot be used in a circuit having a source voltage of more than 10 volts, for

$$P = E^2/R$$
$$= (10^2)/25$$
$$= 4 \text{ watts}$$

Look at the 2-watt lamp in this circuit.



Is the lamp's power rating being exceeded? That is, is more than 2 watts of power being used in the lamp?

Yes Page 102

No Page 108

YOUR ANSWER: 10.8 kw is being expended in the circuit.

No. Bet you wouldn't have made a mistake here if it were dollars instead of power!

Let's go over this carefully.

We'll use the formula, $P = I^2R$. The current, I, is given as 30 amperes. The resistance is the sum of 50 ohms, 40 ohms and 30 ohms, a total of 120 ohms.

Then $P = I^2R = (30)^2 \times 120 = 900 \times 120$

$= 108000$ watts

So, if a kilowatt is 1000 watts, then the number of kilowatts in the answer is just 1/1000 of 108000.

Return to Page 99 and select the right answer.

YOUR ANSWER: Easiest way to make the lamp operate would be to increase the voltage.

Wrong. The only bright thing about this answer would be the lamp going poof!

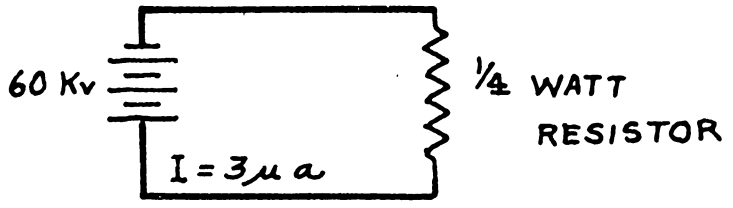
Consider the formula for power in terms of voltage and resistance,

$$P = E^2/R$$

You should readily see the effect of increasing the voltage. Return to Page 102 and choose the right answer.

YOUR ANSWER: The resistance of the resistor is 2×10^{-2} ohms.

No. There are two ways to go wrong in figuring this resistor: to make an arithmetical error, and to come up with the wrong power of 10. You've found one. Let's find out which.



From Ohm's Law,

$$R = E/I$$

As before, $E = 6 \times 10^{4}$ volts, and
$I = 3 \times 10^{-6}$ amperes.

Thus,

$$R = (6 \times 10^{4})/(3 \times 10^{-6})$$
$$= 2 \times (10^{4})/(10^{-6})$$

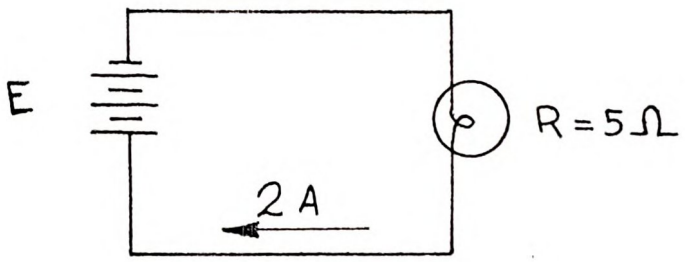
Here's where you went wrong. Remember that for any power of 10, when you move exponents from numerator to denominator, or vice versa, change the exponent from positive to negative, as the case may be.

Thus, $10^{2} = 1/10^{-2}$.

Complete this computation and return to Page 114, and select the right answer.

YOUR ANSWER: No, the power rating is not being exceeded.

Wrong. You have just burned out a bulb. Look at the circuit again.



The current and the resistance are given. To find power, choose the formula using only R and I. This is, $P = I^2R$.

Then it becomes a matter of straightforward substitution.

$$P = (2^2) \times 5$$
$$= 4 \times 5 = 20 \text{ watts}$$

This is considerably more than the 2 watts the bulb is rated for. It would last at most a few seconds. Return to Page 104 and choose the right answer.

YOUR ANSWER: 2500 ohms is the resistance of a 25-watt bulb designed for 100 volt operation.

No. There were two ways to go wrong on this, by doing the arithmetic wrong, and by misplacing the decimal. You managed to go wrong on both. Congratulations!

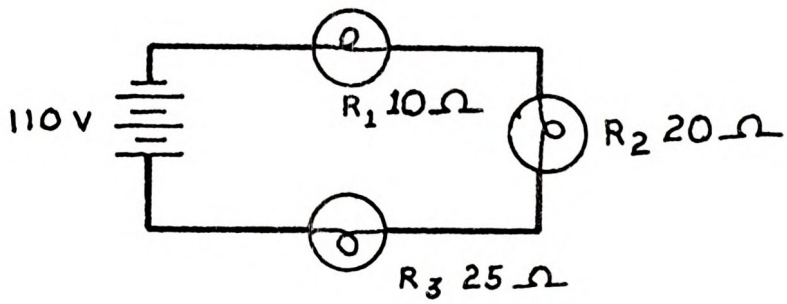
Since voltage and power are given, and resistance is wanted, the proper equation is:

$$P = E^2/R, \text{ solving this for R,}$$

$$R = E^2/P$$

However it appears you multiplied voltage times power, or R = EP. Return to Page 111 and recheck your figures.

Now let's try one a little more difficult. Suppose we have three lamps in series as shown below. Remember lamps are sometimes used to show resistance in a circuit.

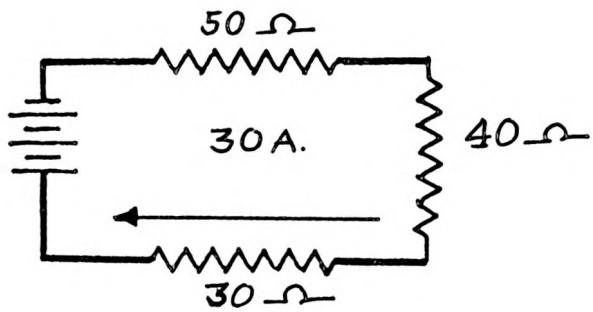


To determine the total power expended must you find the amperage of the circuit?

Yes Page 116

No Page 117

YOUR ANSWER: 108 kw



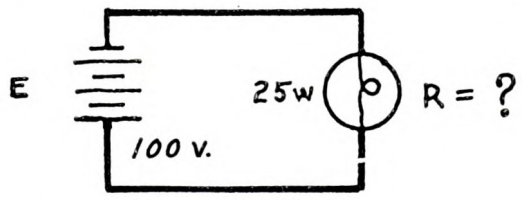
Correct. Using $P = I^2R$ you multiply 30^2 x 120 and get 108,000. Since there are 1000 watts in a kilowatt, you have 108 kilowatts.

You should memorize the three power formulas that we got from Ohm's Law:

$$P = EI \qquad P = \frac{E^2}{R} \qquad P = I^2R$$

Write them down to help remember them. If you can remember only one, be sure to remember that P = EI, power (in watts) equals volts times amperes. You can derive the other forms from this.

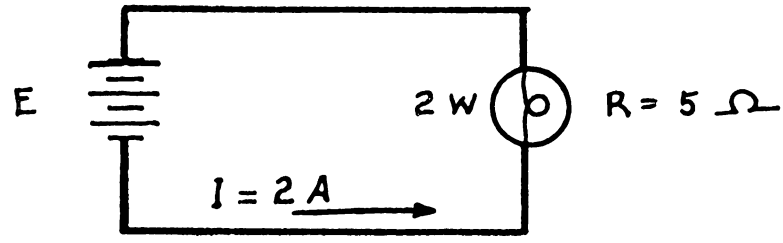
Using the power formulas and Ohm's Law, see if you can solve this problem:



What is the resistance of a 25-watt bulb designed to operate on 100 volts?

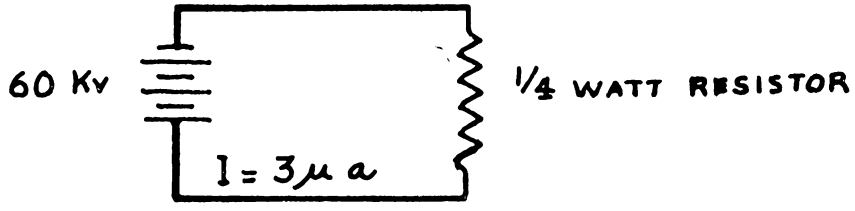
4 ohms	Page 100
400 ohms	Page 104
2500 ohms	Page 109

YOUR ANSWER: You could make the lamp operate properly by putting a resistor in the circuit.



Yes, increasing resistance would decrease the amount of current that could flow in the circuit. If you chose a resistor large enough, you could limit the power expended by the lamp so that it would be operating within its proper limits.

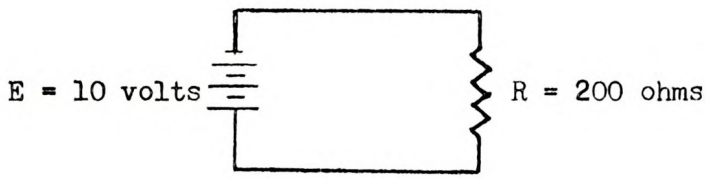
Let's suppose that you have a circuit with 60 kilovolts across a resistor with a power rating of one-fourth watt. If the current is 3 microamperes, is the power rating of the resistor being exceeded?



Yes Page 103

No Page 114

What is the minimum wattage resistor we can use in the diagram below?



a. 2000 watts

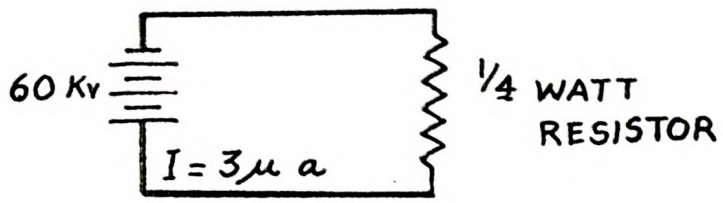
b. 100 watts

c. .5 watts

d. .0025 watts

After selecting an answer go to page 110 and continue.

YOUR ANSWER: No, the power rating of the resistor is not being exceeded.



Correct. You can express 60 kilovolts (60,000 volts) as 6×10^4 volts, and 3 microamperes (0.000003) as 3×10^{-6} amps.

$P = EI = 6 \times 10^4 \times 3 \times 10^{-6}$ or 18×10^{-2}; adjusting the decimal point shows that 0.18 watt is being expended in the resistor. This is under its rating of 0.25 watt.

Just for fun (and to make sure you're still with us), calculate the resistance of the resistor above. Figure the number of ohms in powers of ten.

The 0.25-watt resistor above is:

2×10^{-2} ohms	Page 107
2×10^{10} ohms	Page 115
3×10^{-2} ohms	Page 118
3×10^{10} ohms	Page 120

YOUR ANSWER: Given a resistor with 60 kilovolts across it and a current of 3 microamperes, you could express the resistance as 2×10^{10} ohms.

Correct. Of course this is an unrealistically high resistance.

We hope you didn't waste any time with the formulas involving P. This time you were asked merely to calculate the amount of resistance present. That called for Ohm's law, $R = E/I$.

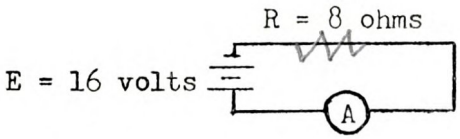
The power formula wouldn't help you find the actual resistance. It would tell you the maximum current you could pass at any given voltage or the maximum voltage you could apply with any given current without applying more power than the resistor is rated to carry.

The calculation as you should have made it, then, was:

$$R = E/I = 6 \times 10^{4}/3 \times 10^{-6} = 2 \times 10^{10} \text{ ohms.}$$

It would take a resistance as large as this to hold current at such a low level with this high amount of voltage.

If the resistance of the resistor in the diagram below decreases what happens to the power?



a. Power increases

b. Power decreases

c. Power stays the same

After selecting an answer go to page 113 and continue.

YOUR ANSWER: Yes, it is necessary to find the amperage of the circuit.

No. If you were flipping a coin, it wasn't your lucky one.

The first definition of power you saw was

$$P = EI$$

But it was shown that if only current and resistance were known in a circuit, this formula could be modified by substituting IR for E, getting,

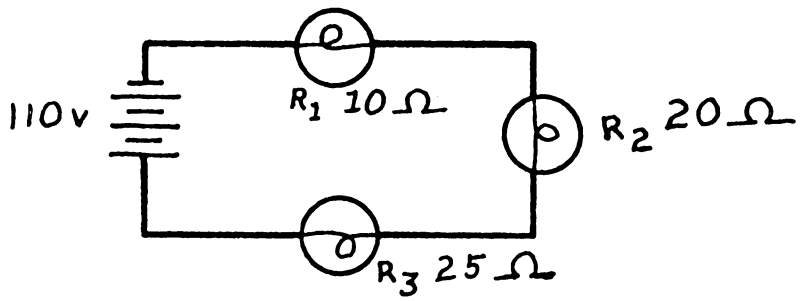
$$P = I^2R$$

Or, if only voltage and resistance were known, you could substitute E/R for I, getting,

$$P = E^2/R$$

Put away that wooden nickel and return to Page 110

YOUR ANSWER: No, you don't have to find the amount of current to determine the total power expended.



Correct. There are three formulas for power: $P = EI$, $P = \frac{E^2}{R}$, $P = I^2R$, so you can find watts with any two of the three electrical units -- voltage, current and resistance.

Use the correct formula, and solve for P with the units given in the diagram. (Be sure to write out your numbers in fraction form and simplify your fraction before multiplying it out.)

What is the total power expended in the circuit?

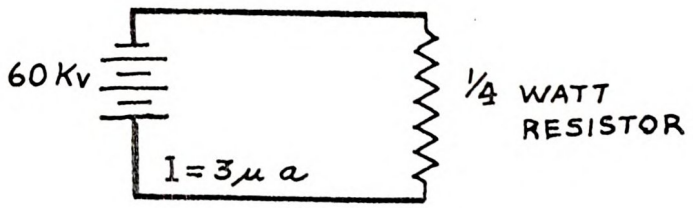
110 watts — Page 121

220 watts — Page 124

6050 watts — Page 127

YOUR ANSWER: 3×10^{-2} is the value, in ohms of the resistor in the circuit.

No. Both the value of the resistor and the power of ten is wrong in your answer. Look at the circuit again.



From Ohm's Law,

$$R = E/I$$

As before, $60 \text{ kv} = 6 \times 10^{4}$ volts

$3 \mu\text{a} = 3 \times 10^{-6}$ amps

Thus, $R = (6 \times 10^{4}) / (3 \times 10^{-6})$

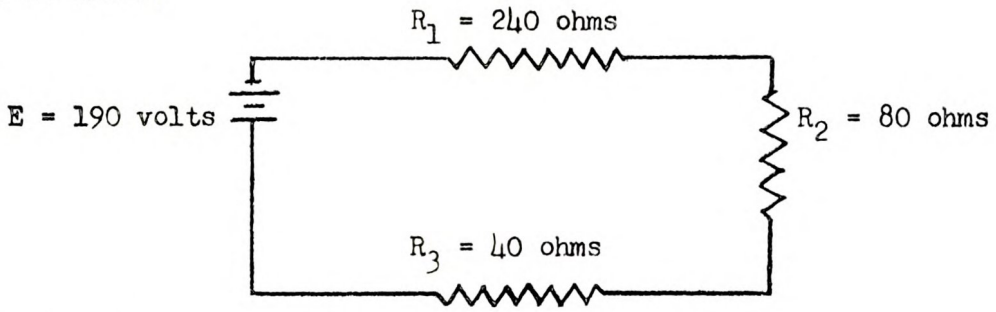
This can be written

$$R = (6/3) \times (10^{4} \times 10^{6})$$

Complete this calculation, then return to Page 114 and choose the right answer. Make sure you understand this before going on, however.

How much power is consumed by the circuit, if the power consumed by R_2 is 20 watts?

1



a. .5 watts

b. 10 watts

c. 60 watts

d. 90 watts

After selecting an answer go on to page 136 and continue

YOUR ANSWER: 3×10^{10} ohms.

You're wrong, but in an odd way.

The purpose of this question was to check your knowledge of manipulation with powers of ten. You handled the powers of ten correctly, but somehow managed to divide wrong.

From Ohm's Law,

$$R = E/I$$

As before, $60 \text{ kv} = 6 \times 10^{4}$ volts

$3 \mu a = 3 \times 10^{-6}$ amps

Thus,

$$R = (6 \times 10^{4}) / (3 \times 10^{-6})$$

This can be written

$$R = (6/3) \times 10^{10}$$

One more small step, and you have the answer. But that's where you blundered. Check your figures and then return to Page 114 for the right answer.

YOUR ANSWER: The power expended in the circuit is 110 watts.

No. Somewhere along the line, your arithmetic has come unstuck.

Here are the figures given: E = 110 volts, R_1 = 10 ohms, R_2 = 20 ohms, R_3 = 25 ohms.

These were the formulas from which you had to pick the one for the job:

$$P = EI \qquad P = \frac{E^2}{R} \qquad P = I^2R$$

The formula you needed was the one which expressed P in the terms given -- voltage and resistance. In other words, the one you needed was:

$$P = \frac{E^2}{R}$$

Using that formula, your calculations should have gone this way:

$$P = \frac{E^2}{R} = \frac{110 \times \cancel{110}^{2}}{\cancel{55}} = \text{?} \text{ watts}$$

That calculation shouldn't be hard to finish. Return to Page 117 and read through it again so that you get the idea clear in your mind, then pick the correct answer.

YOUR ANSWER: $E_1 = 5$ volts, $E_2 = 10$ volts, $E_3 = 12.5$ volts

Wrong.

And if you had remembered that the sum of the voltage drops is equal to the total applied voltage, you would have seen this for yourself.

Here is the information you had: $E = 110$ volts, $R_1 = 10$ ohms, $R_2 = 20$ ohms, $R_3 = 25$ ohms, $P = 220$ watts.

The next thing needed was the current. You had two ways of getting that: $I = E/R$ or, since $P = EI$, $I = P/E$.

$I = E/R = 110/55 = 2$ amps. $I = P/E = 220/110 = 2$ amps.

Now you're in business. The voltage drop across R_1 can be obtained by Ohm's Law:

$$E_1 = IR_1 = 2 \text{ amps} \times 10 \text{ ohms} = 20 \text{ volts}$$

The voltage drops across resistors R_2 and R_3 are found in exactly the same way.

Figure them out and then return to Page 124 with the correct answer.

YOUR ANSWER: $P_1 = 20$ watts, $P_2 = 40$ watts, $P_3 = 50$ watts

No, you forgot at least one thing.

Add up the total number of watts (or wattage) in these resistors. They total 110 watts, don't they?

If this doesn't ring a bell, it's clear that you've forgotten that the total watts used in the circuit was 220. Since you can account for only 110, and there are no other circuit elements, something is wrong.

In the previous question, you were asked to calculate the current in the circuit and then figure out the voltage drops in the individual circuit elements. Since you answered this question correctly, you know the circuit current, and the voltage drop across each resistor.

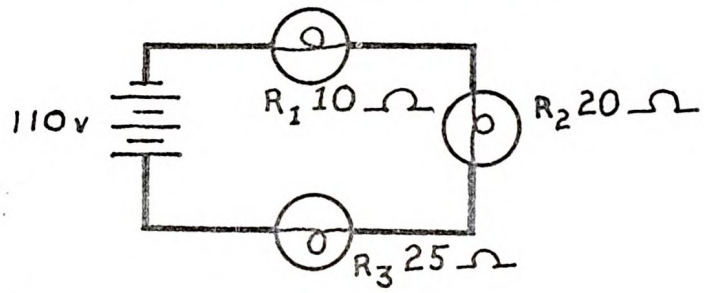
Now all that is necessary is to use:

$$P = EI$$

Do this for each lamp.

Now return to Page 130, and when you have the individual wattages, add them together and see that the total checks.

YOUR ANSWER: 220 watts are used in the circuit.



Correct. The calculation you needed was:

$$P = \frac{E^2}{R} = \frac{110 \times 110}{55} = 220 \text{ watts}$$

Now go ahead and calculate the value of I, so that you can find the voltage drop across each lamp. When you have figured out the three voltage drops, compare your list with those below, and choose the correct one.

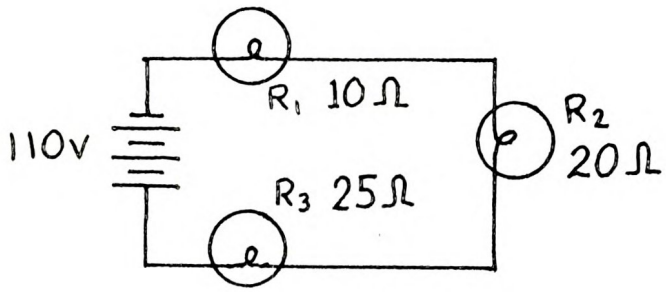
$E_1 = 5$ volts
$E_2 = 10$ volts
$E_3 = 12.5$ volts
} Page 122

$E_1 = 110$ volts
$E_2 = 110$ volts
$E_3 = 110$ volts
} Page 126

$E_1 = 20$ volts
$E_2 = 40$ volts
$E_3 = 50$ volts
} Page 130

None of these — Page 132

YOUR ANSWER: P_1 = 40 watts, P_2 = 80 watts, P_3 = 100 watts. Page 125



Correct. You had to apply the formula **P = EI** for each resistor in turn, using the voltage drop across each resistor for **E**, and using 2 amps for I (the current is the same through each resistor since this is a series circuit).

As you remember, we found the total power expended in the circuit to be 220 watts. Think over what you have learned in this problem, and see if you could make some observation about power in a series circuit.

What is the new thing this problem told us about power in a series circuit?

You can use the power formula in combination with Ohm's Law to determine the power expended in a series circuit. Page 128

Only two of the three electrical units (volts, amperes, and ohms) are needed to calculate power in a series circuit. Page 131

The total power dissipated in a series circuit is equal to the sum of the amounts of power dissipated by the individual components. Page 133

YOUR ANSWER: E_1 = 110 volts, E_2 = 110 volts, E_3 = 110 volts.

No, no and no. The sum of the voltage drops should be equal to the total applied voltage (in this case, 110 volts). Here you have voltage drops which total three times the applied voltage. Something's wrong. Let's do it the right way.

Here is the information you had: E = 110 volts, R_1 = 10 ohms, R_2 = 20 ohms, R_3 = 25 ohms, P = 220 watts.

The next thing needed was the current. You had two ways of getting that: I = E/R or, since P = EI, I = P/E.

I = E/R = 110/55 = 2 amps. I = P/E = 220/110 = 2 amps.

Now you're in business. The voltage drop across R_1 can be obtained by Ohm's Law:

$E_1 = IR_1$ = 2 amps x 10 ohms = 20 volts

The voltage drops across resistors R_2 and R_3 are found in exactly the same way.

Figure them out and then return to Page 124 with the correct answer.

YOUR ANSWER: The power expended in the circuit is 6050 watts.

No. You really came unstuck. It looks as if you obtained your answer by multiplying the resistance by voltage. And that means you have made up a formula of your own for power, which seems to say: $P = ER$. No. It won't do.

We'll begin at the beginning again. Here are the figures you had to work with: $E = 110$ volts, $R_1 = 10$ ohms, $R_2 = 20$ ohms, $R_3 = 25$ ohms.

These were the formulas from which you had to pick the one best suited for the job:

$$P = EI \qquad P = \frac{E^2}{R} \qquad P = I^2R$$

The formula you needed was the one which expressed P in the terms given -- voltage and resistance. In other words, the one you wanted was:

$$P = \frac{E^2}{R}$$

Using that formula, your calculations should have gone this way:

$$P = \frac{E^2}{R} = \frac{110 \times 110}{55} = ? \text{ watts}$$

Finish the calculation. That shouldn't be hard. Then return to Page 117 and read it through again so that you really understand it before picking the correct answer.

YOUR ANSWER: You can use the power formula in combination with Ohm's Law to determine the power expended in a series circuit.

Yes, but it's not the answer we hoped for.

It's true, of course, but you've known this for some time -- you couldn't have gotten this far otherwise.

What the question aimed at was, which of the choices presented contains a statement not previously stated?

Return to Page 125 and read the choices again.

YOUR ANSWER: $P_1 = 220$ watts, $P_2 = 220$ watts, $P_3 = 220$ watts

Three times, "NO".

When you figured the power expended in the circuit, you used the formula: $P = E^2/R$ to get an answer of 220 watts.

Since then you have found that the circuit current is 2 amps. This gives you another check on the earlier figure by using

$P = EI = 2$ amps $\times$ 110 volts $= 220$ watts

What else do you know about the 110 volts in the circuit? It's the sum of the voltage drops in the individual lamps, isn't it? So we could have written:

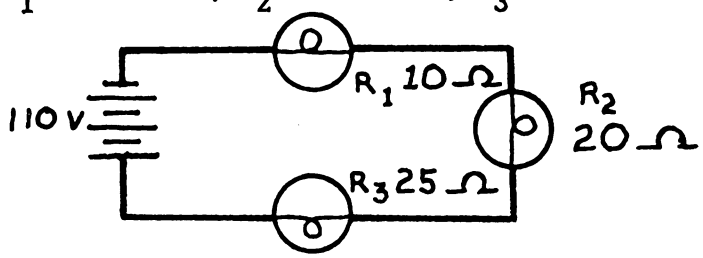
$P = EI = (E_1 + E_2 + E_3) \times I = (20 + 40 + 50) \times 2 = 220$ watts

But this is the same as:

$P = EI = 20 \times 2 + 40 \times 2 + 50 \times 2 = 220$ watts

Complete the problem in terms of each lamp, and return to Page 130, making sure you're quite certain of yourself before going on.

YOUR ANSWER: $E_1 = 20$ volts, $E_2 = 40$ volts, $E_3 = 50$ volts.



Yes, in a series circuit, the sum of the voltage drops is equal to the total applied voltage. If you remembered this you didn't have any doubts when it came to checking your arithmetic, for this was the only group of numbers that added up to 110.

Using the formula $I = \frac{E}{R}$, you should have found that there is a 2-ampere current in the circuit. Using the values you have at hand calculate the power dissipated by each resistor. In other words, how many watts are expended in each resistor?

$P_1 = 20$ watts
$P_2 = 40$ watts
$P_3 = 50$ watts
} Page 123

$P_1 = 40$ watts
$P_2 = 80$ watts
$P_3 = 100$ watts
} Page 125

$P_1 = 220$ watts
$P_2 = 220$ watts
$P_3 = 220$ watts
} Page 129

YOUR ANSWER: Only two of the three units (volts, amperes, and ohms) are needed to calculate power in a series circuit.

Yes, but it's not the answer we hoped for.

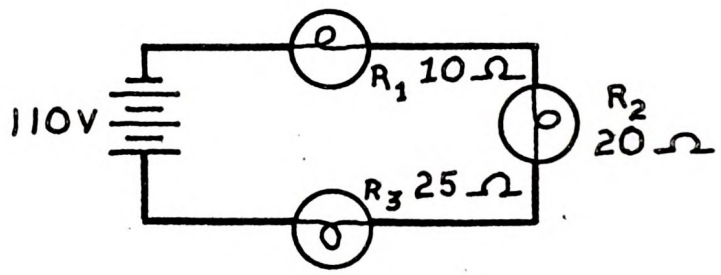
It's true, of course, but you've known this for some time -- you couldn't have gotten this far otherwise.

What the question aimed at was, which of the choices presented contains a statement not previously stated?

Return to Page 125 and read the choices again.

YOUR ANSWER: None of these.

No. Why can't you determine the voltage drops? In the question it was suggested you calculate the current. Look at the circuit again:



The resistances are given, R_1 = 10 ohms, R_2 = 20 ohms and R_3 = 25 ohms. It should be a simple matter to add these together to find the value of R_T, and using $I = E/R_T$ to find the current.

Since in a series circuit the same current flows through each element, the voltage drop in each element can be obtained by using Ohm's law for each resistor, or lamp. And since the sum of the individual voltage drops adds up to the total circuit voltage, you can check your figures.

Read this over if it still isn't clear, then return to Page 124 and work the problem again.

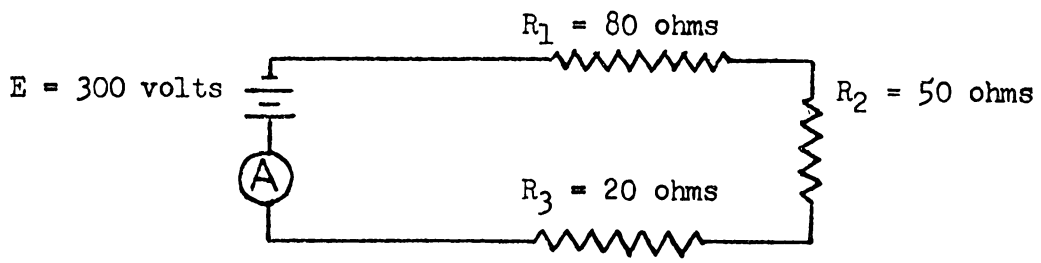
YOUR ANSWER: The total power consumed in a series circuit is equal to the sum of the amounts of power consumed by the individual components.

Correct. You have also learned these facts about a series circuit:

1. The current in a series circuit is the same at all points in the circuit.
2. The total applied voltage of a series circuit is equal to the sum of the voltage drops across the individual components.
3. The total resistance of a series circuit is equal to the sum of the individual resistances.

These last three facts are true of series circuits only. A different set of facts applies to parallel circuits. But note this: The statement about power given in the answer at the top of the page is true of both series and parallel circuits. You should remember that.

How much power is consumed by R_2 if the power consumed by R_1 is 320 watts?



a. 50 watts

b. 100 watts

c. 200 watts

d. 320 watts

After selecting an answer go to page 119 and continue.

YOUR ANSWER: $E_1 = 5$ volts, $E_2 = 10$ volts, $E_3 = 15$ volts

Wrong. How did you do it?

Add up your voltages:

$$E_{total} = E_1 + E_2 + E_3$$
$$= 5 + 10 + 15 = 30 \text{ volts}$$

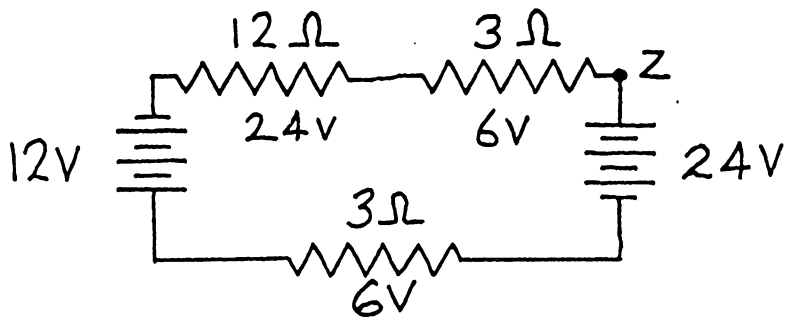
Long before you heard of Kirchhoff's Laws, you knew that the sum of the voltage drops (or IR drops) in a series circuit had to equal the source voltage. And the source voltage in this case is 60 volts.

Count to ten slowly, take a deep breath, and return to Page 143 and choose what you knew was the right answer all the time!

YOUR ANSWER: The algebraic sum of 60, -10, -20, and -30 is zero.

Correct. This fits Kirchhoff's second law for voltage: The algebraic sum of the EMFs and voltage drops around a closed circuit is zero.

That circuit had only one battery, so there was only one EMF to consider. However, Kirchhoff's law applies just the same where there is more than one source of EMF. Take a look at this circuit:



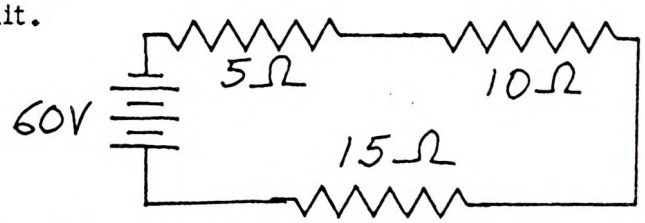
Here are two EMFs to produce current. Again there are 2 amperes of current in the circuit, and the voltage drops are given with each resistor. Remember, now, the negative end of the resistor is the end toward the negative pole of the battery. If you start at point Z, which of the lists below shows the numbers to be added algebraically to analyze the circuit?

+24	- 6	+24
- 6	-24	- 6
+12	+12	-12
-24	- 6	-24
- 6	-24	- 6
Page 137	Page 141	Page 144

Kirchhoff's second law is for voltage: The algebraic sum of the EMF's and the voltage drops around a closed circuit is zero. Often you will hear voltage drops referred to as IR drops.

This means that in any closed circuit the applied EMF is equal to the sum of the IR drops around the circuit. This, of course, is a form of Ohm's Law, E = IR.

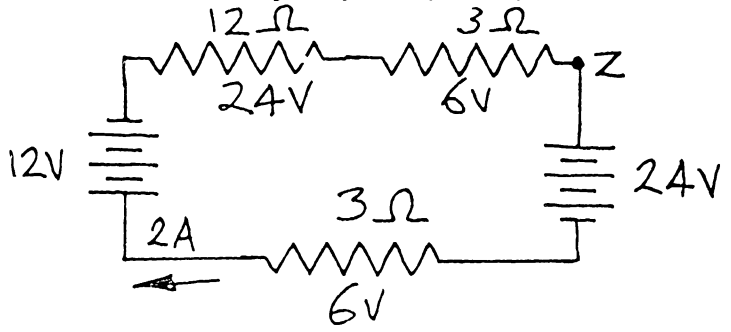
It is what you have already learned about the voltage drops in a series circuit. Shortly we'll see how it applies to parallel circuits. But first, let's see how this would work in a simple series circuit.



What is the current in this circuit?

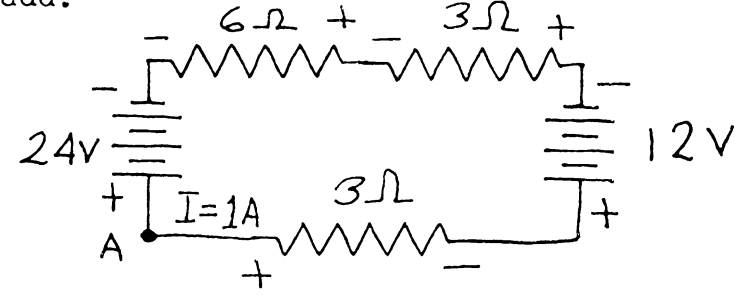
0.5 amp	Page 138
2 amps	Page 143
4 amps	Page 145

YOUR ANSWER: Starting from Z, the analysis of this circuit according to Kirchhoff's Law calls for you to add +24, -6, +12, -24, and -6.



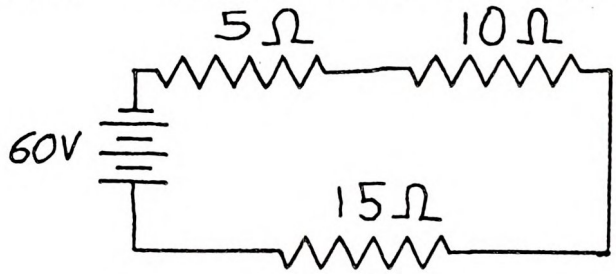
Yes, the result is zero, of course. And you analyzed the circuit in the direction of current flow, as indicated by the arrow.

Now look at the diagram below. Again we have two batteries, but now the smaller battery is turned around so that its EMF opposes that of the larger battery. Accordingly, there is now just 1 ampere of current in the circuit. Starting at point A below, analyze the circuit and choose the list that gives the numbers you should add.



+24	+ 3	+24
- 6	+12	- 6
- 3	+ 3	- 3
+12	+ 6	-12
- 3	-24	- 3
Page 140	Page 142	Page 147

YOUR ANSWER: 0.5 amps is the current in this circuit.



You are wrong, and you shouldn't be at this stage. This is a series circuit, you can add up the resistances in the circuit:

$$R = 5 + 10 + 15 = 30 \text{ ohms}$$

The voltage is given as:

$$E = 60 \text{ volts}$$

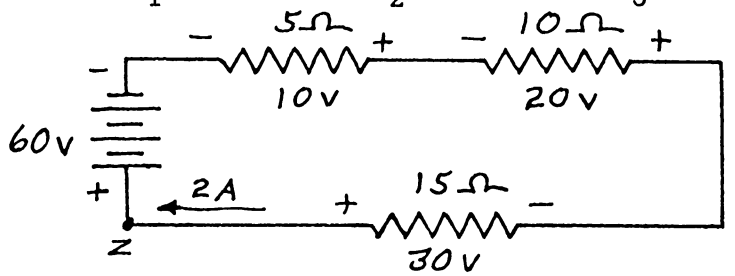
By Ohm's Law, $I = E/R$

$$I = 60/30 = \ ?\ \text{amperes}$$

Now that's the way you've been doing it for quite some time. Nothing has been changed, or will be changed for such simple computations. Of course, if you get careless and use Ohm's Law as $I = R/E$, it won't matter how well you know the material, the answer will still be wrong.

Return to Page 136 and turn your formula right side up.

YOUR ANSWER: E_1 = 10 volts, E_2 = 20 volts, E_3 = 30 volts.



Yes, using E = IR, you multiply each resistance by 2 (the number of amperes) to find the voltage drop across each resistor.

The diagram lists the voltage drops with the resistors and also shows the polarity of the voltage drop.

Note that the battery is labelled + and -, indicating that the direction of current is from the battery to the 5-ohm resistor and then on around the circuit. The polarity of each resistor is given, too. Note that they are given just as you would apply a voltmeter; the negative end of each resistor is the end toward the negative end of the battery.

If it helps you to remember the polarity of the resistor, think of the resistor as a counter-force to the EMF of the battery. This means that the polarity of the resistor is opposite to that of the battery.

To analyze this circuit according to Kirchhoff's second law, let's begin at point Z, near the positive pole of the battery. Going in the direction of the current flow, we pass through the battery and then through the resistors, adding the EMFs and voltage drops algebraically. We call them positive if we run into a + first, and we call them negative if we find a - first.

Starting from Z, we add these numbers algebraically:

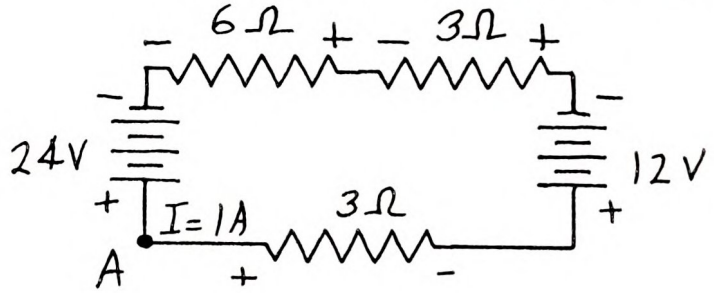
+60, -10, -20, -30

What is the result?

0 Page 135

120 Page 146

YOUR ANSWER: The list of numbers to be added in analyzing this circuit is: +24, -6, -3, +12, -3.



No, you were asleep at the switch here, and got caught on a real blooper.

Add up your list:

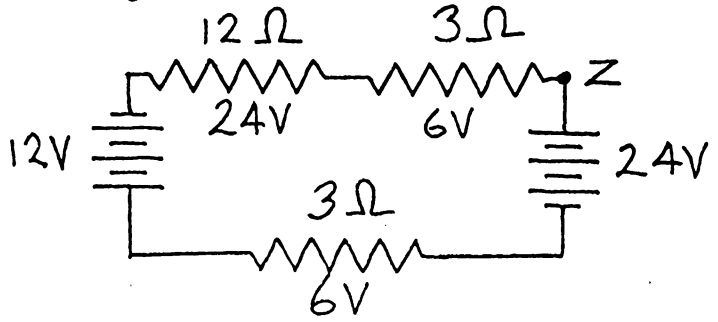
$$+24 \quad -6 \quad -3 \quad +12 \quad -3 = +24$$

It is certainly no news to you that the sum of the IR drops must equal the source voltage, and that since they are equal, their difference must be zero. How then can their difference add up to +24?

It looks as if you forgot that we reversed a battery on you. Return to Page 137 and check the battery polarities.

YOUR ANSWER: The algebraic sum of the components in the series circuit shown is: -6 -24 +12 -6 -24

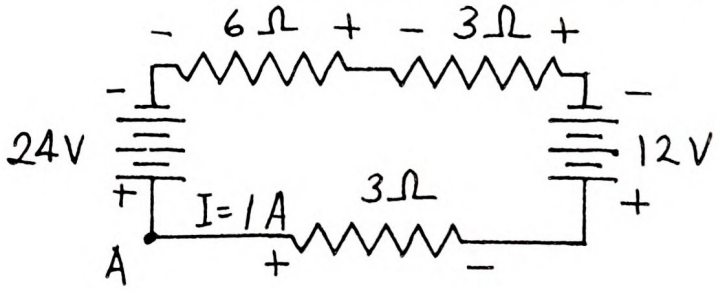
Wrong on two counts. In the first place it is customary to read in the direction of current flow. As for the other, look at the circuit again.



Note particularly the batteries. If you trace the direction of current from each, do they take the same direction? If so won't they have the same sign?

This was only a small mistake, but the effect was just as wrong as if you didn't have the slightest idea of what was going on. Someday this can be embarrasing so start being more careful now. Return to Page 135 and choose the right answer.

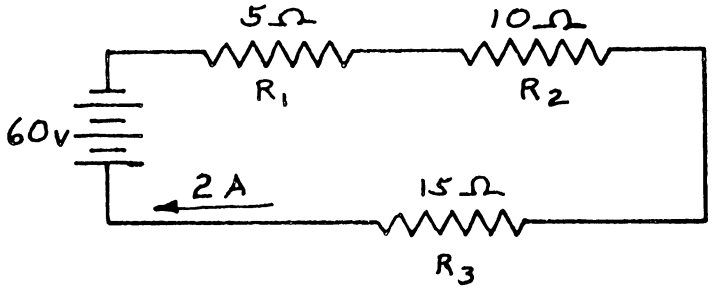
YOUR ANSWER: The list of numbers to be added in analyzing this circuit is: +3, +12, +3, +6, -24.



No, but it's not an error that will ever cost you money.

The convention in analyzing such a circuit is to proceed in the direction of the current. The result here will be the same, but later on it might cause confusion. Return to Page 137 and recheck the direction of current.

YOUR ANSWER: 2 amperes are flowing in the circuit.



Correct. $I = \frac{E}{R} = \frac{60}{30} = 2$ amps.

You know that there must be a total voltage drop in the circuit of 60 volts, and that this voltage drop is shared among the resistors in proportion to their resistance. These voltage drops can be labelled E_1, E_2, E_3, etc., with the subscript (the figure below the line as in E_1) corresponding to the resistor number.

Calculate the voltage drops above and choose the correct list below:

$E_1 = 5$ volts
$E_2 = 10$ volts
$E_3 = 15$ volts

Page 134

$E_1 = 10$ volts
$E_2 = 20$ volts
$E_3 = 30$ volts

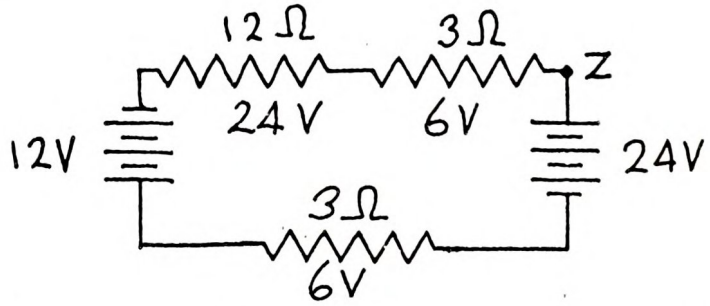
Page 139

$E_1 = 15$ volts
$E_2 = 30$ volts
$E_3 = 60$ volts

Page 148

YOUR ANSWER: The algebraic sum of the components in the series circuit shown is: +24, -6, -12, -24, -6.

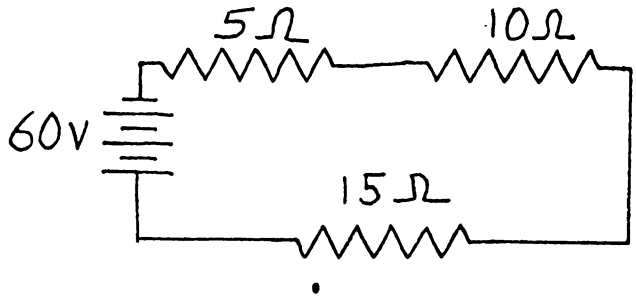
No, you were careless in reading the circuit. Look at it again.



Note particularly the batteries. If you trace the direction of current from each, do they take the same direction? If so won't they have the same sign?

This was only a small mistake, but the effect was just as wrong as if you didn't have the slightest idea of what was going on. Someday this can be embarrasing so start being more careful now. Return to Page 135 and choose the right answer.

YOUR ANSWER: 4 amps is the current in this circuit.



It would be hard to be more wrong.

Add up the resistances in the circuit:

$$R = 5 + 10 + 15 = 30 \text{ ohms}$$

The voltage is given as:

$$E = 60 \text{ volts}$$

By Ohm's Law, $I = E/R$

$$I = 60/30 = \ ?\ \text{amperes}$$

Now that's the way you've been doing it for quite some time. Nothing has been changed or will be changed for such simple computations. Of course, if you get careless and forget to add up all the resistances, it won't matter how well you know the material, the answer will still be wrong.

Return to Page 136 and check your work before going on.

YOUR ANSWER: (+60) + (-10) + (-20) + (-30) = (+120)

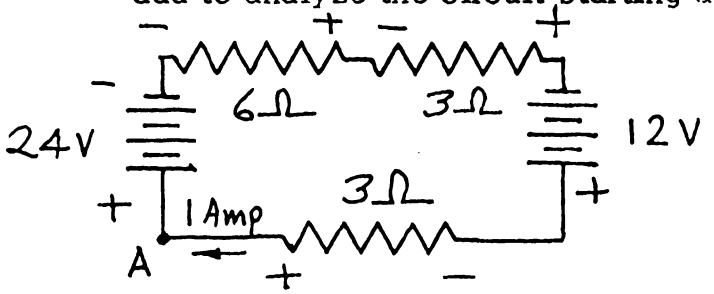
Not this year.

Or next year either. This was carelessness on your part, for you surely know how to add negative values. If it makes it easier for you to total all the negative values and subtract the sum of these, the computation becomes:

$$(+60) - (10 + 20 + 30) = \ ?$$

Perhaps you should take a breather before returning to Page 139 and choosing the right answer.

YOUR ANSWER: +24, -6, -3, -12, -3 are the numbers you should add to analyze the circuit starting at point A.



Good, The -12 is for the battery. Since it is connected so as to oppose the EMF of the 24-volt battery, its EMF must be called negative. It subtracts voltage from the larger battery. Note that the 12-volt battery acts just like a resistor in this circuit.

Good,

You have done very well by completing this lesson in this amount of time. On your answer sheet write down the amount of time it took you to complete the lesson.

YOUR ANSWER: $E_1 = 15$ volts, $E_2 = 30$ volts, $E_3 = 60$ volts

Wrong. How did you do it?

Add up your voltages:

$$E_{total} = E_1 + E_2 + E_3$$
$$= 15 + 30 + 60 = 105 \text{ volts}$$

Long before you even heard of Kirchhoff's Laws, you knew that the sum of the voltage drops (or IR drops) in a series circuit had to equal the source voltage. The source voltage in this case is 60 volts.

Count to ten slowly, take a deep breath, and return to Page 143, and choose what you knew was the right answer all the time!

PARALLEL CIRCUITS

3-C



NAVAL AIR TECHNICAL TRAINING COMMAND

Acknowledgements

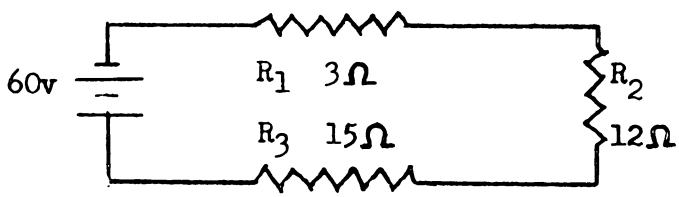
This program was adapted by the Naval Air Technical Training Center, Memphis, Tennessee, from a larger one developed under contract No. AF 33 (616)-6983 CPFF between the U.S. Air Force and Western Design and Electronics. In a letter dated 27 July, 1961 from the Aeronautical Systems Division, Air Force Systems Command, United States Air Force, use of these materials by other governmental agencies was confirmed. Appreciation is expressed to the Aeronautical Systems Division and to Western Design and Electronics for assistance in making the original program available.

In a series circuit, the sum of the voltage drops across the resistors is equal to the applied voltage. This concept can be stated mathematically:

$$E_t = E_1 + E_2 + E_3 + \ldots . E_n .$$

E_t is the total or applied voltage. E_1, E_2, etc., stand for the voltage drops across each of the resistors (which will normally be numbered correspondingly, R_1, R_2, etc.).

Calculate the voltage drops across each resistor in this circuit and then choose the list that gives all the drops correctly.



Page 2

$E_1 = 20v$

$E_2 = 20v$

$E_3 = 20v$

$E_t = 60v$

Page 4

$E_1 = 6v$

$E_2 = 24v$

$E_3 = 30v$

$E_t = 60v$

Page 7

$E_1 = 30v$

$E_2 = 24v$

$E_3 = 6v$

$E_t = 60v$

YOUR ANSWER: E_1 = 20v, E_2 = 20v, E_3 = 20 v, and E_t = 60v.

The total voltage drop is 60 volts. But the values of the individual resistors are not the same. We are now considering a circuit in which the value of resistance varies from resistor to resistor. In this case, the voltage drop varies too. It must, because the current can't change. We have seen many times that current is the same in all parts of a series circuit.

As we have said, the total voltage drop still equals the applied voltage. Varying the resistances just changes the proportion of the voltage that had to be expended across each resistor.

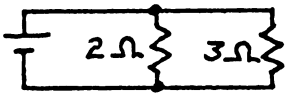
You can calculate voltage drops in two steps. First, find the circuit current by Ohm's Law, $I = \frac{E}{R}$. Since the voltage is 60, and the total resistance 30 ohms, the current is 2 amperes.

Then, you apply the formula $E = I R$, to each resistor. In all cases, the current is 2 amperes. To find the voltage drop across each resistor, multiply the individual resistance by 2 amperes.

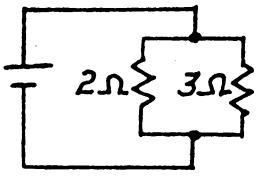
Now, return to page 1 and select the correct answer.

YOUR ANSWER: Diagram A is not electrically identical to the others.

No. Here are the diagrams again:

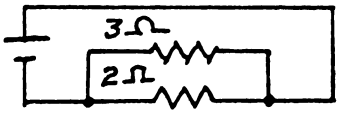


(A)



(B)

(C)



The voltage drop across each component connected in parallel is the total voltage of the source.

When we told you that, we explained that the negative ends of resistors connected as in (A) above could be considered electrically identical to each other and to the negative pole of the battery, while the positive ends of the resistors could be considered as electrically identical to each other and to the positive pole of the battery.

Let's put it another way: We join one end of each resistor in a circuit. If it is possible to trace one end of each resistor back to a single point on the path from the negative pole of the voltage source and to trace the other end of each back to a common point on the path from the positive pole, the resistors are in parallel.

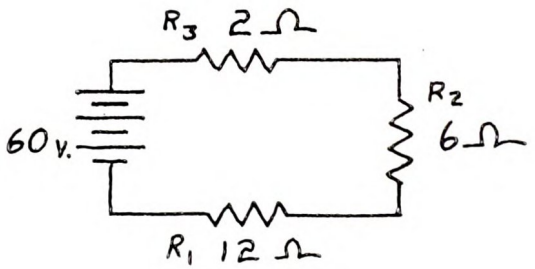
Check that out against the diagrams above and then return to Page 10 for another answer.

YOUR ANSWER: E_1 = 6v, E_2 = 24v, E_3 = 30v, and E_t = 60v.

Correct. The total resistance is 30 ohms, allowing 2 amperes to flow in the circuit. Multiplying 2 times the value of each resistor gives voltage drops across the individual resistors.

As you can see, the voltage drops steadily in a series circuit. The voltage drop is proportional to the resistance and total drop equals the applied voltage.

Now look at this circuit:

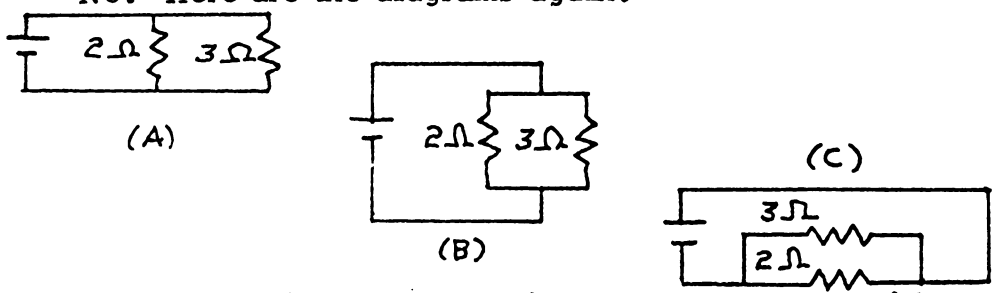


What is the voltage drop across R_1?

6 volts	Page 6
18 volts	Page 9
36 volts	Page 11

YOUR ANSWER: Diagram B is not electrically identical to the others.

No. Here are the diagrams again.



The voltage drop across each component connected in parallel is the total voltage of the source.

When we told you that, we explained that the negative ends of resistors connected as in (A) above could be considered electrically identical to each other and to the negative pole of the battery while the positive ends of the resistors could be considered as electrically identical to each other and to the positive pole of the battery.

Let's put it another way: We join one end of each resistor in a circuit. If it is possible to trace one end of each resistor back to a single point on the path from the negative pole of the voltage source and to trace the other end of each back to a common point on the path from the positive pole, the resistors are in parallel.

Check that out against the diagrams above and then return to Page 10 for another answer.

YOUR ANSWER: The voltage drop across R_1 is 6 volts.

You've picked the wrong resistor, apparently. The resistor you were asked about is R_1.

If you simply chose the wrong resistor, return now to Page 4 and calculate the voltage drop for resistor R_1. It is labelled R_1, so there should be no trouble finding it.

YOUR ANSWER: $E_1 = 30v$, $E_2 = 24v$, $E_3 = 6v$, and $E_t = 60v$.

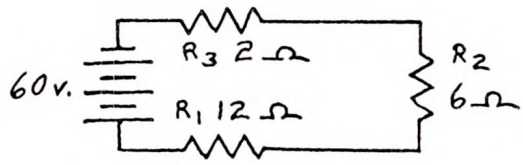
You're guessing, or else you got your math mixed up a good deal. The total voltage drop still equals the applied voltage, which is 60 volts.

You can calculate voltage drops in two steps. First, find the amperage of the complete circuit by Ohm's Law, $I = \frac{E}{R}$. Since the voltage is 60, and the total resistance 30 ohms, the current is 2 amperes.

Then, you apply the formula $E = IR$, to each resistor. In all cases, the current is 2 amperes. To find the voltage drop across each resistor, multiply the individual resistance by 2 amperes.

Now, return to Page 1 and select the correct answer.

YOUR ANSWER: 6 volts applied to R_3.



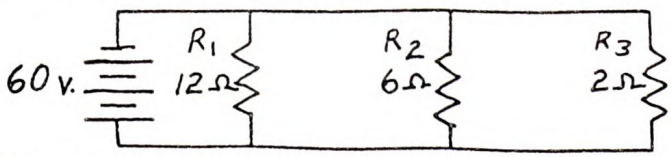
Correct. With 3 amperes in the circuit, E_1 = 36 volts and E_2 = 18 volts; there is a 54 volt drop across R_1 and R_2. The 6 volts remaining are applied to R_3, and this is equal to the voltage drop across the last resistor.

All of the circuits we have discussed in this section have been series circuits. You should know these things about series circuits by heart now:

1. The amount of current in each device in the circuit is the same.
2. The total resistance of the circuit is the sum of the resistances of the individual devices.
3. The sum of the voltage drops across each device in the circuit is equal to the total applied voltage.

Another type of circuit is the parallel circuit. The three statements above do not apply to parallel circuits; we must learn a new set of characteristics for them.

Here are the same three values of resistance shown above, but now they are connected in parallel.



Look at R_3, at the far right. Is it connected directly to the power source?

Yes Page 10

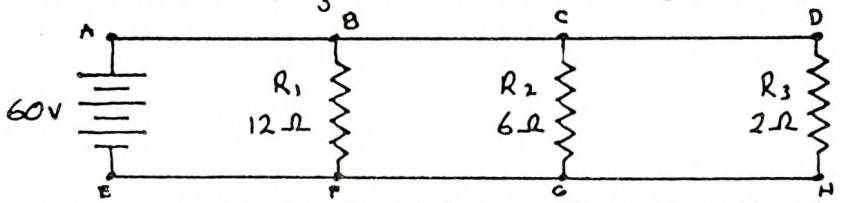
No Page 15

YOUR ANSWER: The voltage drop across R_1 is 18 volts.

You've picked the wrong resistor, apparently. The resistor you were asked about is R_1.

If you simply chose the wrong resistor, return now to Page 4 and calculate the voltage drop for resistor R_1. It is labelled R_1, so there should be no trouble finding it.

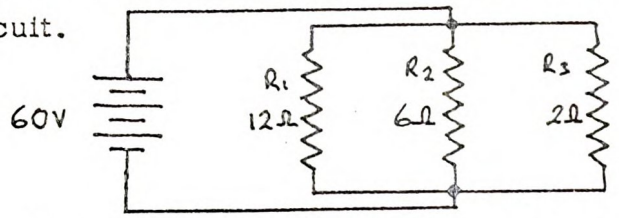
YOUR ANSWER: Yes, R_3 is connected directly to the power source.



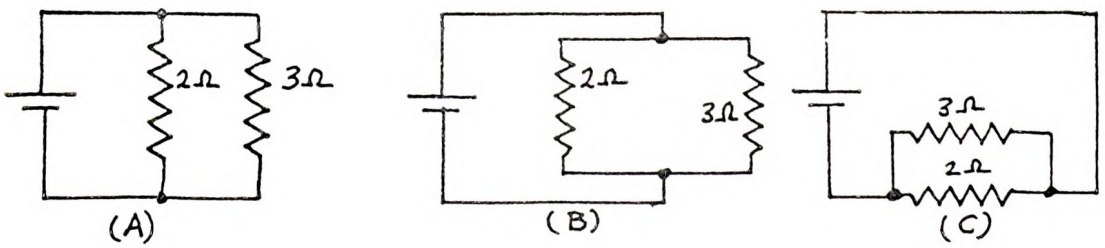
Correct. Points B, C and D are all electrically identical with point A, the positive pole. Likewise, points F, G and H are electrically identical with point E, the negative pole. The lower ends of all three resistors are all connected to the negative side of the power source; the upper ends of the resistors are all connected to the positive side.

If you had a struggle to visualize the above as a parallel circuit when you first looked at it, it may have occurred to you that there are other ways of showing a parallel circuit.

For instance, the following is a parallel circuit that is electrically identical to the one above. However, this new diagram may make it plainer why it is considered a parallel circuit.



Now look at these three diagrams. Which is not electrically identical to the others?



A — Page 3

B — Page 5

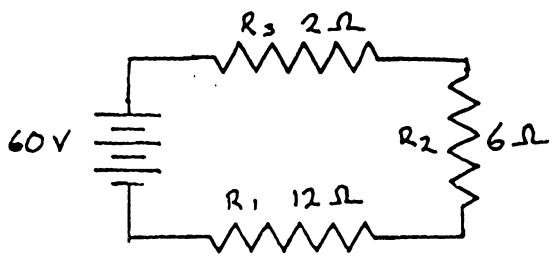
C — Page 13

They are all the same. — Page 18

They are all different. — Page 21

YOUR ANSWER: 36 volts.

Yes, R_1 is at the bottom this time, but it's labelled so you should have had no trouble finding it. Usually the first resistor in the direction of current flow is designated "R_1". The negative side of the battery is toward the bottom of this diagram.



In this circuit there is a total of 20 ohms resistance, so 3 amperes flow. You can multiply this current times the rating of each resistor (in ohms) to find the voltage drop across it. Do this for all the resistors in this circuit, so you can answer the following question.

How much voltage is applied to R_3?

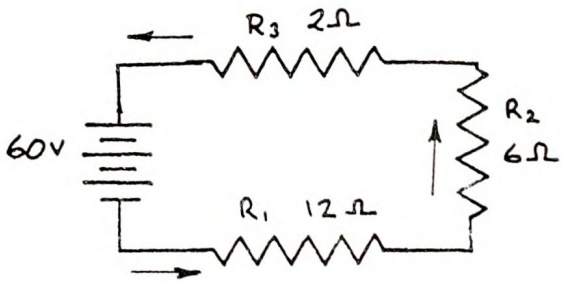
6 volts — Page 8

54 volts — Page 12

60 volts — Page 16

YOUR ANSWER: 54 volts.

That is an improbable choice. Here is the diagram again. An arrow has been inserted to show the direction of current flow.



We know that the current through each resistor is the same as the circuit current (3 amperes) since the current is the same at all points in a series circuit.

We can use the E = IR form of Ohm's law to figure the voltage drop across each resistor. Thus the drop across R_1 is 3 x 12 = 36 volts, across R_2 it is 3 x 6 = 18, and across R_3 it is 3 x 2 = 6 volts.

Let's add these together:

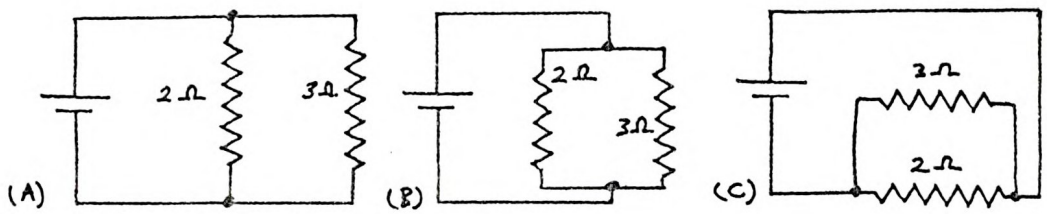
$E_1 + E_2 + E_3 = 36 + 18 + 6 = 60$ volts.

In other words, in a series circuit the sum of the voltage drops is equal to the total applied voltage.

Now return to Page 11 and select the correct answer to the question.

YOUR ANSWER: Diagram C is not electrically identical to the others.

No. Here are the diagrams again:



The voltage drop across each component connected in parallel is the total voltage of the source.

When we told you that, we explained that the negative ends of resistors connected as in (A) above could be considered electrically identical to each other and to the negative pole of the battery, while the positive ends of the resistors could be considered as electrically identical to each other and to the positive pole of the battery.

Let's put it another way: We join one end of each resistor in a circuit. If it is possible to trace one end of each resistor back to a single point on the path from the negative pole of the voltage source and to trace the other end of each back to a common point on the path from the positive pole, the resistors are in parallel.

Check that out against the diagrams above and then return to Page 10 for another answer.

YOUR ANSWER: Each lamp in the series string has 110 volts applied to it, and there is a voltage drop of 11 volts across each lamp in the parallel string.

No.

Consider the first part of your answer: Each lamp in the series string has 110 volts applied to it. The total voltage drop in the series circuit must be 110 volts. But won't there be a voltage drop at the first lamp? If there is, how can the second lamp have 110 volts applied to it?

As for the second part, it appears you've forgotten the first thing you learned about parallel circuits, which was:

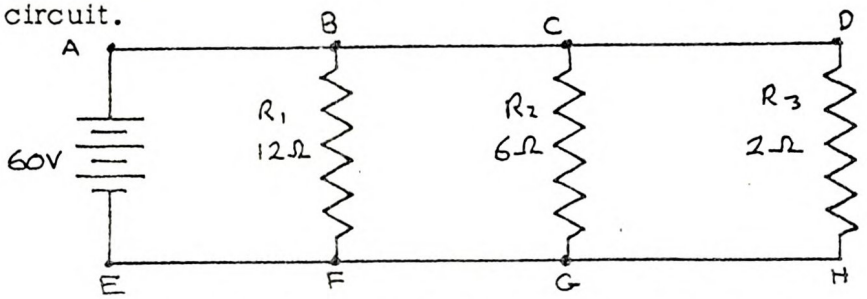
> In a parallel circuit, the same voltage is applied to each resistor, or in this case lamp.

This is the case since, as we saw, each lamp is connected directly to an extension of the power source terminals.

Return to Page 25 now, review it and then make another choice.

YOUR ANSWER: No, R_3 is not directly connected to the power source.

You're wrong, but at this stage of the game there's no reason to feel bad about it. Let's look at point D of the circuit.

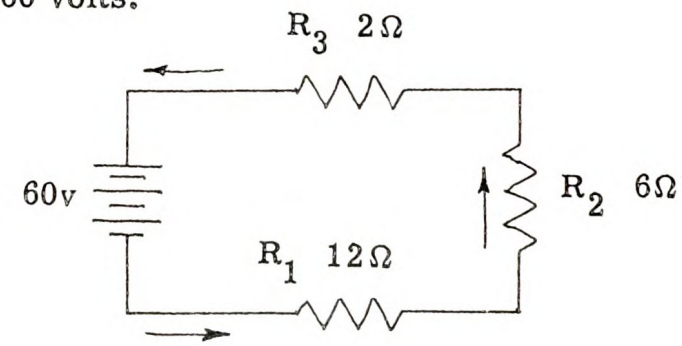


You'll notice that there is no circuit element between A and D. Since this is so, it must be simply an extension of the positive pole of the power supply. Similarly, point H is merely an extension of point E, the negative pole of the power source.

It should not be difficult to conclude the same things about R_1 and R_2.

Return to Page 8 and try again.

YOUR ANSWER: 60 volts.



We know that the current through each resistor is the same as the circuit current (3 amperes), since the current is the same at all points in a series circuit.

We can use the E = IR form of Ohm's law to figure the voltage drop across each resistor. Thus the drop across R_1 is 3 x 12 = 36 volts, across R_2 it is 3 x 6 = 18, and across R_3 it is 3 x 2 = 6 volts.

Let's add these together:

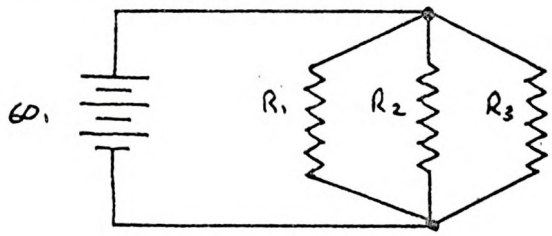
$E_1 + E_2 + E_3 = 36 + 18 + 6 = 60$ volts.

In other words, in a series circuit the sum of the voltage drops is equal to the total applied voltage.

Now return to Page 11 and select the correct answer to the question.

YOUR ANSWER: No amperes flow through R_1.

You're about as wrong as you could be here, but it looks as if you may have been on the right path. Let's look at the circuit again; but we'll redraw it slightly so that you can see more plainly what is happening.



Apparently you remembered what we said about current -- in a parallel circuit, it divides. If you reasoned that since R_1 offered more resistance than R_2, and R_2 more than R_3, then the current would all go through R_3, you were closer than the answer indicates. It will turn out that R_3 will have a larger share in the total current, but don't rule out the other two entirely.

Return to Page 19 and choose again.

YOUR ANSWER: The circuits are all electrically identical.

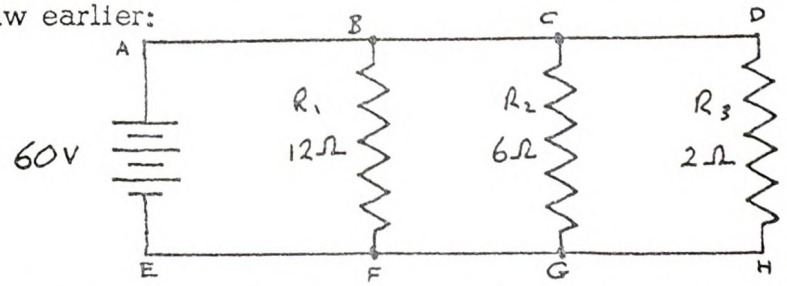
Well done. They are all circuits containing two resistors connected in parallel across a voltage source.

In a circuit containing more than one resistor, if it is possible to trace one end of each back to a single point on the path from the voltage source's negative pole and to trace the other end of each back to a common point on the path from the positive pole, the resistors are in parallel.

We'll investigate parallel circuits in more detail later on, but for the moment it is important that you understand this:

> In a series circuit, the voltage is divided between the several resistors and the voltage drops across the individual resistors add up to the total applied voltage.
>
> In a parallel circuit, the total voltage is applied to each resistor.

And to help fix this in your mind, here's the diagram you saw earlier:



Look at R_2, the resistor in the middle. What voltage is applied across R_2?

10 volts — Page 20

20 volts — Page 23

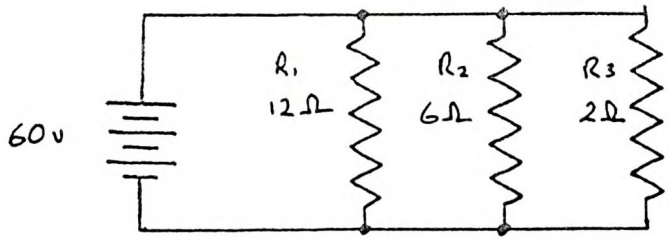
60 volts — Page 25

YOUR ANSWER: Each lamp in the parallel string has 110 volts applied, and there is a voltage drop of 11 volts across each lamp in the series string.

Yes. One of the most important characteristics of the parallel circuit is the fact that each device has the full voltage applied to it. This is quite different from the series hook-up where each device receives only a share of the voltage that left the power source.

Parallel circuits differ from series circuits when it comes to computing current, too. In a series circuit all of the current flows through each device in the circuit; each component has the same number of amperes through it. In a parallel circuit, the current is divided up, part going through one branch and part going through another.

Here is the parallel circuit we had before:



If a current of 45 amperes is leaving the battery, what can we say about R_1?

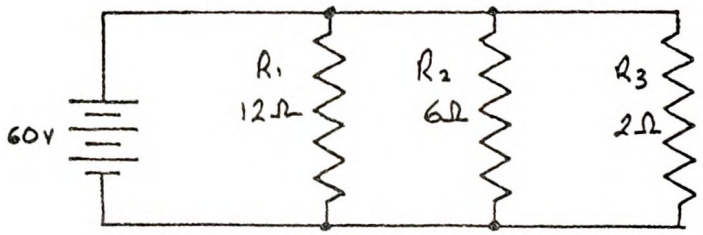
No amperes flow through R_1. Page 17

45 amperes flow through R_1. Page 22

Fewer than 45 amperes flow through R_1. Page 26

More than 45 amperes flow through R_1. Page 27

YOUR ANSWER: 10 volts.

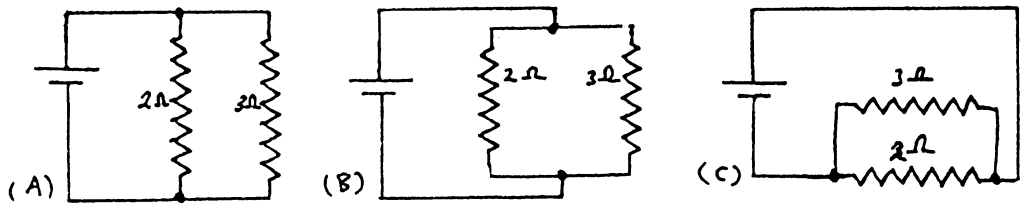


No. If you recall, we agreed that each resistor is connected directly to the power source, further, our last statement included: . . . the total voltage is applied to each resistor.

Return to Page 18 recheck these points and then choose the right answer.

YOUR ANSWER: The circuits are all electrically different.

Wrong. Let's look at the diagrams again:



The point we made about the earlier parallel circuits was that each resistor was electrically identical to its neighbors at the end connected to the negative pole of the power source and that, similarly, each was electrically identical to its neighbors at the other end, which was connected to the positive pole of the power source.

In the case of the above circuits, isn't it true that in each one there are two resistors? Isn't it true that in each circuit, each resistor is electrically identical at one end with the negative pole of the battery and at the other end with the positive pole of the battery? And doesn't this seem to make them fit the definition of parallel circuits?

These are indeed parallel circuits that are electrically identical. All that is different here is the way in which they are drawn.

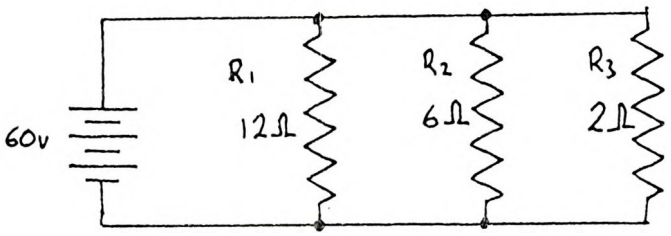
Return to Page 10 and select the correct answer.

YOUR ANSWER: 45 amperes flow through R_1.

You're way off here. How much flows through R_2 and R_3? We said current divides, that is, each resistor gets a share.

Return to and share the current in a more democratic fashion.

YOUR ANSWER: 20 volts.



No. If you recall, we agreed that each resistor is connected directly to the power source, further, out last statement included: . . . the total voltage is applied to each resistor.

Return to Page 18 recheck these points and then choose the right answer.

YOUR ANSWER: Each lamp in either string has 110 volts applied to it.

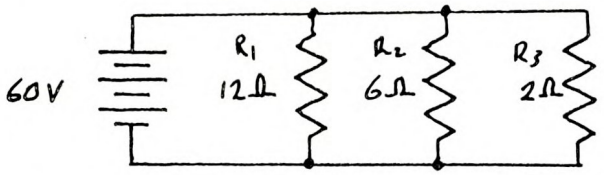
It sounds as though you were playing it cagey here, and thought you'd be at least half right. The trouble is you're also half wrong.

The same voltage is applied to each resistor in a parallel circuit. In this case, each lamp in the string has the full 110 volts applied to it.

In the series string, however, there will be a voltage drop of 110 volts for the whole circuit. It will be shared among all the components so that each lamp will have 1/10 of this total across it. Consider the second lamp in the string. Will it get a full 110 volts?

Return to Page 25 review the material until you're sure of yourself and then make another choice.

YOUR ANSWER: There are 60 volts applied across R_2.



Good. The size of the resistor doesn't affect the voltage applied in a parallel circuit. R_2 is connected directly to the power source, and the full EMF of the power source is being applied to it.

You could remove R_1 and R_3 from the circuit, and the flow of electrons would continue. But in a series circuit there would be no current if a device were removed, the circuit would be broken.

You have probably noticed this difference in strings of Christmas tree lights. It used to be that almost all of these lights were connected in series circuits. One burnt-out bulb would interrupt the whole circuit. The more recent light strings are connected in parallel circuits in which only a burned-out bulb will not light.

Let's say you have two strings of Christmas tree lights, one in parallel, the other in series. Each has 10 bulbs or lamps in it.

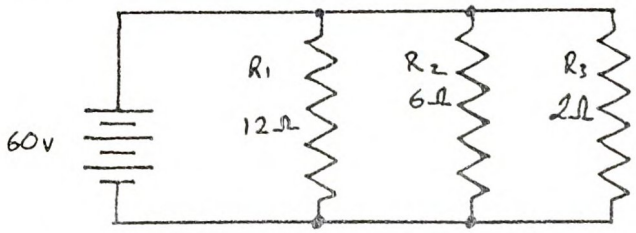
Which one of these statements is correct?

Each lamp in the series string has 110 volts applied to it, and there is a voltage drop of 11 volts across each lamp in the parallel string. Page 14

Each lamp in the parallel string has 110 volts applied to it, and there is a voltage drop of 11 volts across each lamp in the series string. Page 19

Each lamp in either string has 110 volts applied to it. Page 24

YOUR ANSWER: Fewer than 45 amperes flow through R_1.



Correct. When the current arrives at the resistors, it divides, some flowing through each resistor. You should expect current through each resistor since you know that the full 60 volts is applied to each resistor. Ohm's Law will tell you the current value. Of course, you would expect the current to prefer R_3 with just two ohms of resistance to the tougher going offered by R_1 and R_2. But some of the current will find its way through R_1 and R_2 as well. We will take that up in more detail later.

TURN TO PAGE 28 AND CONTINUE

YOUR ANSWER: There is more than 45 amperes flowing through R_1

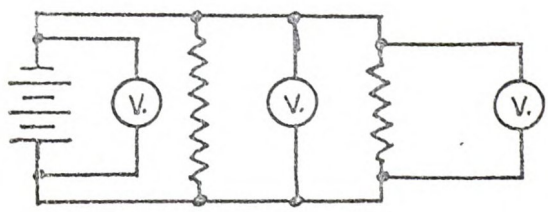
No. You're a bit confused here. When we said that the current is divided in a parallel circuit, we meant that each resistor would get only a portion of the total current. In a sense, germs multiply by dividing. You can't say that about current.

Go back to Page 19 and choose again.

CONTINUED FROM PAGE 26

In a simple parallel circuit the total voltage is applied to each branch of the circuit. Ordinary house wiring is all in parallel, and you can measure about 117 volts at every outlet.

In the circuit below, two resistors are connected in parallel across a power supply. There are also three voltmeters in the circuit. Are all the voltmeters parallel with the rest of the circuit?



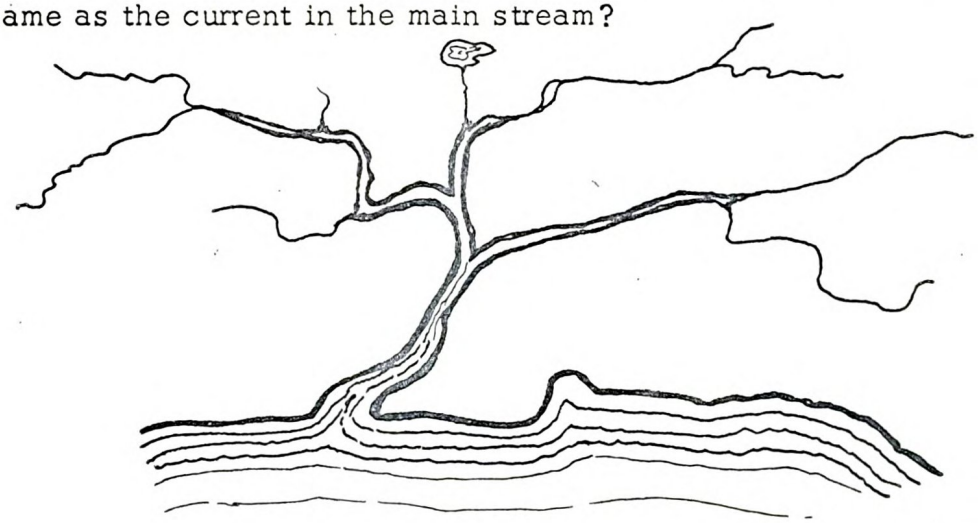
Yes Page 33

No Page 35

YOUR ANSWER: Yes, the same current is found at all points in a parallel circuit.

Electrical current in a circuit behaves in some ways very like currents of water in a river system.

Would you say that the current, that is, the flow of water in gallons per minute, was the same in all creeks, branches, runs, and other tributaries? And that each of these was the same as the current in the main stream?



Neither is it true of currents in parallel electrical circuits.

Go back now to Page 33 and find the better answer.

YOUR ANSWER: Yes, I_1 is larger than I_2.

Do you really believe that most of the current will go the hardest way, and only a little of it will take the short-cut through the easiest path?

Or, to go right back to basics, do you really believe that the branch with the fewest free electrons will conduct better than another path with many?

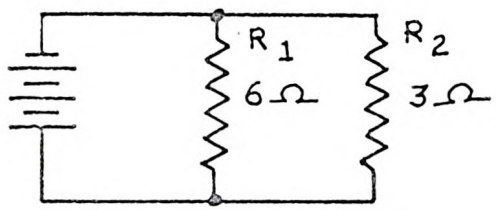
If you were driving from here to there (by yourself), would you take the longest, narrowest, crookedest streets with the most traffic on them, or would you prefer a freeway with no traffic congestion?

Better return to Page 36 and use common sense to find a better answer.

YOUR ANSWER: No, the same current is not found at all points in a parallel circuit.

Correct. The total current is divided between the various branches of the parallel circuit. As you would expect, more current will flow through a low-resistance branch than through a branch with higher resistance. However, each branch will carry some current.

In the circuit below we have two resistors in parallel:



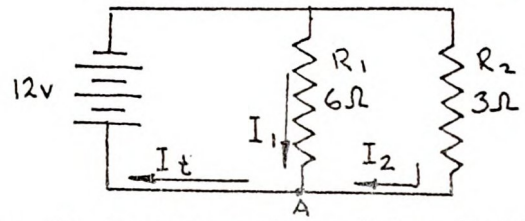
It's true to say that R_2 is in parallel with R_1 or vice versa. We may also say that each is in parallel with the power supply.

Sometimes we say that a component is "in shunt" with another component. This means about the same as being in parallel. A shunt is an electrical bypath, whereby the current divides and flows partly through the shunt and partly through the device that is shunted. We could say, for instance, that a voltmeter is shunted across a circuit for a voltage measurement.

In this circuit, then, R_2 is shunted across R_1. R_1 offers twice as much resistance to current as does R_2. Is the same voltage applied to each resistor?

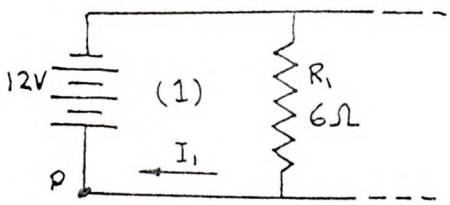
Yes Page 36
No Page 40

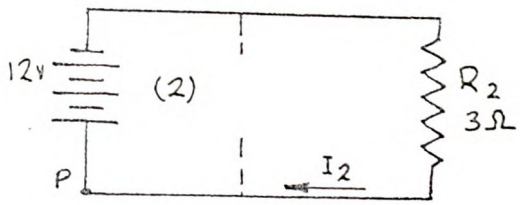
YOUR ANSWER: No, I_1 will not be larger than I_2.



You are right. R_1 is the larger resistor, but this means that it's easier for electrons to go through the other resistor. So you are correct in assuming that more current passes through the lower resistance, R_2. The fact that R_1 has twice the resistance doesn't mean that it gets left out altogether, though. Wherever there is a closed circuit available for electron flow, an EMF will cause some current, even if the resistance is very high.

Kirchhoff's second law (for voltage) says that the algebraic sum of all voltages around a closed circuit is zero. The circuit above actually contains two closed circuits. That is, there are two different paths that electrons may take on their way from the negative pole to the positive pole of the battery.

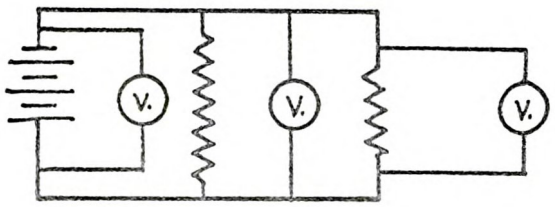




Starting from point P in each closed circuit, each circuit can be analyzed the same way: 12 - 12 = 0. There is just one voltage drop in each circuit. The current, too, can be figured for each circuit, using Ohm's Law. What current is flowing in each circuit?

I_1 = 1.33 amps	I_2 = 1.33 amps	Page 34
I_1 = 2 amps	I_2 = 4 amps	Page 38
I_1 = 4 amps	I_2 = 2 amps	Page 42
I_1 = 6 amps	I_2 = 3 amps	Page 43

YOUR ANSWER: Yes, all the voltmeters are in parallel with the rest of the circuit.



Correct. Each should give the same reading, for the total voltage in a simple parallel circuit is applied across each component. You can trace the wiring and see that each voltmeter is connected directly to the power supply.

So here's one important thing you must remember about parallel circuits: The voltage across each branch is equal to the voltage across every other parallel branch and to the voltage applied.

Is it also true that the same current is found in all parts of a parallel circuit?

Yes — Page 29

No — Page 31

YOUR ANSWER: $I_1 = 1.33a$, $I_2 = 1.33a$.

Does this mean that you believe that if they have a choice, as many electrons will go the hard way as will take the easy way?

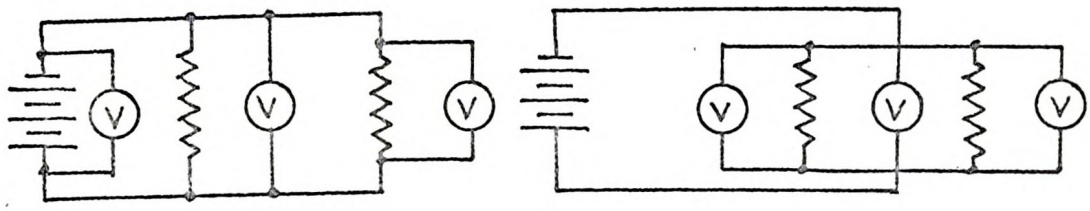
Or did you figure that Ohm's Law means that $I = \frac{12}{6}$ has the same answer as $I = \frac{12}{3}$?

Or did you just glance at the diagram so carelessly that you didn't really know what the question was?

Better return to **Page 32** and take a little more care.

YOUR ANSWER: No, not all the voltmeters are in parallel with the rest of the circuit.

Sorry, but you didn't look at the diagram carefully enough. Here's the same diagram repeated, then redrawn in a slightly different fashion:

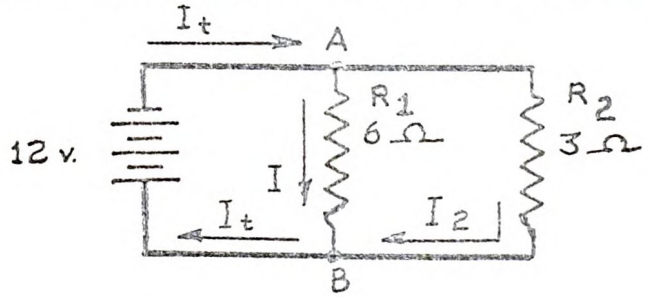


Look at the second and see whether all the meters are in parallel with all the resistors. Then carefully compare the second drawing with the first and make sure you see how they are actually electrically identical. Now return to Page 28 and answer the question correctly.

YOUR ANSWER: Yes, the same voltage is applied to each resistor.

Right. This is a characteristic of all parallel circuits. The same voltage is applied to each resistor, but the current divides some of it flowing through each resistor in the circuit.

If the total EMF is 12 volts, then this amount is applied to each resistor. We can say: $E_t = E_1 = E_2$. The voltage drop across each resistor is equal to the total applied voltage. If you study the circuit below, you will see that this is the same thing as saying that the total voltage is applied to each branch.



Kirchhoff's first law (for current) reminds us that there must be as much current flowing away from a point as there is flowing toward it. The total current, I_t, divides at point A. At point B, the current (I_1) flowing through R_1 meets the current (I_2) that has come from R_2. They add together and form the total current again. We may say: $I_t = I_1 + I_2$.

Is I_1 larger than I_2?

Yes — Page 30

No — Page 32

I don't know — Page 37

YOUR ANSWER: I don't know whether I_1 is larger or smaller than I_2.

Well, let's figure it out by Ohm's Law, $I = \frac{E}{R}$.

$E = 12v$ $R_1 = 6$ ohms Therefore $I_1 = \frac{12}{6}$, or 2 amps.

$E = 12v$ $R_2 = 3$ ohms Therefore $I_2 = \frac{12}{3}$, or 4 amps.

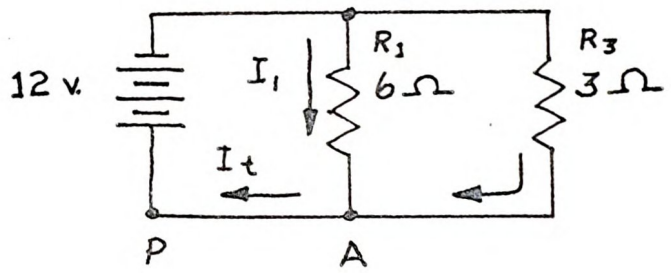
The only remaining problem to be solved is whether 2 is larger or smaller than 4!

We could put this another way: most of the electrons will take the easier way. R_2 must have more free electrons to carry the current than R_1; if it had fewer, its resistance would be higher, not lower than R_1. If R_2 has more free electrons, then the way is easier for current to flow through it than through R_1. If this is the easier way, then more current will flow this way.

Now go back to Page 36 and find the right answer.

YOUR ANSWER: I_1 = 2 amperes, I_2 = 4 amperes.

Yes, you can solve for current with the formula $I = \frac{E}{R}$ just as though these were two separate circuits. There is nothing "tricky" about it.



You have seen that the total current in the circuit can be found by adding together the currents through each branch, $I_t = I_1 + I_2$. So, in this case, adding 2 and 4 gives the total current of the parallel circuit, 6 amperes. There are 6 amperes of current passing through the battery.

Now use Ohm's Law to find the total resistance of the parallel circuit. What resistance does the battery encounter in moving 6 amperes of current?

2 ohms	Page 41
1/2 ohm	Page 44
3 ohms	Page 46

YOUR ANSWER: The resistance would increase.

If part of the way is made easier, it certainly won't make the total harder, will it?

Use the general rule you just learned: the total must now be less than 2 ohms (the value of the smallest resistor), but not less than 2/2 (the value of the smallest resistor divided by the number of resistors in parallel).

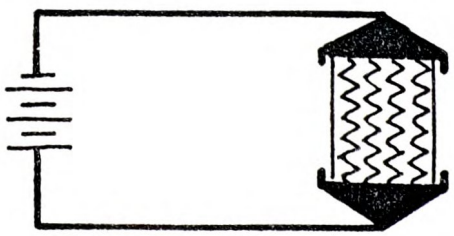
The limits considered in the last example were: not more than 3 ohms, not less than 3/2 ohms.

Now go back to Page 41 and choose the better answer.

YOUR ANSWER: No, the same voltage is not applied to each resistor.

Let's consider an ordinary composition resistor. This device is made of graphite mixed with clay, then fired the same as a brick would be. The result is many highly resistive paths of graphite of very small cross sectional area, separated by particles of non-conductive baked clay.

Here is a diagram of the internal electrical arrangement of such a device, connected to a battery through metal caps on the ends of the resistor:

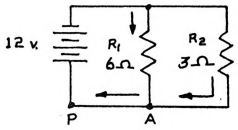


Now if you'll look very closely at the diagram, you will see a large number of resistances in parallel all connected in series with a source of EMF. Is the battery voltage applied to only one of these resistive paths? To only a few? Or is the same battery of the same voltage connected in the same way to all of the paths in parallel?

Sorry; you made a boo-boo on that one. Return to Page 31 and try again!

YOUR ANSWER: The total resistance of the circuit is 2 ohms.

Correct. Use the formula $R = \frac{E_t}{I}$. In this case, you will use $\frac{E_t}{I_t}$, and you may call your result R_t. Dividing 12 (volts) by 6 (amperes), you get 2 ohms for your answer.



It may be hard to believe that the total resistance of this parallel circuit is lower than either of the resistors. This is, however, a universal rule: The total resistance of parallel resistors is ALWAYS less than that of the smallest resistor. It is also NEVER less than the value of the smallest resistor divided by the number of resistors in parallel. The total resistance here, then, must be less than 3 ohms, but not less than 3/2 ohms.

Resistance, you remember, depends upon the cross-sectional area of the resistor (among other things). With two resistors in parallel there is a larger total cross-sectional area, so there is less resistance.

What would happen if you used a 2-ohm resistor instead of 3 ohms for R_2?

The resistance would increase. Page 39

The resistance would decrease. Page 45

YOUR ANSWER: $I_1 = 4a$, $I_2 = 2a$

The form of Ohm's law to use here is I = E/R.

In both circuits you have to use the same value for E, the 12 volts supplied by the battery.

To obtain I_1 you divide the voltage by 6 ohms. You arrive at I_2 by dividing the voltage by 3 ohms.

Won't this make the value of I_2 greater than the value of I_1?

And doesn't your answer show just the reverse of this, with I_1 greater than I_2?

Return to Page 32 and select your answer a little more carefully.

YOUR ANSWER: $I_1 = 6a$, $I_2 = 3a$.

The current in a circuit is **NOT** proportional to the resistance, it's INVERSELY proportional.

That means that the circuit with the highest resistance will have the lowest current.

Regardless of equations and arithmetic, plain common sense should tell you that the 6-ohm resistor will not pass twice as much current as the 3-ohm.

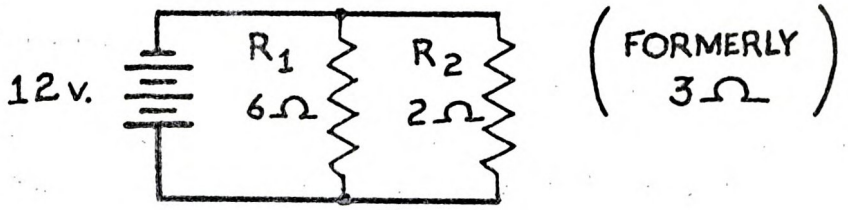
Please pay more attention to the question on Page 32 as you go over it again.

YOUR ANSWER: 1/2 ohm.

Oops! You slipped.

You divided current by voltage, instead of dividing voltage by current, as you should have. Maybe you just didn't look at the conditions of the problem carefully enough. Better take another look at Page 38 and make sure which number represents E and which I.

YOUR ANSWER: Putting in a 2-ohm resistor for R_2 would decrease the total resistance still more.



Yes, if all the current were forced through the 2-ohm resistor, there would just be 2 ohms of resistance in the circuit. But one-fourth of the total current goes through R_1. The effect is to lower the total resistance of the circuit below 2 ohms.

We usually speak of this total resistance as the <u>equivalent resistance</u> of the circuit.

See if you can figure out the equivalent resistance of this new circuit with its 6-ohm and 2-ohm resistors in parallel. You already know that 2 amperes are flowing through the 6-ohm resistor, R_1. That has not been changed, and the same current is still flowing. But more current will now flow through R_2, for it has less resistance.

Calculate the new value of I_2, I_t, and R_t (the equivalent resistance).

$I_2 = 4$ amps, $I_t = 6$ amps, $R_t = 2$ ohms Page 47

$I_2 = 8$ amps, $I_t = 10$ amps, $R_t = 1.2$ ohms Page 49

$I_2 = 6$ amps, $I_t = 8$ amps, $R_t = 1.5$ ohms Page 52

YOUR ANSWER: 3 ohms.

Now that's too bad; you got an answer that would have been right if the problem had applied only to the right-hand half of the circuit.

But you'll never get a good grade by finding the right answer to the wrong question. Better take another look at Page 38 and see if you can see all the problem.

YOUR ANSWER: $I_2 = 4$ amps, $I_t = 6$ amps, $R_t = 2$ ohms.

No.

It looks as if you used the same value, 3 ohms, for this problem, as was given for the previous one. When we changed the resistor, though, the problem was also changed.

Return to Page 45 and use the correct values to work out a better answer.

YOUR ANSWER: 1/12 + 1/6.

No.

You've apparently added the reciprocal of the voltage to the reciprocal of one resistance value.

If you added 1/12 of an orange to 1/6 of a dollar, how many children would you have? Let's return to Page 52 and stick to one subject at a time.

YOUR ANSWER: $I_2 = 8$ amps, $I_t = 10$ amps, $R_t = 1.2$ ohms.

Somehow you must have added the current through that 6-ohm resistor twice. Watch your step a little more carefully and you'll have a better chance of finding the right answer to such problems as this on Page 45

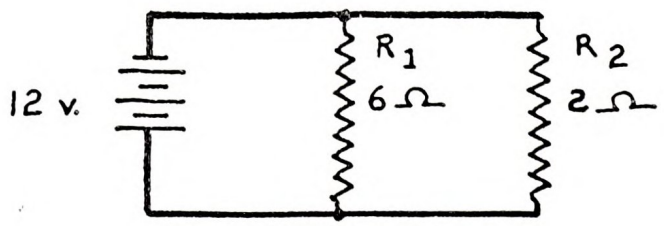
YOUR ANSWER: You should add the fractions $\frac{1}{6} + \frac{1}{2}$ to get $\frac{1}{R_t}$.

Yes, the formula is: $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}$

This is the reciprocal formula for finding the equivalent resistance of a parallel circuit.

As you remember, the reciprocal of a whole number is that number divided into one. The reciprocal of 2 is 1/2, the reciprocal of 4 is 1/4, etc.

The reciprocal formula for finding the equivalent resistance of a parallel circuit is: The reciprocal of the equivalent resistance is equal to the sum of the reciprocals of all the resistances in parallel.



When you add the reciprocals of the two resistors in parallel above, what is the result?

1/8 Page 53

2/3 Page 55

YOUR ANSWER: 2

You must have worked the problem correctly, but you went too far.

You were asked the sum of the reciprocals, not the total resistance.

Try Page 55 again and stop when you have answered the question asked.

YOUR ANSWER: $I_2 = 6$ amps, $I_t = 8$ amps, $R_t = 1.5$ ohms.

Correct. The equivalent resistance is still lower than the smaller of the two resistors, which had a value of 2 ohms.

There's a fairly simple way to find the equivalent resistance of two known resistors in parallel -- even when you don't know voltage or current. We come up with this formula by some algebraic jiggling of Ohm's Law. Follow these equations carefully.

$$I_1 = \frac{E_1}{R_1}; \quad I_2 = \frac{E_2}{R_2}; \quad I_t = \frac{E_t}{R_t}$$

And, since $I_t = I_1 + I_2$, then

$$\frac{E_t}{R_t} = \frac{E_1}{R_1} + \frac{E_2}{R_2}$$

Now in a parallel circuit, $E_t = E_1 = E_2$. So, $\frac{E}{R_t} = \frac{E}{R_1} + \frac{E}{R_2}$.

Divide by E and you get

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}, \text{ or } R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}.$$

So as you can see, you can find the total resistance by standing each resistance value on its head, adding the resulting fractions, $\frac{1}{R_1} + \frac{1}{R_2}$, and then standing the fractional sum back on its feet.

If $R_1 = 6$ ohms, $R_2 = 2$ ohms, and $E = 12$ volts, what fractions should be added together to find $\frac{1}{R_t}$?

$\frac{1}{12} + \frac{1}{6}$ Page 48

$\frac{1}{6} + \frac{1}{2}$ Page 50

YOUR ANSWER: 1/8

Please, we don't add the numbers and then find their reciprocal; we find each reciprocal and then add these reciprocals, which gives an entirely different sum.

Return to Page 50 and try it the right way.

YOUR ANSWER: 37/63 ohms

Oh-Oh, you've slipped!

Your answer gives the sum of the reciprocals, not the total resistance.

You've got to find the reciprocal of that sum of the reciprocals to get the right answer to that problem on page 61

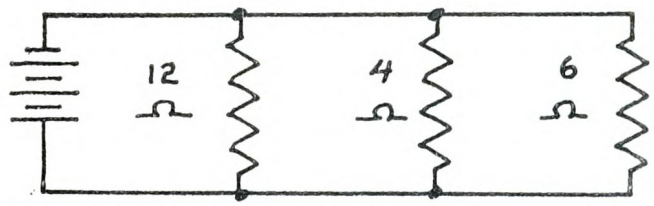
YOUR ANSWER: The sum of the reciprocals of the two resistors is 2/3.

Right. To add 1/6 and 1/2, you first change 1/2 into 3/6 and then your total will be 4/6 or 2/3. This fraction is not the answer to the problem, but it is equal to the reciprocal of the equivalent resistance.

We now have: $\frac{1}{R_t} = \frac{2}{3}$. To solve for R_t we just invert our two fractions:

$$R_t = \frac{3}{2} \quad \text{or} \quad 1.5$$

Now use the reciprocal formula for R_t in this three-resistor circuit.



What is the sum of the three reciprocals?

2	Page 54
1/2	Page 57
7/12	Page 59

YOUR ANSWER: $R_t = 76.9$ ohms.

Yes, the sum of the reciprocals is 13/1000, and when you invert and divide 13 into 1000, you get the answer above.

When you have only two resistors in parallel, you can use a simpler version of the reciprocal formula. The formula as we have had it so far is:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}$$

To simplify this, first, add the two reciprocals together, using $R_1 \times R_2$ for a common denominator:

$$\frac{1}{R_t} = \frac{R_2}{R_1 \times R_2} + \frac{R_1}{R_1 \times R_2}$$

The result is:

$$\frac{1}{R_t} = \frac{R_2 + R_1}{R_1 \times R_2}$$

And when you invert both sides of the equation, you get this simplified form:

$$\frac{R_t}{1} = R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

As you can see, all you have to do is divide the sum of the two resistances into their product.

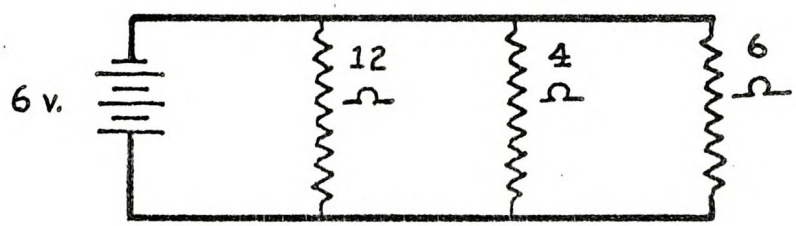
Use this simplified formula to find the equivalent resistance of two resistors in parallel, one 6 ohms and the other 4 ohms.

Which equation below follows the formula?

$R_t = \frac{12}{5}$ Page 62

$R_t = \frac{5}{12}$ Page 65

YOUR ANSWER: The sum of the reciprocals is 1/2.



Correct. You use 12 for the common denominator, and you can form the following fractions from the reciprocals: 1/12, 3/12 and 2/12. The total, 6/12, can be reduced to 1/2. Any number of resistors in parallel may be handled this way.

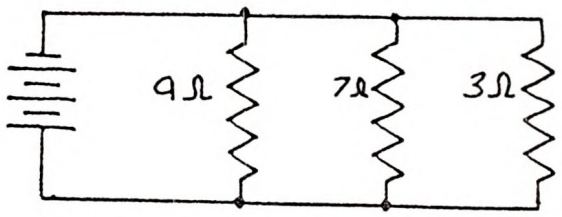
To check your answers you can use this reciprocal of the general rule for resistors in parallel: The sum of a number of fractions is always larger than the largest fraction, but never larger than that largest fraction multiplied by the number of fractions. The answer above, then, must be more than 1/4 but not more than 3/4.

Now complete the solution for R_t in the circuit above, and figure out the total current flow through the 6-volt battery.

3 amps Page 61

12 amps Page 63

YOUR ANSWER: R_t is 1.7 ohms.



Correct. The sum of the reciprocals is 37/63. This is equal to the reciprocal of R_t, or, to put it mathematically:

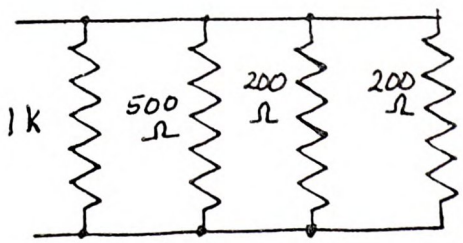
$$\frac{1}{R_t} = \frac{37}{63}$$

Inverting both sides, we get:

$$\frac{R_t}{1} = R_t = \frac{63}{37}$$

And when 37 is divided into 63, we get 1.7 ohms approximately.

The reciprocal formula will work for any number of resistors in parallel. Figure out the equivalent resistance of the four-resistor circuit below:



76.9 ohms Page 56

130 ohms Page 64

YOUR ANSWER: 7/12

Handling three reciprocals at once is a little more confusing, isn't it? You must have figured that 4/12 is the equivalent of 1/4.

Try Page 55 again and be a little more careful with your fractions.

YOUR ANSWER: The equivalent resistance is 8.77 ohms.

Ouch!

It looks as if you picked the answer that seemed to fall within the limits of the general rule.

But . . .

The resistors you were considering had values of 13K and 27K. That is to say, they had values of 13,000 ohms and 27,000 ohms.

$$K = 10^3 = 1000$$

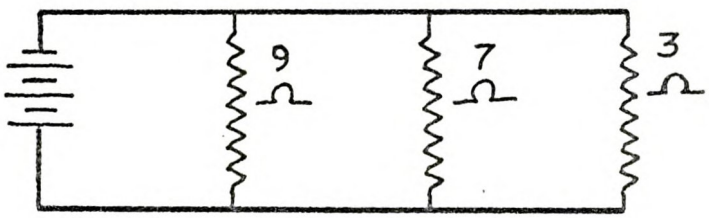
That letter K makes a difference.

Return to Page 66 and this time figure the problem a little more carefully, using powers of ten.

YOUR ANSWER: There will be 3 amperes of current in the battery.

Yes. R_t (the equivalent resistance) is 2 ohms. Therefore, the current in the battery ($I = E/R$) = $6/2$ = 3 amps.

Now let's try one where the arithmetic is less simple.



By multiplying 9 and 7 together we get 63 which will serve as a common denominator for the three reciprocals. We have:

$$\frac{1}{R_t} = \frac{1}{9} + \frac{1}{7} + \frac{1}{3}$$

When we use our common denominator:

$$\frac{1}{R_t} = \frac{7}{63} + \frac{9}{63} + \frac{21}{63}$$

What is the equivalent resistance (R_t) of the circuit above?

37/63 ohm Page 54

1.7 ohms Page 58

YOUR ANSWER: 12/5

Right. The correct equation is:

$R_t = \frac{6 \times 4}{6 + 4} = \frac{24}{10} = \frac{12}{5}$ which is equal to 2.4 ohms.

If you ever get mixed up on which computation comes first, just remember to

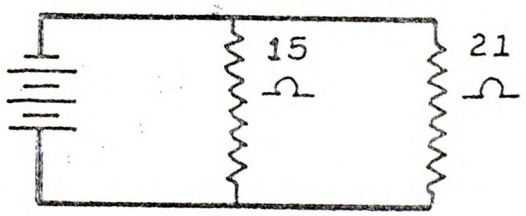
Multiply
Add

then

Divide

and get M A D!

Now try it with two larger resistors as in the circuit below.



What is the equivalent resistance of this circuit?

8.75 ohms Page 66

9.25 ohms Page 67

11.5 ohms Page 70

YOUR ANSWER: 12 amperes.

It looks as if you didn't set that 1/2 back on its feet again, to get the total resistance, before you divided.

Remember, what you did to find that value of one-half was simply to add all the individual reciprocals. That gave you $1/R_t$, not R_t itself. What is the reciprocal of $1/R_t$?

When you think you know, try Page 57 again.

YOUR ANSWER: 130 ohms.

No.

Let's get this thing straight: The total resistance of resistors in parallel is the reciprocal of the sum of the reciprocals.

You apparently remembered the general rule for resistors in parallel, but you had to doctor your answer by shifting the decimal point to make it stick.

The trouble was that you forgot to find that final RECIPROCAL of the sum.

Now try Page 58 again, and do it right; then you won't have to juggle a decimal point to be within the limits of the general rule.

YOUR ANSWER: 5/12

No.

It looks as if you tried to use the reciprocal formula instead of this simplified form:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

Or did you add for the numerator and multiply to find the denominator?

Whatever the reason, you had better return to Page 56 and do it the right way.

YOUR ANSWER: R_t is 8.75 ohms.

Correct. Put your numbers in this form: $R_t = \frac{15 \times 21}{15 + 21}$. and the result is the equivalent resistance of these two resistors in parallel.

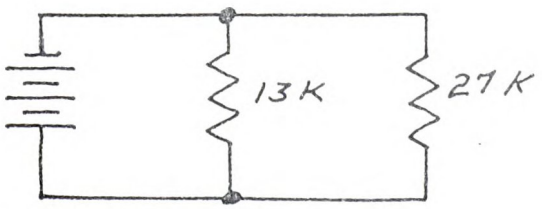
This simplified formula will work for any number of resistors if you work out the equivalent resistance for each pair, then use the same formula again for pairs of totals, and again for pairs of pair equivalents, etc. The job becomes rather complicated for more than two resistors, though.

With only four resistors in parallel, the complete equation looks like this:

$$R_t = \frac{\frac{R_1 \times R_2}{R_1 + R_2} \times \frac{R_3 \times R_4}{R_3 + R_4}}{\frac{R_1 \times R_2}{R_1 + R_2} + \frac{R_3 \times R_4}{R_3 \times R_4}}$$

And for twice as many resistors the formula becomes four times as large as that. Obviously, the simplified formula isn't very practical in such cases.

In the circuit below we have only two resistances; a 13K resistor shunted across a 27K resistor.



What is the equivalent resistance in ohms?

8.77 ohms Page 60

8780 ohms Page 68

877 ohms Page 74

YOUR ANSWER: 9.25 ohms.

This is sheer guesswork, and not a lucky guess at that!

It's close, but not nearly close enough.

Return to Page 62 and actually do some arithmetic on this problem.

YOUR ANSWER: R_t is 8780 ohms.

Yes, this is the result rounded off to three significant figures.

There is another short cut available if all the resistors in parallel are equal. To find the total resistance for any number of equal resistors connected in parallel, divide the resistance of one resistor by the number of equal resistors.

This can be expressed: $R_t = \frac{R_1}{N}$, where R_1 is the resistance of one resistor, and N is the number of resistors.

This is simple enough to figure out, if you consider what happens in a parallel circuit containing N resistors all of equal value. The basic formula for resistors in parallel gives you:

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_1} + \frac{1}{R_1} \ldots . \text{(N times)}} = \frac{1}{\frac{N}{R_1}}$$

and that, of course, is the same as:

$$R_t = \frac{R_1}{N}$$

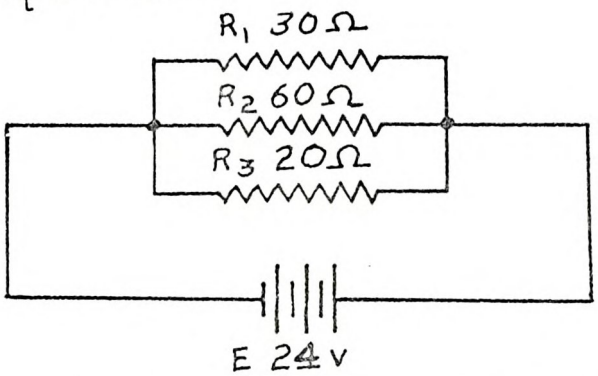
If you have five 10-ohm resistors, you may just divide 10 by 5, to get R_t = 2 ohms.

What would be the equivalent resistance of six 30-ohm resistors in parallel?

5 ohms Page 71

$\frac{1}{5}$ ohms Page 73

YOUR ANSWER: R_t is 10 ohms.



Correct. There are several ways to solve this problem. You could have added the reciprocals, used an assumed voltage (60 volts is the least common multiple), or you could have figured out the actual current through each branch and added the currents to get I_t so as to use Ohm's law.

If you don't need to know the current through each branch, it's easiest to calculate the equivalent resistance first.

Using the reciprocal formula or the assumed voltage method, we find that R_t is 10 ohms. Ohm's law (using $I = E/R$) then shows that 2.4 amperes will flow with 24 volts applied.

Now calculate the current through each branch. Which list below is correct?

I_1 = 0.8 amp	I_1 = 0.8 amp
I_2 = 0.4 amp	I_2 = 0.4 amp
I_3 = 0.12 amp	I_3 = 1.2 amp

YOUR ANSWER: 11.5 ohms

You not only forgot the whole MAD idea, but you juggled the decimal point to make your wrong answer come within the limits of the general rule.

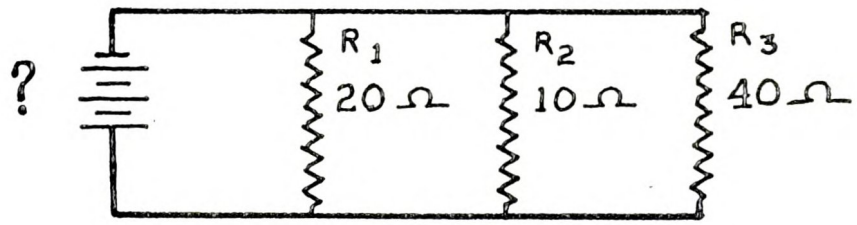
Maybe you'd better remember that two wrong procedures don't make a right answer.

Now try Page 22 again.

YOUR ANSWER: The equivalent resistance of six 30-ohm resistors in parallel would be 5 ohms.

Right. To find the total resistance of any number of equal resistors connected in parallel, you just divide the number of resistors into the value of any one of them.

Many of our problems of finding the equivalent resistance have included no reference to the power supply in the circuit. Sometimes it's possible to solve a parallel circuit for resistance by <u>assuming</u> that a certain voltage is applied. Then you figure out what current would flow in each branch if such a voltage were applied, add the currents to get the total current, and then divide the total current into the <u>assumed</u> voltage to find R_t. All of this is much less complicated than it may seem. Let's try an example.



For this circuit, let's say that 80 volts are applied across the resistors. It doesn't matter whether this voltage is actually applied or not. We will still be able to calculate R_t by using this (or any other) value. If the EMF were 80 volts, what would be the current through each branch?

$I_1 = 4$ amps, $I_2 = 0.8$ amp, $I_3 = 2$ amps Page 75

$I_1 = 4$ amps, $I_2 = 8$ amps, $I_3 = 2$ amps Page 76

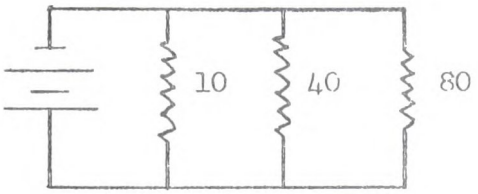
YOUR ANSWER: 17.4 ohms.

That's right. You could also have solved this by the reciprocal formula, or you could have figured up the actual current from the 3.9-volt battery.

Using the 3.9 volts shown would have made the problem much more complicated than necessary, of course. The assumed voltage method is much more convenient in a case like this.

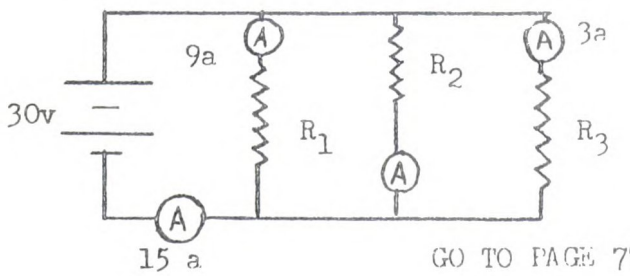
If you assume a voltage of 400, you get 5 amperes through the 80-ohm resistor, 8 amperes through the 50-ohm resistor, and 10 amperes through the 40-ohm resistor. Added together, the total current is 23 amperes. Divide this into 400 (the assumed voltage) and you get 17.4 ohms.

NOW, TRY THESE PROBLEMS:



R_t =

1. 130 ohms
2. 8 ohms
3. 26.6 ohms
4. 7.2 ohms



I_2 =

1. 12a
2. 6a
3. 3a
4. 4a

GO TO PAGE 77 AND CONTINUE

YOUR ANSWER: 1/5 ohm

Sorry; that's the result of dividing 6 by 30, but 6/30 is not the correct quotient.

To find the total resistance of any number of equal resistors connected in parallel, divide the resistance of one resistor by the number of equal resistors. $R_t = \frac{R_1}{N}$

Now return to Page 68 and follow instructions more carefully.

YOUR ANSWER: 877 ohms.

Well, the digits are nearly right, but the decimal point is in the wrong place.

Perhaps you worked out the problem almost correctly then fooled yourself into thinking that, since 8770 seemed to be about right as far as digits go, the only answer containing those figures, 877, was the right one.

A little more arithmetic would have shown that the answer is actually 8775, not 877.0.

Try Page 66 again, and watch those decimals.

YOUR ANSWER: $I_1 = 4$ amps, $I_2 = 0.8$ amps, $I_3 = 2$ amps.

Sorry, that's not right. It can't possibly be right. You'll find that R_2 has only 1/4 the value of R_3. That means R_2 must pass 4 times as much current as R_3, and 4 x 2 is certainly not 0.8.

Return to Page 71 and try again.

YOUR ANSWER: $I_1 = 4$ amps, $I_2 = 8$ amps, $I_3 = 2$ amps.

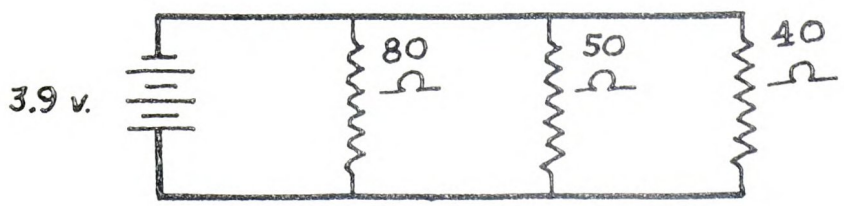
Correct. It doesn't matter whether these currents actually flow or not, so long as you are trying to find total resistance. NOT total current.

Adding these branch currents together, $I_t = 14$ amperes. Using $R = \frac{E}{I}$, dividing 14 into the "imaginary" 80 volts, gives 5.71 ohms.

This is the actual value of R_t, even though you may have used an incorrect voltage in your calculations.

If you want to check this result using the reciprocal formula, add your reciprocals and you will get 7/40. Invert and divide and you will still get 5.71 ohms.

This is the <u>assumed voltage</u> method of finding the equivalent resistance of a parallel circuit. When you use this method, it's always best to choose a voltage higher than your largest number of ohms, so that you can avoid current values of less than one.



Pay no attention to the voltage given in this schematic, but choose some other convenient voltage to figure R_t by the assumed voltage method. What is R_t?

17.4 ohms Page 72

17.6 ohms Page 78

PARALLEL CIRCUITS

You should by now have these points about parallel circuits firmly fixed in your mind:

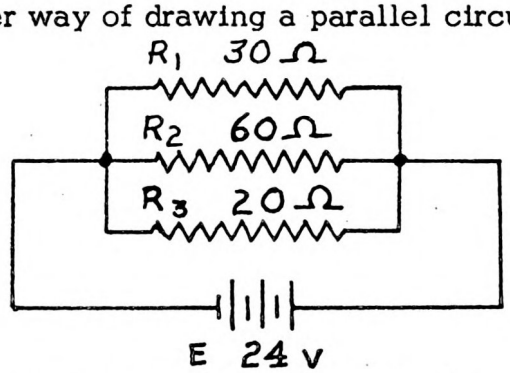
(1) The applied voltage is the same for all branches of the circuit.

(2) The total current is divided among the branches.

(3) The lower the resistance in a branch, the greater the "share" of the current in that branch.

(4) The equivalent resistance of a parallel circuit is always less than the value of the smallest resistor, but not less than that value divided by the total number in parallel.

Before we go further with parallel circuits, look at this diagram. This is just another way of drawing a parallel circuit, of course.



Three resistors are in parallel with each other and the group is in series with the power supply. Using any method you want, find the value of R_t.

10 ohms Page 69

12 ohms Page 82

YOUR ANSWER: 17.6 ohms.

No, your arithmetic slipped somewhere, or you were guessing.

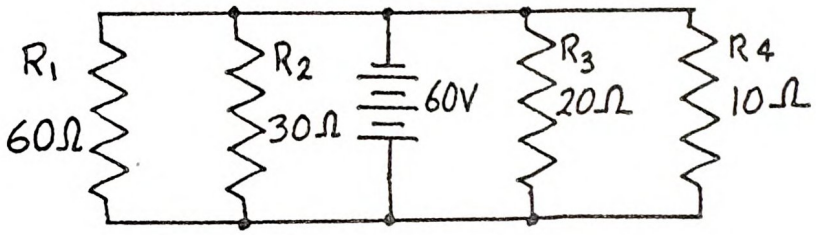
Perhaps you made the problem harder than necessary by your choice of an assumed voltage.

The Least Common Multiple of the resistances is a good number to use here; then you don't have any fractional amperes to deal with.

Try Page 76 again, using that multiple.

YOUR ANSWER: $I_1 = 0.8A$, $I_2 = 0.4A$, $I_3 = 0.12A$.

You were doing well until your arithmetic broke down. Check your figures again and then return to Page 69 and get the correct answer.

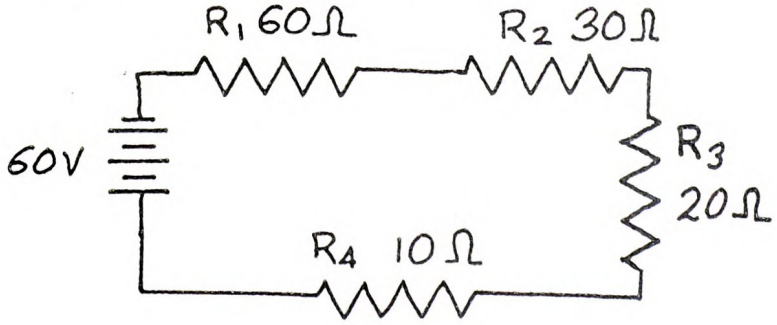


YOUR ANSWER: R_t = 5 ohms.

Yes, the sum of the reciprocals is 12/60, and when you invert this fraction, it becomes 5.

We'll say that the power supply is rated at 60 volts. Now you can quickly figure the current through the power supply and through the individual resistors.

Here are the same four resistors and the same power source, but now they are connected in series:



Is the same amount of power expended in each circuit?

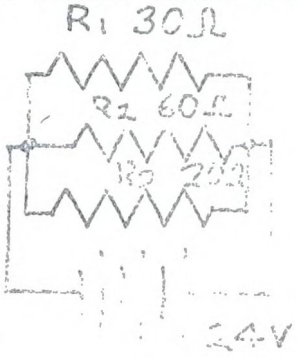
Yes — Page 88

No — Page 91

YOUR ANSWER: P_{R_1} = 19.2 watts, P_{R_2} = 9.6 watts, P_{R_3} = 28.8 watts.

Correct. Let's review the solution for R_1, 30 ohms. You could have used P = EI (24 x 0.8), $P = I^2R$ (0.8 x 0.8 x 30), or $P = \frac{E^2}{R}$ ($\frac{24 \times 24}{30}$). All of these give you the same value for P_{R_1}: 19.2 watts.

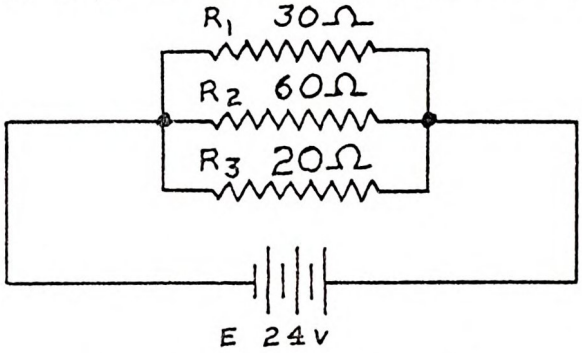
Adding together the power demands of all three resistors, we get 19.2 + 9.6 + 28.8 = 57.6 watts. Make a note of that figure.



You have seen that the total current from the power supply is 2.4 amperes. Using P = EI, what is the total power drawn from the power supply?

YOUR ANSWER: 12 ohms.

Wrong. Either you're guessing or your arithmetic is simply shocking.



You have three resistors in parallel with each other and with the power supply. You are asked to find the value of R_t -- the total resistance -- and you may use any method you want.

Perhaps the easiest approach is to use the reciprocal formula

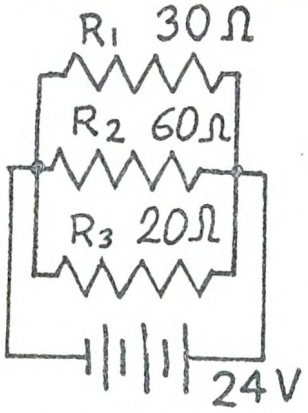
$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

But you can use the assumed voltage method, or, using the values given, figure the current in each branch and then use Ohm's law to get your answer.

That should be enough to put you back on the right track so that you can return to Page 77 and select the correct answer.

YOUR ANSWER: I_1 = 0.8 amp, I_2 = 0.4 amp, I_3 = 1.2 amp.

Yes, the current through the three branches must add up to 2.4 amperes, the total current that should flow through the power supply. You have already calculated the equivalent resistance of the circuit at 10 ohms.



You may need to know the amount of power used up in each resistor. Use any form of the power formula (since you now know the values of volts, ohms, and amperes for each resistor) and find the amount of power expended in each resistor.

1	2	3
P_{R_1} = 19.2 watts	P_{R_1} = 19.4 watts	P_{R_1} = 19.6 watts
P_{R_2} = 9.6 watts	P_{R_2} = 9.4 watts	P_{R_2} = 9.2 watts
P_{R_3} = 28.8 watts	P_{R_3} = 28.8 watts	P_{R_3} = 28.8 watts

Page 81 Page 85 Page 90

YOUR ANSWER: 56.6 watts.

Oh, come, now; 2.4 (amperes) times 24 (volts) certainly does not equal 56.6 (watts).

This answer makes it look as if you're not bothering with calculations. You should actually do this arithmetic. Then, unless it's horribly bad, you'll get better answers than the one above.

Even more to the point, you'll get closer to understanding what you're doing, and that is vital at this stage. If the foundations of your learning are wobbly, you're not going to be able to build on them.

Return to Page 81 and use a piece of paper and a pencil this time.

YOUR ANSWER: $P_{R_1} = 19.4$ watts, $P_{R_2} = 9.4$ watts, $P_{R_3} = 28.8$ watts.

Don't look now, but your arithmetic is slipping. Either that, or you're just guessing. There shouldn't be any need to guess. Surely by this time you know the equations?

$$P = EI$$
$$P = I^2R$$
$$P = E^2/R$$

Return to Page 83 and do a little accurate figuring.

YOUR ANSWER: 3.75 ohms.

You slipped a little in converting one of those reciprocals to a common denominator. You know the principles; you've done it right before; you can do it right again.

So do it!

Return to Page 89 and try.

YOUR ANSWER: $P_{R_1} = 60$ W, $P_{R_2} = 30$ W, $P_{R_3} = 20$ W, $P_{R_4} = 10$ W.

And your answer is wrong.

In a parallel circuit, the voltage is the same across each branch. The smallest resistor will have the most current flowing through it.

And multiplying that current by the voltage will give the highest power for the smallest resistor.

But you have the highest power listed with the biggest resistor.

Return to Page 94 and check your calculations. You should use the formula $P = E^2/R$.

YOUR ANSWER: Yes, the same amount of power is expended in each circuit.

That's just a guess, and not a very good one.

You don't even need to do the arithmetic on this one. For instance:

$$P_t = \frac{E_t^2}{R_t}$$

E_t, and hence E_t^2, is the same in both circuits.

But in the series circuit, R_t is larger than the largest resistance, whereas in the parallel circuit it is smaller than the smallest.

So how can the two different answers, whatever they are, be the same?

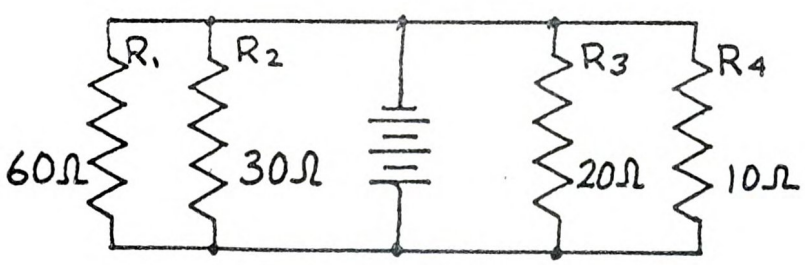
Think about it -- you're going to have to think some more about it in a minute, anyway -- and then return to Page 80 and try again.

YOUR ANSWER: The power supply produces 57.6 watts.

Correct. This brings us to another characteristic of parallel circuits: The total power used up in the circuit is equal to the sum of the quantities of power expended in the branches.

A similar statement was made of series circuits, you may recall. In series and parallel circuits alike, the total power expended is equal to the sum of the amounts of power used in each component.

Below are four resistors in a circuit. This is another simple parallel circuit -- each resistor has one end connected to one side of the power source and the other end connected to the other side of the power source. You may find parallel circuits shown in many different ways, but the important thing is to see how the resistances are connected to the power source.



What is the equivalent resistance of this circuit?

5 ohms Page 80

3.75 ohms Page 86

YOUR ANSWER: $P_{R_1} = 19.6$ watts, $P_{R_2} = 9.2$ watts, $P_{R_3} = 28.8$ watts.

A wild guess is no worse than this tame one. If it isn't just a guess, you need to review your arithmetic, or your knowledge of formulas, or your application of them. Here are the formulas again:

$$P = EI$$

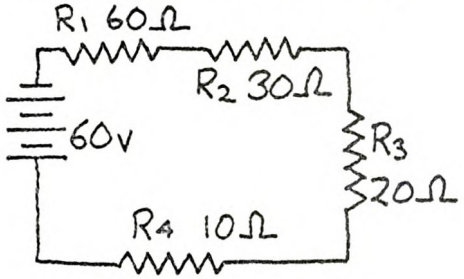
$$P = I^2R$$

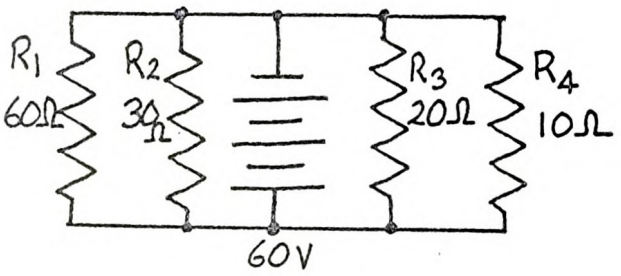
$$P = E^2/R$$

Now, return to Page 83 and make a better try.

YOUR ANSWER: No, the same amount of power is not expended in each.

Right. The parallel circuit offers much less resistance, so there is much more current than there is in the series circuit. Therefore, there will be much more power expended in the parallel circuit.





The total amount of power expended in either circuit can be found by adding together the amounts of power used in the various components. This is true for series and parallel circuits alike, but it doesn't mean that the same total power is used whether the components are in series or in parallel.

What amounts of power are used in each of the resistors connected in series?

P_{R_1} = 15 watts

P_{R_2} = 7.5 watts

P_{R_3} = 5 watts

P_{R_4} = 2.5 watts

Page 94

P_{R_1} = 60 watts

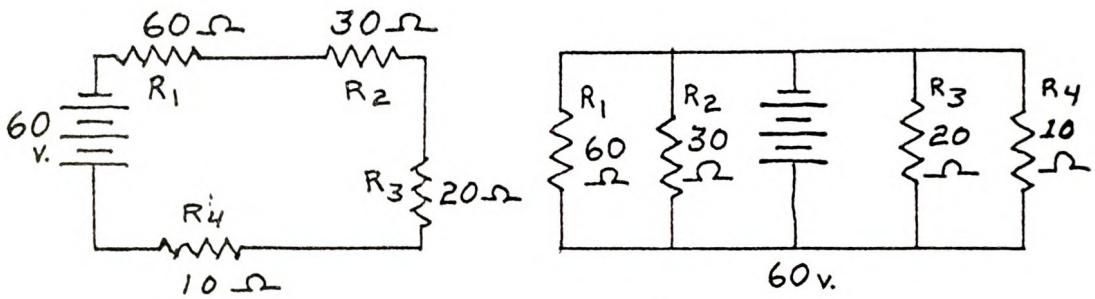
P_{R_2} = 30 watts

P_{R_3} = 20 watts

P_{R_4} = 10 watts

Page 98

YOUR ANSWER: The amounts of power expended by the four resistors in the parallel circuit are (in numbered order) 60 watts, 120 watts, 180 watts, and 360 watts.



Right.

The best form of the power formula for this problem is $P = \frac{E^2}{R}$, since the voltage is the same across all branches of a parallel circuit. Even though a lot more power is expended in the parallel circuit, it is still true that the total power used by the circuit is equal to the sum of the amounts of power used in each component in the circuit.

R_t for this parallel circuit is 5 ohms. With an EMF of 60 volts thereeshould be 12 amperes of current. Using $P = EI$, the total power expended in the circuit is $60 \times 12 = 720$ watts, and this is equal to the sum of the values given in the answer.

Why is more power expended in resistors in parallel than in equal resistors in series?

Because there is a voltage drop across each resistor in the series circuit. Page 95

Because the combined resistance of the parallel circuit is much lower. Page 102

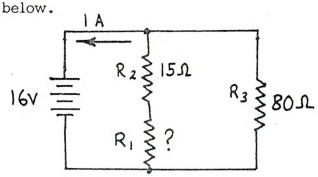
YOUR ANSWER: The largest resistance in a series circuit dissipates the most power, but the largest resistance in a parallel circuit dissipates the least power.

Correct. We can confirm this by using the formulas for power.

In the series circuit, the current is the same in all parts of the circuit. In the formula $P = I^2R$, since the value of I is constant throughout the circuit, the value of I^2 is constant, too. And if I^2 doesn't change in value, then the larger the resistor, the greater the value of P -- the more power used, if you like -- since I^2 is multiplied by a larger number.

In the parallel circuit, however, it is the voltage that doesn't change from one part of the circuit to another. Voltage is the same across each branch of the circuit. Using the formula $P = E^2/R$, E^2 is the same for each branch of the circuit. And if E^2 doesn't change in value, then the larger the resistor, the smaller the value of P -- the smaller the amount of power used.

Let's say you want to find the power dissipated by each of the three resistors below.



You'll need to know the value of R_1. As a first step, find the current through the 80-ohm resistor.

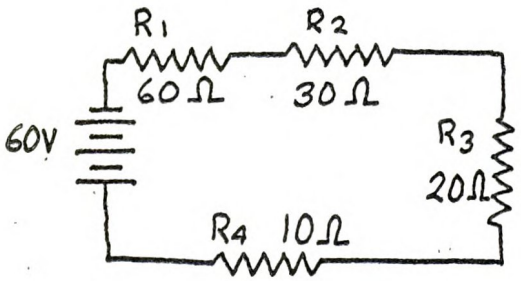
The current through the 80-ohm resistor is:

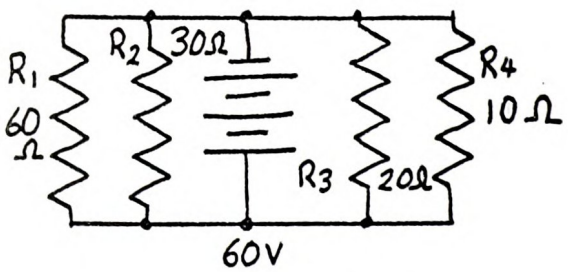
0.2 amp Page 96
0.5 amp Page 100
0.8 amp Page 103

YOUR ANSWER: The amounts of power expended by the four resistors in the series circuit are (in numbered order) 15 watts, 7.5 watts, 5 watts, and 2.5 watts.

Correct. And the total power used in this circuit is 30 watts. R_t for the series circuit, found by adding the resistors together, is 120 ohms. With 60 volts you know there is 60/120 = 0.5 ampere of current. You can then solve for each resistor using $P = I^2R$.

Note again: The total power used in the series circuit is equal to the sum of the amounts of power expended by each component.





Now calculate the amount of power used in each branch of the parallel circuit above. You will need a different form of the power formula, since the current will be different in each branch.

Which list below is correct?

$P_{R_1} = 60$ w
$P_{R_2} = 30$ w
$P_{R_3} = 20$ w
$P_{R_4} = 10$ w

Page 87

$P_{R_1} = 60$ w
$P_{R_2} = 120$ w
$P_{R_3} = 180$ w
$P_{R_4} = 360$ w

Page 92

YOUR ANSWER: More power is expended in resistors in parallel because there is a voltage drop across each resistor in a series circuit.

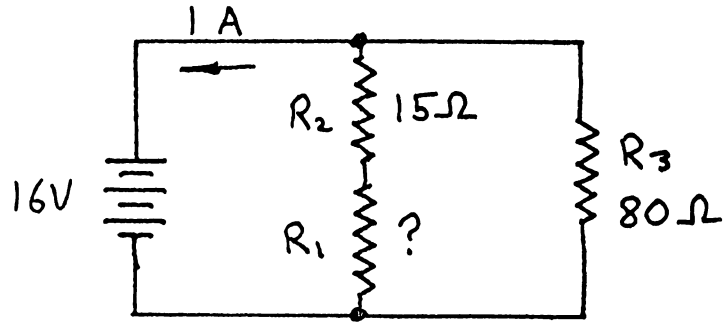
There certainly is a voltage drop across each resistor in a series circuit.

But it is also true that there is a voltage drop across each resistor in a parallel circuit, even though each of those voltage drops is the same.

So the reason you have chosen isn't really a reason. It's a misleading statement.

Now return to Page 92 and find an accurate statement.

YOUR ANSWER: 0.2 ampere flows through the 80-ohm resistor.



Yes. $I = E/R = 16/80 = 0.2$ amps. This leaves 0.8 ampere to flow through the other branch. Now you can use Kirchhoff's law to find the value of R_1. You know that there is a 16-volt drop across the inner branch with the two resistors, and that 0.8 ampere is flowing through this branch of the circuit.

What is the value of R_1?

20 ohms	Page 105
5 ohms	Page 108
0.2 ohm	Page 112

YOUR ANSWER: The largest resistor in a series circuit dissipates the least power, but the largest resistor in a parallel circuit dissipates the most power.

No. Let's go over it again.

- The largest resistor in a parallel circuit will carry the smallest current; the voltage is the same across each resistor of the circuit.

- The largest resistor in a series circuit has the largest voltage drop across it; but all the resistors in a series circuit carry the same current.

The largest resistor in a parallel circuit carries the smallest current; the largest resistor in a series circuit carries the same current as all the other resistors.

A small number multiplied by a fixed number isn't larger than a larger number multiplied by the fixed number, is it?

Yet that is what your answer seems to say. The fixed number is, of course, the value of the resistance; the number that varies is the value of current through the resistor.

Go over the points again and then return to Page 102 and reason out the accurate answer.

YOUR ANSWER: $P_{R_1} = 60$ W, $P_{R_2} = 30$ W, $P_{R_3} = 20$ W, $P_{R_4} = 10$ W.

In a series circuit, the power used up by each resistor is proportional to the resistance. The ratio of the resistances is 1 : 2 : 3 : 6. So:

R_3 must burn up twice as much power as R_4

R_2 must burn up three times as much as R_4

and R_1 must burn up twice as much as R_2.

$$I_t = \frac{E}{R_t} = \frac{60}{120} = 0.5 \text{ amps.}$$

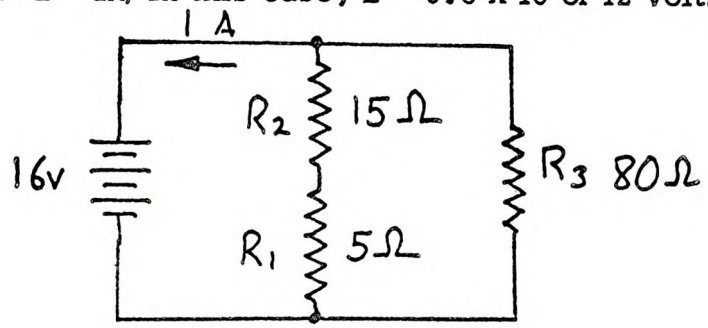
So $$P_{R_4} = I^2R = 0.5 \times 0.5 \times 10 = 2.5 \text{ watts.}$$

And the rest are in proportion, as shown above.

Figure them out and then return to Page 91 with the correct answer.

YOUR ANSWER: There is a 12-volt drop across the 15-ohm resistor.

Yes. E = IR; in this case, E = 0.8 x 15 or 12 volts.



Now calculate the power used by each resistor in the circuit.

Which resistor dissipates the most power?

The 5-ohm resistor Page 104

The 15-ohm resistor Page 110

The 80-ohm resistor Page 113

YOUR ANSWER: The current through the 80-ohm resistor is 0.5 amp.

No. Here's the way your calculation should have gone:

In a parallel circuit the voltage is the same across each branch. In this case, since there are no complications, the voltage across each branch is the voltage across the power source, 16 volts. The resistance, R_3, is given as 80 ohms.

$$I_3 = E/R = 16/80 = ?$$

That's simple enough. Maybe your approach was more complicated?

Complete the calculation and then return to Page 93 to select the correct answer.

YOUR ANSWER: The largest resistor in a circuit always dissipates the most power.

Not so.

In a series circuit, all resistors carry the same current. So I^2R will be largest for the largest R.

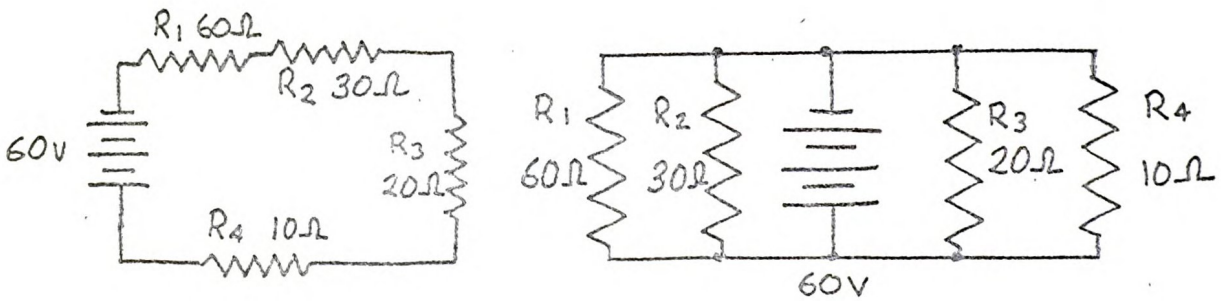
So far, your reasoning is okay.

In a parallel circuit the largest resistor carries the smallest current. So I^2R is smallest for the largest R.

Your answer just doesn't stand up. Return to Page 102 and reason a little more carefully to find the right answer.

YOUR ANSWER: More power is expended in resistors in parallel than in the same resistors in series, because the combined resistance of the parallel circuit is much lower than that of the series circuit.

Correct. The lower resistance allows more current to flow in the parallel circuit. Assuming the voltage is the same in each case, and since $P = EI$, this will mean that more power is expended in the parallel circuit.



Now that you have calculated the amount of power used by each of the resistors above, what could you say about the power expended in R_1, the largest resistor in each circuit?

The largest resistance in a series circuit dissipates the most power; in a parallel circuit, the largest resistance dissipates the least power. Page 93

The largest resistance in a series circuit dissipates the least power, but the largest resistance in a parallel circuit dissipates the most power. Page 97

The largest resistance in a circuit always dissipates the most power. Page 101

YOUR ANSWER: The current through the 80-ohm resistor is 0.8 amp.

No. Here's the way your calculation should have gone:

In a parallel circuit the voltage is the same across each branch. In this case, since there are no complications, the voltage across each branch is the voltage across the power source, 16 volts. The resistance, R_3, is given as 80 ohms.

$$I_3 = E/R = 16/80 = ?$$

That's simple enough. Maybe your approach was more complicated?

Complete the calculation and then return to Page 93 to select the correct answer.

YOUR ANSWER: The 5-ohm resistor dissipates the most power.

Did you guess that this must be right, since the smallest resistor in a parallel circuit dissipates the most power?

You remembered the general rule, all right, but you overlooked something. There's another resistor in series with that 5-ohm resistor.

It is possible to get the right answer to this problem without doing the arithmetic, but not by missing the fact that this branch of the parallel circuit is itself a series circuit.

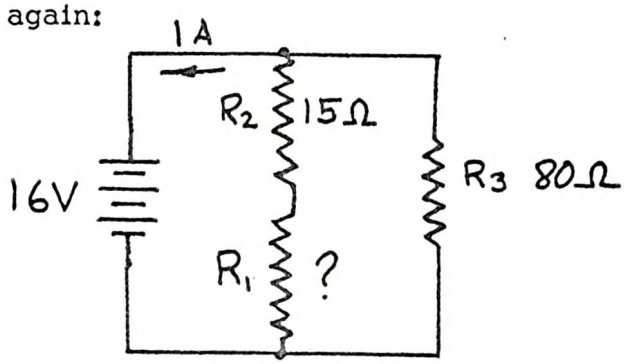
Please go to Page 99 (19) and read the reasoning there with a more enlightened eye.

YOUR ANSWER: 20 ohms.

No. You haven't gone far enough; you overlooked R2, which is in series with Rl.

There was a hint that you would need Kirchhoff's law to help find the value of R_1. Kirchhoff's law for voltage says that the algebraic sum of EMFs and voltage drops around a closed circuit is zero.

Now let's round up the things known about the circuit. Here's the diagram again:



In the center branch of the circuit, we know that E_t = 16 volts. We know that I in this branch is 0.8 amps. Using Ohm's law, E = IR, we can figure that E_2 (the voltage across R_2) is 0.8 x 15 volts and that E_1 is 0.8 x R_1 volts.

And Kirchhoff's law as quoted above comes to this:

$$E_t - E_1 - E_2 = 0.$$

If you substitute the values of E, you should now be able to simplify your equation to get the value of R_1.

When you have it, return to Page 96 and select the correct answer.

YOUR ANSWER: Circuit A will use the most power.

Wrong.

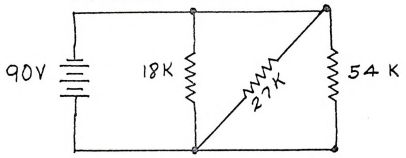
This is not really a problem in arithmetic, it's a test of recognition.

Circuit A is a parallel circuit, drawn in conventional form. It is quite true that a parallel circuit uses more power than a series circuit across the same voltage, and both of these are certainly across the same voltage.

But is circuit B a series circuit?

Return to Page 110 and look more closely this time before selecting another answer.

YOUR ANSWER: Half of the total power is dissipated in the 18,000-ohm resistor.



Yes, you can see this in the reciprocals. You get 3/54 as the equivalent of the reciprocal of 18. The sum of the reciprocals is 6/54, and you can see that the 18K resistor accounts for half of this sum.

In a parallel circuit, more current goes through a small resistor than through a large resistor, as you've seen. The amount of current, which is determined with Ohm's law, varies inversely with the size of the resistor. That is, a 5-ohm resistor carries twice as much current as a 10-ohm resistor in parallel.

This relationship shows up in the reciprocal. You might like to think of it this way: A smaller number has a bigger reciprocal. For instance, the reciprocal of 10 is 1/10. The reciprocal of 2 is 1/2 (or 0.5).

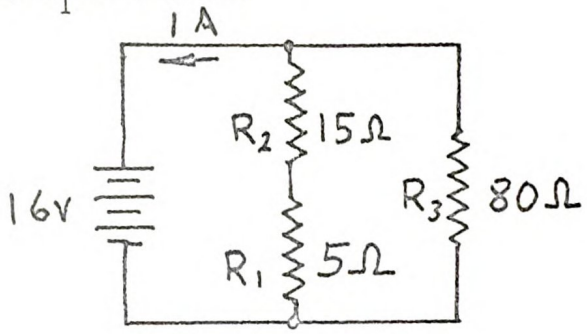
If you remember that the current and the amount of power expended are directly proportional to the size of the reciprocal, you may be able to save yourself some arithmetic in analyzing parallel circuits.

You know that 0.45 watt is used in the 18K resistor above. What power is expended in the 54,000-ohm resistor?

0.15 watt Page 116

1.35 watt Page 123

YOUR ANSWER: R_1 is 5 ohms.



Correct. Using the formula $E = IR$, E_1 can be written as $0.8 \times R_1$ or $0.8\ R_1$. And using Kirchhoff's law that the algebraic sum of the EMFs and voltage drops around a closed circuit is zero, we can say:

$$E_t - E_1 - E_2 = 0$$
$$16 - 0.8\ R_1 - (0.8 \times 15) = 0.$$

That will simplify to:

$$0.8\ R_1 = 4$$
$$R_1 = \frac{4}{0.8}$$
$$R_1 = 5 \text{ ohms}$$

Now you know that the inner branch has a 5-ohm and a 15-ohm resistor. This is the same as a 20-ohm resistor in shunt with the 80-ohm resistor.

The two resistors of the inner branch are actually in series with each other, so it is proper to say that there is a partial voltage drop across each one.

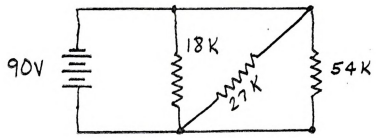
What is the voltage drop across the 15-ohm resistor?

12 volts — Page 99

15 volts — Page 111

YOUR ANSWER: 0.9 watt is used in this circuit.

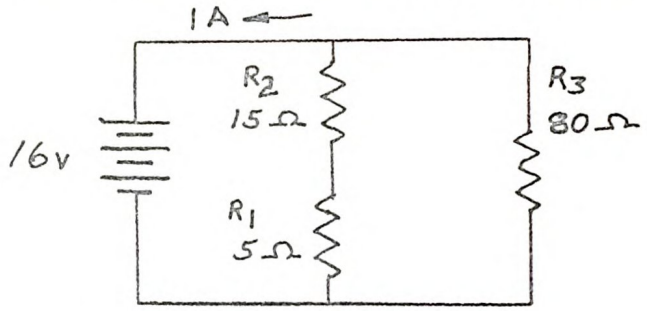
Correct. Adding the reciprocals of these resistors, you have $1/R_t = 6/54$, and this gives you 9K for R_t. This will allow 0.01 ampere or 10 milliamperes to flow through the power supply, and the circuit will use 0.9 watt of power.



How much of the total power is dissipated in the 18,000-ohm resistor?

Half of the power.	Page 107
More than half of the power.	Page 115
Less than half of the power.	Page 121

YOUR ANSWER: The 15-ohm resistor dissipates the most power.



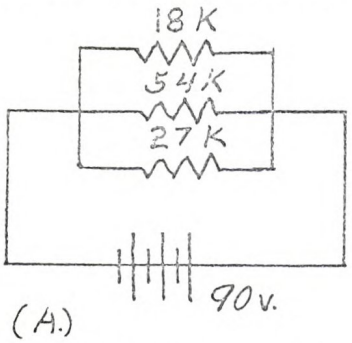
Correct.

You have learned that the smallest resistor in a simple parallel circuit uses the most power. And, as you may have seen for yourself already, this problem does not really contradict the general rule.

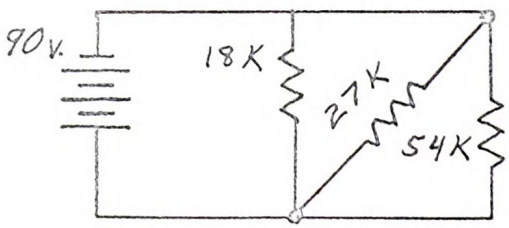
You must think of the 5-ohm and the 15-ohm resistor as joined to make a 20-ohm resistor, since they are in series in this branch of the circuit. Now the 20-ohm branch dissipates the most power: 12.8 watts against the 3.2 watts used by the 80-ohm resistor.

R_2 is $\frac{15}{20}$ or $\frac{3}{4}$ of the total resistance in the series branch. Therefore, 3/4 of the power in this branch is dissipated by R_2. 3/4 of 12.8 is greater than 3.2 watts.

Which circuit below will dissipate the most power?



(A.)



(B.)

Circuit A will use the most power. Page 106
Circuit B will use the most power. Page 114
Both will use the same amount of power. Page 117
I don't know. Page 122

YOUR ANSWER: 15 volts.

Now this is sheer guesswork, and poor guesses don't pay off. You'll get along much faster if you take time to use the figures you are given.

Now return to Page 108 and stop trying to cut corners.

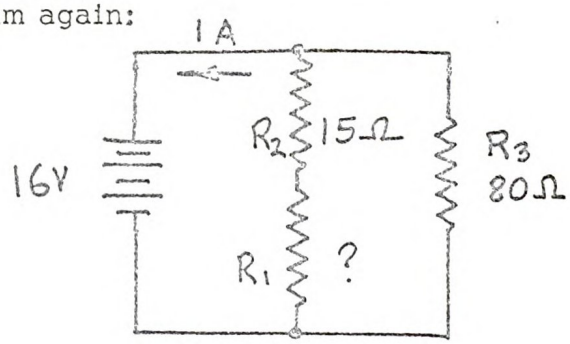
YOUR ANSWER: 0.2 ohm.

No. Decimal points cause trouble when they get in the wrong place, as in your answer.

But more important still, you apparently forgot that there was more than one resistor in this branch of the circuit.

There was a hint that you would need Kirchhoff's law to help find the value of R_1. Kirchhoff's law for voltage says that the algebraic sum of EMFs and voltage drops around a closed circuit is zero.

Now let's round up the things known about the circuit. Here's the diagram again:



In the center branch of the circuit, we know that $E_t = 16$ volts. We know that I in this branch is 0.8 amps. Using Ohm's law, $E = IR$, we can figure that E_2 (the voltage across R_2) is 0.8×15 volts and that E_1 is $0.8 \times R_1$ volts.

And Kirchhoff's law as quoted above comes to this:

$$E_t - E_1 - E_2 = 0.$$

If you substitute the values of E, you should now be able to simplify your equation to get the value of R_1.

When you have it, return to Page 96 and select the correct answer.

YOUR ANSWER: The 80-ohm resistor dissipates the most power.

No.

You seem to have forgotten the general rule that in a parallel circuit, the SMALLEST resistance dissipates the most power. That should have given you a hint that your answer was wrong. Please notice that we said the smallest resistance, not the smallest resistor.

Begin again with the reasoning on Page 93

YOUR ANSWER: Circuit B will use the most power.

How can you arrive at that conclusion?

Circuit A is obviously a parallel circuit. The values of the individual resistors are the same in both circuits, the voltage is the same in both.

If circuit B were a series circuit (which it isn't), then circuit A would use the most power.

Return to Page 110 and study circuit B carefully before picking another answer.

YOUR ANSWER: More than half the power is dissipated in the 18,000 ohm resistor.

You remembered, correctly, that in a parallel circuit, the least resistance dissipates the most power. But that doesn't necessarily mean that the smallest resistor will dissipate more than all the other resistors put together.

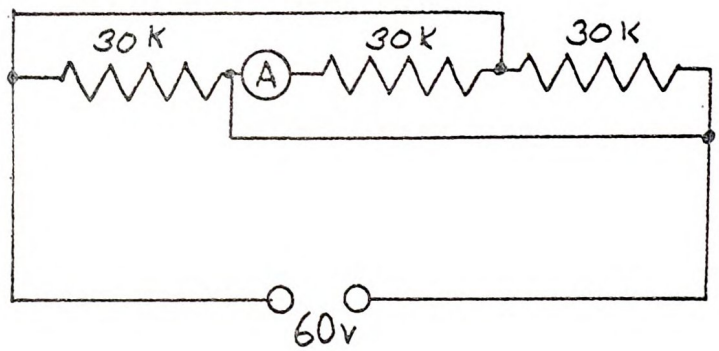
Suppose you had one 2-ohm resistor in parallel with eight 8-ohm resistors. The equivalent resistance of the eight in parallel would be one ohm, wouldn't it? And one ohm of resistance would dissipate more power than the two ohms. The smallest single resistor certainly wouldn't dissipate more than the combination of all the others in that case.

So return to Page 109 and try again.

YOUR ANSWER: Knowing that 0.45 watt is used in the 18,000-ohm resistor, you can see that 0.15 watt is used in the 54,000-ohm resistor.

Correct. Because 54 is three times as large as 18, the reciprocal of 18 is three times as large as the reciprocal of 54. Therefore, the 18K resistor carries three times as much current and expends three times as much power as the 54K resistor.

If you thought the diagonal resistor set-up looked odd, take a look at this:



What is the current shown on the ammeter?

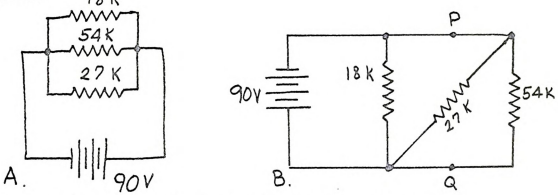
0.004 ampere Page 124

0.002 ampere Page 125

0.006 ampere Page 126

YOUR ANSWER: Both circuits will use the same amount of power.

Correct. Both are simple parallel circuits with identical components.



Circuit B may look a little peculiar, but it's still just a parallel circuit. If the 27K-ohm resistor were connected from points P to Q, it would have the same effect it has now, and it would look more like the circuits you have seen.

Now figure out how much power is used by either of these circuits.

0.9 watt	Page 109
900 watts	Page 120

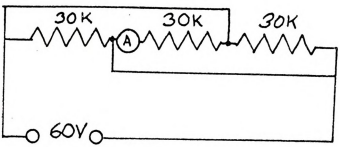
YOUR ANSWER: 0.12 watt is the total power.

No. You have figured the amount of power dissipated by one resistor.

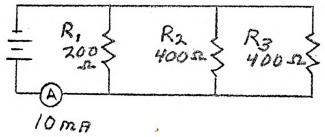
You can't find a total of any kind by ignoring some of the things that make up that total.

Return to Page 125 and consider those other things too.

YOUR ANSWER: 0.36 watt is dissipated in the circuit.



Correct. R_t is found by dividing 30,000 by 3, since they are equal resistors, and, using $I = \frac{E}{R}$, $I_t = \frac{60}{10,000} = 0.006$ ampere.



$P_{R_1} =$

1. 5mw
2. 10w
3. 10mw
4. .005mw



In the circuit above, if R_3 is removed, I_t will

1. increase
2. decrease
3. remain the same

GO TO PAGE 131

YOUR ANSWER: 900 watts.

Watch those decimals! Your answer might have been right if you had kept in mind that those resistors are NOT 18, 27, and 54 ohms.

Please look carefully at the diagram when you return to Page 117 and see for yourself.

YOUR ANSWER: Less than half the power is dissipated in the 18,000-ohm resistor.

You should know that can't be so, even without using arithmetic.

This is a parallel circuit. Stop a moment and remember the general rule for currents in the branches of a parallel circuit -- the smallest resistance draws the most current.

That should be enough to make you suspicious about this answer.

Now return to Page 109 and try arithmetic -- it really works!

YOUR ANSWER: I don't know.

At least that's honest.

The trouble, probably, is that you didn't recognize circuit B. The circuit certainly isn't drawn in conventional form. But you'll find many circuits in electronics which are not. So let's fix this firmly in mind:

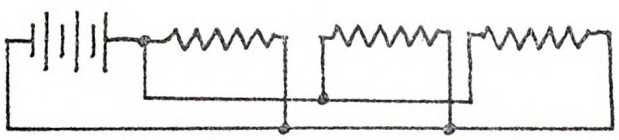
Whether a circuit is "this" or "that" depends not on how the circuit is drawn, but on how it is connected.

Electrons don't flow through lines on pieces of paper, but within conductors in electronic equipment.

Circuit diagrams rarely show the actual or even the relative locations of the parts; they merely show how the parts are connected together. Usually they are drawn with two ideas in mind: to show the circuit most clearly, and/or to draw the diagram in the least time and the least space.

So whenever you study any circuit diagram, look to see what kind of circuit it is, before you do anything else.

Consider this one, for instance:



That's a parallel circuit, even though it's drawn more nearly like a conventional diagram of a series circuit. Study it for a bit, and see why.

Then return to Page 110 and try again.

YOUR ANSWER: 1.35 watt is used in the 54,000-ohm resistor.

Where were you when that last image was on the screen?

The amount of power expended is DIRECTLY PROPORTIONAL TO THE SIZE OF THE RECIPROCAL OF THE RESISTANCE.

The bigger the resistor in a parallel circuit, the smaller the power consumed.

The largest resistor does NOT dissipate the most power in a parallel circuit. To repeat, the larger the resistor, the smaller the power consumed.

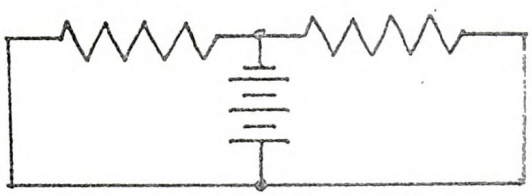
If you are comparing two resistors in parallel and one is three times bigger than the other, the bigger one uses not three times the power but the reciprocal, one-third the power used in the smaller resistor.

Remembering that, return to Page 107 and figure out a more accurate answer.

YOUR ANSWER: 0.004 ampere will be shown by the ammeter.

When a circuit is drawn in what seems to be unconventional form, or whenever you don't recognize it, try redrawing it. This tip will help you not only in this course, but in your actual work on any kind of electronic device.

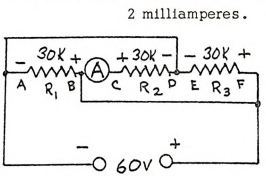
This drawing, for instance, does NOT show two resistors in series:



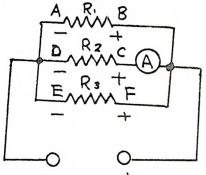
If you redraw the circuit of image 3818 in more conventional form, you'll see at once that the meter does not measure the current through two of the resistors in parallel.

Now return to Page 116 and try redrawing that circuit.

YOUR ANSWER: The ammeter should show 0.002 ampere or 2 milliamperes.



A.



B.

Correct. No matter what your first reaction, this is just a simple parallel circuit. At right is the same circuit drawn in a more usual fashion. In figure A we have indicated the polarity of each end of the resistors and lettered them as well. In figure B are the same resistors, and you can see that they are really connected in the same way.

Note that the positive ends of the resistors are all connected together, and that they are all connected directly to the positive side of the power source. Similarly, the negative ends of the resistors are all joined directly to the negative side of the power source.

The ammeter is in series with one resistor only, and does not indicate total current, but only the current through that one resistor.

Now calculate the total current and from that determine the total power dissipated in the circuit.

0.12 watt Page 118

0.36 watt Page 129

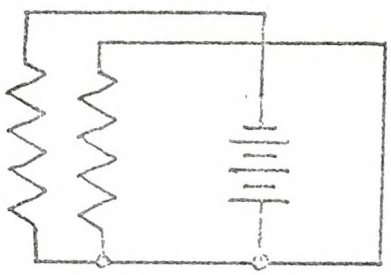
1.2 watt Page 127

3.6 watts Page 128

YOUR ANSWER: 0.006 ampere will be shown on the ammeter.

When a circuit is drawn in what seems to be unconventional form, or whenever you don't recognize it, try redrawing it. This tip will help you not only in this course, but in your actual work on any kind of electronic circuit.

This drawing, for instance, does NOT indicate two resistors in parallel:



If you redraw the circuit of image 3818 in more conventional form, you'll see at once that the meter does not measure the current through all the resistors in parallel.

Now return to Page 116 and try redrawing it.

YOUR ANSWER: 1.2 watts is the total power dissipated in the circuit.

That's a double error. You've got the decimal point in the wrong place, and you've also neglected two-thirds of the circuit.

That's no way to find a total.

Return to Page 125 and consider all parts of the circuit, then watch that decimal point to see that it doesn't wander.

YOUR ANSWER: 3.6 watts is the total power dissipated in the circuit.

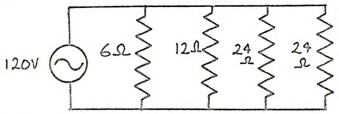
And your answer would be right if only the decimal point didn't matter.

But the decimal point does matter.

Check your calculations and then return to Page 125 and don't let that decimal point get away from you again.

YOUR ANSWER: When one branch of the circuit is removed the generator current decreases.

Yes, the equivalent resistance of the circuit increases when you remove one branch.



The sum of the reciprocals is 8/24, and you can quickly see that R_t = 3 ohms.

Or you can find R_t even faster by combining like resistors: The two 24-ohm resistors at right are equivalent to 12 ohms; combine this with the other 12-ohm resistor and you get 6 ohms, and combine that with the 6-ohm resistor and you get 3 ohms.

Remove the 6-ohm resistor and R_t becomes 6 ohms; remove a 24-ohm resistor and it becomes about 3.4 ohms. There is an increase in total resistance when you remove any of them.

Well done. You have come to the end of the lesson. On your answer sheet write down the length of time it took you to complete this lesson.

YOUR ANSWER: The generator current would remain the same if one branch of the parallel circuit were removed.

But the generator is supplying the total current through the circuit, isn't it?

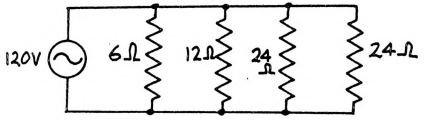
When the applied voltage is constant, as here, the total current depends only on the total resistance.

Your answer thus means that the total resistance remains the same when you remove part of the resistance!

So try image Page 131

CONTINUED FROM PAGE 119

Remember that the voltage across each branch is the same. Assuming that voltage from the generator remains constant, Ohm's law determines the current in each branch independent of the others.



What will happen to the generator current when one branch is removed?

Decrease. Page 129

Remain the same. Page 130

APPENDIX D

ANSWER SHEETS USED WITH SKINNER PROGRAM

LESSON 1-S ANSWER SHEET

NAME_____ RATE_____ SERVICE NO._____ DATE_____

CLASS_____ SECT._____

	ANSWERS	WORK
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		

10.

MEASUREMENT	SYMBOL	UNIT
current	( )	____
pressure	( )	____
resistance	( )	____

11.

12.

13.

14.

15.

16.

17.

18.

19.

20.

21.

22.

23.

24.

25.

26.

27.

28.

29.

30. I=
R=
E=

31. most R ( ) current in A ( )_____
most emf ( ) current in B ( )_____

32.

33.

34. resistance_____ ( )
_____volts ( )
current _____ I

35.

36.

37.

38. most current ( ) R in A ( )_____
most emf ( ) R in B ( )_____

39.

40.

41.

42.

43.

44.

45.

46.

47.

48.

49.

50.

51.

52. 1. 4.
2. 5.
3.

53. 1. 3.
2.

54.

55.

56.

57.

58.

59.

60.

61.

62.

63.

64.

65.

66. 1. 10^3 4.
2. 5.
3. 6.

67.

68.

69.

70.

71.

72.

73.

74.

75.

76.

77.

78.

79.

80.

81.

82.

83. 1. 4.

2. 5.

3.

84.

85.

86.

87.

88.

89.

90.

91.

92.

93.

94.

95.

96.

97.

98.

99.

100.

101.

102.

103.

104.

105.

106.

107.

108.

109.

110.

111.

112. A. C.

B.

113.

114.

115.

116.

117.

118.

119.

120.

121.

122.

123.

124.

125.

126.

127.

128.

129.

130.

131.

132.

133.

134.

135.

136.

137.

Time to complete lesson_____

LESSON 2-S ANSWER SHEET

NAME_____RATE_____SERVICE NO._____DATE_____

CLASS_____SECT._____

	ANSWERS	WORK
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.	E_{DE} = ( ) E_{BC} = ( ) E_{AE} = ( )	
12.		
13.		
14.		
15.		

16.

17. E_{AB} = ( )v

E_{BC} = ( )v

E_{CD} = ( )v

18. E_{AB} = ( )

E_{BC} = ( )

E_{CD} = ( )

19.

20.

21.

22.

23.

24.

25.

26.

27. E_{AB} = ( )

E_{BC} = ( )

E_{CD} = ( )

28.

29.

30., 31., 32., 33., 34., and 35.

	AB	BC	CD	TOTAL
R				
I				
E				

36.

	AB	BC	CD	TOTAL
R				
I				
E				

37:

38.

	AB	BC	CD	TOTAL
R				
I				
E				

39.

	AB	BC	CD	TOTAL
R				
I				
E				

40. 1. 3.

2. 4.

41.

42.

43.

44.

45.

46. 1.

2.

47.

48.

49.

50.

51.

52.

53.

54.

55.

56.

57.

58.

59.

60.

61.

62.

63.

64.

65. P =

I =

E =

66.

67.

68.

69.

70.

71.

72.

73.

74.

75.

76.

77.

78.

79.

80. E_{AD} =

R_{AD} =

I =

81.

82.

83.

84.

85. E =

I =

P =

86.

87.

88.

89. A.

B.

C.

90.

91.

92. I_{AC} =

R_{BD} =

E_{EF} =

93. R_{AB} = I_{GH} =

E_{CD} = I_{IJ} =

R_{EF} = E_{KL} =

94.

95. I_{AB} =

E_{CD} =

P_{EF} =

96. 1. E_{AB} =
2. I_{CD} =
3. R_{EF} =
4. E_{GH} =
5. P_{GH} =
6. I_{IJ} =
7. R_{KL} =
8. P_{KL} =

97. ( ) ( ) _____ ( ) ( )

98., 99., 100.

	AB	BC	CD	TOTAL
R				
I				
E				

101.

102.

103.

104.

105.

106.

107.

108.

109. P_{AD} =

E_{AD} =

110.

111.

112.

113.

114.

115.

116. E_{AE} =

E_{AF} =

117. P_{AD} =

P_{CD} =

P_{AF} =

118.

119.

Time to complete lesson_____

LESSON 3-S ANSWER SHEET

NAME_____ RATE_____ SERVICE NO._____ DATE_____

CLASS_____ SECT._____

ANSWERS	WORK
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	
11. I=	
R=	
E=	
12.	
13.	

14. 1. ( )

2. ( )

3. ( )

15.

16. E^2=( ) R=( )

I^2=( ) R=( )

17.

18.

19.

20.

21.

22.

23.

	AB	CD	TOTAL
R	2Ω	4Ω	
I	2a	( )	3a
E	( )	( )	4v

24.

	AB	CD	TOTAL
R			
I			
E			

25.

26.

27. 1. 2.

3. 4.

28.

29.

30.

31.

32.

33.

34.

35.

36.

37.

38.

39.

40.

41.

42.

43.

44. $I_2 =$ $I_T =$

45.

46.

47.

48.

49.

50.

	AB	CD	TOTAL
R	( )	( )	( )
I	2a	4a	6a
E	12v	12v	12v

51.

52.

53. R_I = ( ) I_T = ( )

R_2 = ( ) R_T = ( )

54.

55.

56. I_1 = ( ) I_T = ( )

I_2 = ( ) R_T = ( )

57.

58.

59.

60.

45.

46.

5

53.

54.

55.

56. $I_1 =$

$I_2 =$

57.

58.

59.

60.

61.

62.

63.

64.

65.

66.

67.

68.

69.

70.

71.

72.

73.

74.

75.

76.

77.

78.

79.

80.

81.

82. E_T = ( )

E_{BC} = ( )

I_2 = ( )

83. I_2 = ( )

I_3 = ( )

I_4 = ( )

84.

85.

86.

87.

88.

89.

90.

91.

92.

93.

94.

95.

96.

97.

98.

99.

100. A. C.

B.

101.

102.

103.

104.

105.

106.

107.

108.

109.

110.

111.

112.

113, 114, 115, 116, 117.

	AB	CD	TOTAL
R			
I			
E			
P			

118. R_T = ( )

I_T^2 = ( )

P_T = ( )

119.

	AB	BC	CD	TOTAL
R				
I				
E				
P				

Time to complete lesson _____

APPENDIX E

ANSWER SHEETS USED WITH CROWDER PROGRAM

LESSON 1-C, 2-C, 3-C, (Circle One)

Name_____ Rate____ Service No._____ Date_____

Class_____ Section_____

Item	Page	Answer	Work
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			

Item	Page	Answer	Work
28			
29			
30			
31			
32			
33			
34			
35			
36			
37			
38			
39			
40			
41			
42			
43			
44			
45			
46			
47			
48			
49			
50			
51			
52			
53			
54			
55			
56			
57			

APPENDIX F

CRITERION TESTS

FORM S1

INSTRUCTIONS TO TRAINEES

1. Check the number of pages to make certain the test is complete and legible.
2. Do not mark this test in any manner. Do not use the answer sheet, front or back, for scratch paper.
3. Fill in the data section of both Answer Sheets as the instructor indicates.
4. Completion and fill-in questions: Use the separate answer sheet marked "Completion Questions." Write the word or words that make the statement complete and true. Do not write any completion answers on the IBM Answer Sheets.
5. Multiple Choice questions: Choose the most complete and correct answer and black in the proper space on the IBM Answer Sheet. Be sure to black in the complete space and use only the IBM pencil which is provided.
6. If you wish to change an answer, erase your first answer completely.
7. Be sure your answer number corresponds to the question number.
8. Turn in all scratch paper. Do not make notes.
9. Any necessary additional instructions will be given by the instructor.

HANDLE IN A CONFIDENTIAL MANNER

1. Ohm's Law states that current is_____ proportional to resistance and_____ proportional to voltage.

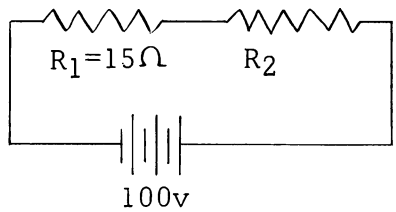
2. An electromotive force of _____ is required to push .5 amperes of current through a resistance of 8 ohms.

3. 20 picounits times 10 kilounits divided by 5 microunits equals_____.

4. 10 kinoamps is equal to _____ milliamps.

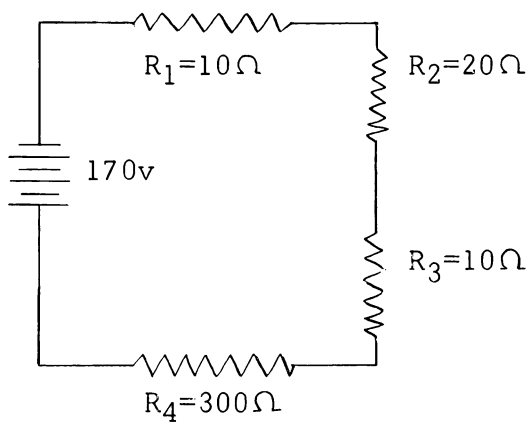
5. $(2.5 \times 10^{-6})\ (4 \times 10^{3}) =$ _____ $\times 10^{-2}$

6. In the circuit below, current equals 4 amperes. The resistance of R_2 is _____.

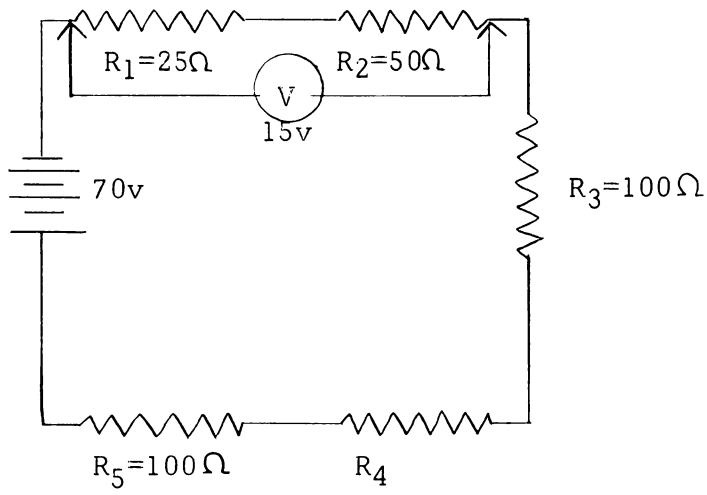


7. The current flow through a 4 ohm resistor which is dissipating 100 watts is _____.

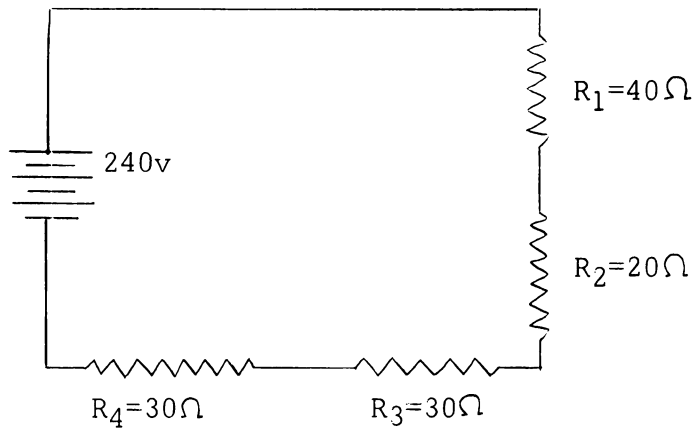
8. In the circuit below, I_{R1} is equal to _____.



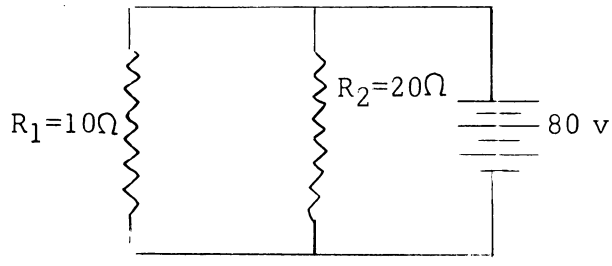
9. In the circuit below, E_{R4} is equal to _____.



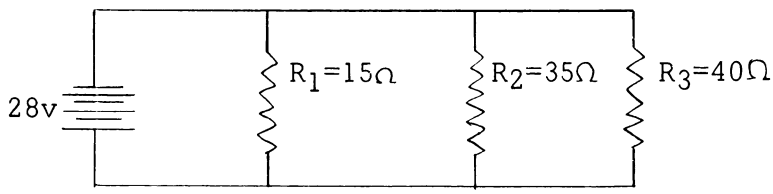
10. In the circuit below, the total power dissipated is _____.



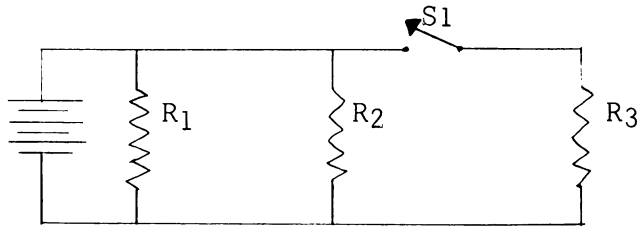
11. In the circuit below, _____ amperes of current is flowing from the battery.



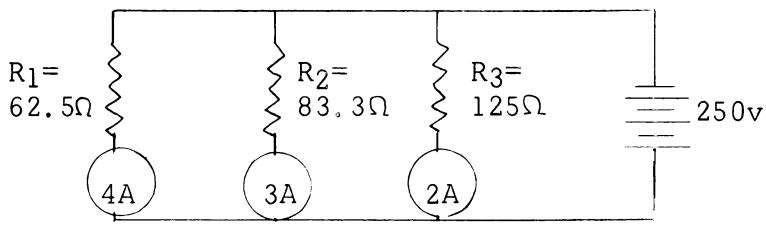
12. In the circuit below, the power dissipated by R_3 is _____.



13. In the circuit below, when S_1 is closed, I_{R1} will _____.



14. In the circuit below, the total resistance equals _____.



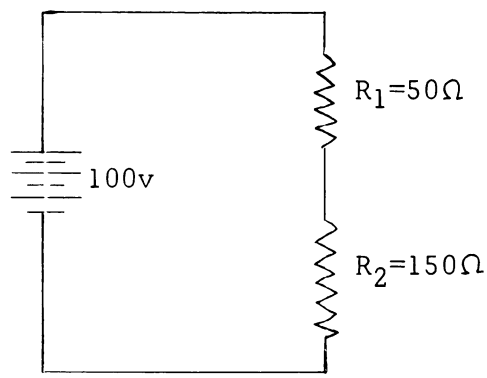
15. Adding a resistor in parallel with another resistor will cause a/an _____ in total current.

16. INCREASING the voltage applied to a resistor will cause the

    1. current to decrease.
    2. current to increase.
    3. resistance to increase.
    4. power to decrease.

17. In the following circuit, the current through R_1 equals

1. 1.5 amps.
2. 1 amps.
3. .5 amps.
4. 2 amps.



18. $(4 \times 10^{-5})\ (3 \times 10^{6}) = ?$

1. 1.2×10^{2}
2. 1.2×10^{-2}
3. 12×10^{-1}
4. 12×10^{2}

19. Convert 22 KΩ to μΩ.

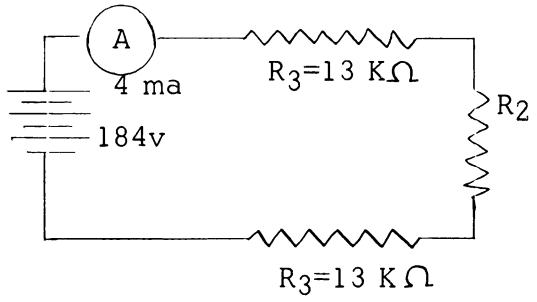
1. 22×10^{9} μΩ
2. 22×10^{6} μΩ
3. 22×10^{-9} μΩ
4. 22×10^{-6} μΩ

20. 324,000,000 x 8900 = ?

1. 2.70×10^{11}
2. 27.00×10^{12}
3. 2.70×10^{12}
4. $.27 \times 10^{11}$

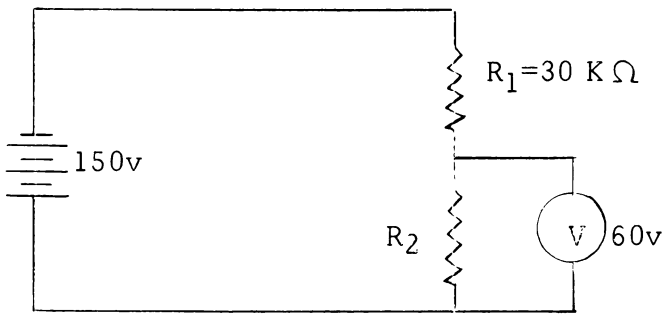
21. Find E_{R2} in the following circuit.

1. 56 volts.
2. 14 volts.
3. 76 volts.
4. 108 volts.



22. In the circuit below, the value of R_2 is

1. 75 KΩ.
2. 50 KΩ.
3. 30 KΩ.
4. 20 KΩ.

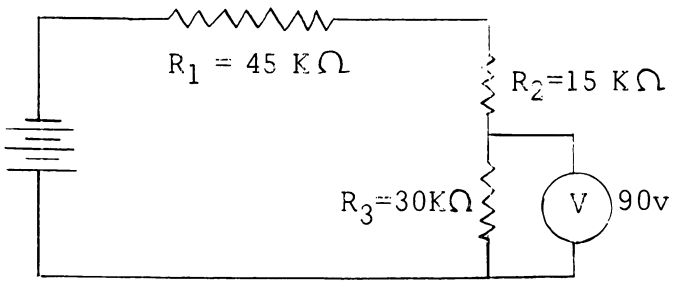


23. In a series circuit containing three resistors, which of the statements concerning current is correct?

1. $I_T = I_1 = I_2 = I_3$
2. $I_1 - I_T - I_2 - I_3$
3. $I_T = I_1 + I_2 + I_3$
4. $I_T - I_1 - I_2 - I_3 = 0$

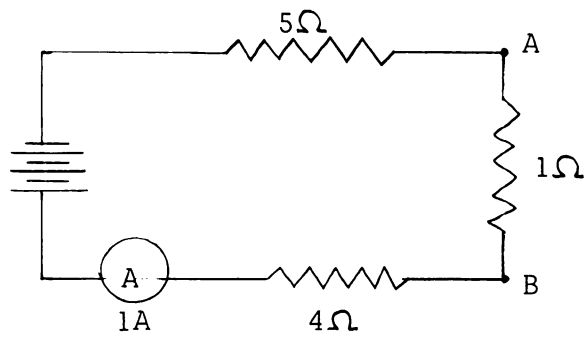
24. In the circuit below, P_t is

1. 81 milliwatts.
2. 270 milliwatts.
3. 750 milliwatts.
4. 810 milliwatts.



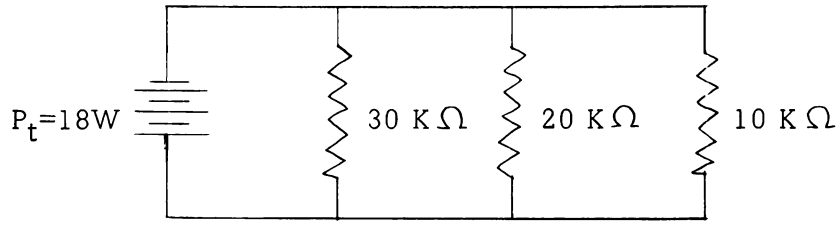
25. In the circuit below, the voltage at point A with reference to point B is

1. -1 volts.
2. 1 volt.
3. -5 volts.
4. 5 volts.



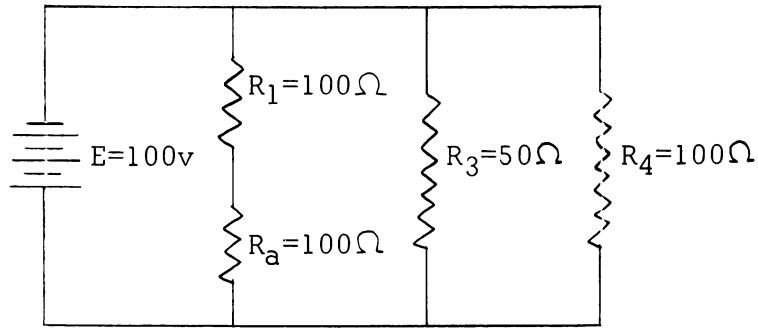
26. The power dissipated in each branch of the circuit below will

1. be 6 watts.
2. vary directly with the resistor wattage rating.
3. be 18 watts.
4. vary inversely with branch resistance.



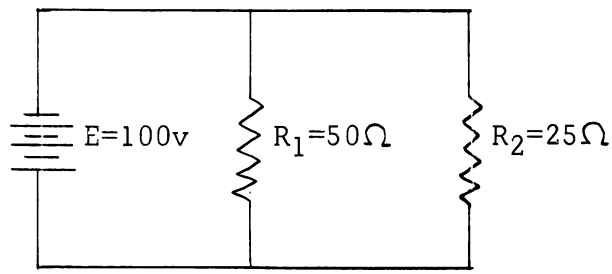
27. In the circuit below, I_{R2} is

1. .5 a.
2. 1.0 a.
3. 2.9 a.
4. 5.5 a.



28. In the circuit below, current through R_1 is

1. 2 amps.
2. 4 amps.
3. 6 amps.
4. .5 amps.

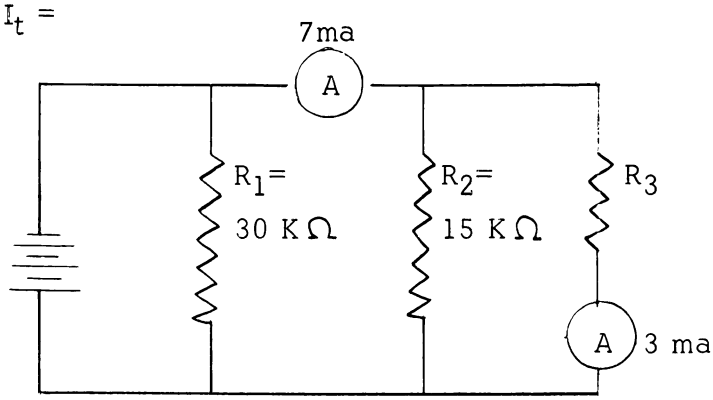


29. Four resistors are connected in parallel directly across a voltage source. If a lead to one of the resistors should be opened the effect would be to

1. increase the amount of current drawn from the source.
2. increase the voltage across the remaining resistors.
3. decrease the total current drawn from the source.
4. decrease the voltage across the remaining resistors.

30. In the circuit below, I_t =

1. 17 ma.
2. 10 ma.
3. 9 ma.
4. 7 ma.



FORM S2

INSTRUCTIONS TO TRAINEES

1. Check the number of pages to make certain the test is complete and legible.
2. Do not mark this test in any manner. Do not use the answer sheet, front or back, for scratch paper.
3. Fill in the data section of both Answer Sheets as the instructor indicates.
4. Completion and fill-in questions: Use the separate answer sheet marked "Completion Questions." Write the word or words that make the statement complete and true. Do not write any completion answers on the IBM Answer Sheets.
5. Multiple Choice questions: Choose the most complete and correct answer and black in the proper space on the IBM Answer Sheet. Be sure to black in the complete space and use only the IBM pencil which is provided.
6. If you wish to change an answer, erase your first answer completely.
7. Be sure your answer number corresponds to the question number.
8. Turn in all scratch paper. Do not make notes.
9. Any necessary additional instructions will be given by the instructor.

HANDLE IN A CONFIDENTIAL MANNER

1. If the resistance in a circuit is increased, it is necessary to _____ the EMF in order to maintain the same current flow.

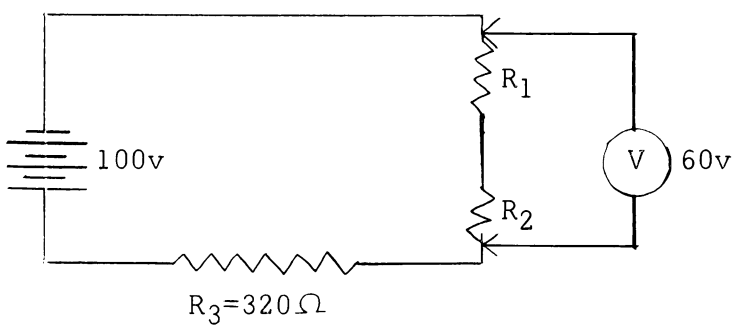
2. If the current doubles in a circuit when the resistance is halved, the EMF has _____.

3. 165×10^{-10} expressed in scientific notation is _____.

4. 100 μ units equals _____ basic units.

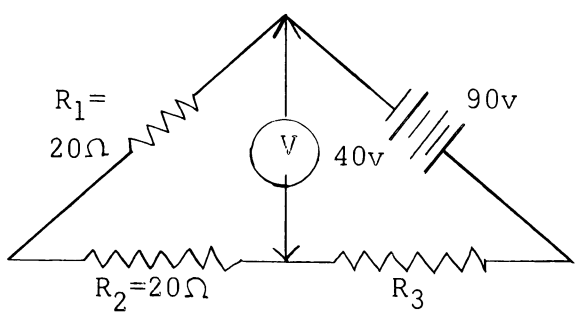
5. $\frac{(1.25 \times 10^{-8})(2 \times 10^{5})}{5 \times 10^{-4}} =$ _____.

6. In the circuit below, _____ watts of power is dissipated by R_3.

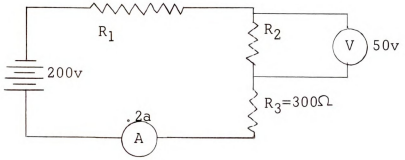


7. The mathematical relationship between total current and the current flow through three resistors in a series circuit can be expressed as _____.

8. In the circuit below, R_3 equals _____.

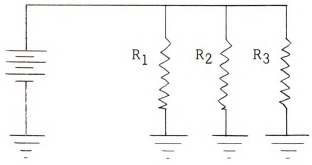


9. In the circuit below, R_1 equals _____.

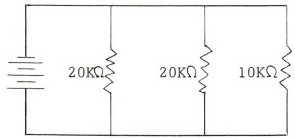


10. A formula that shows the relationship between individual votage drops and the total voltage in a series circuit containing three resistors is _____.

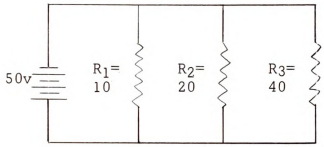
11. In the circuit below, if R_3 opens, the current through R_2 will _____.



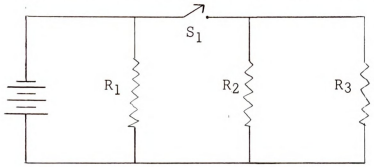
12. In the circuit below, the total resistance is _____.



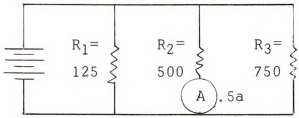
13. In the circuit below, the power dissipated by R_3 is _____.



14. In the circuit below, when S_1 is closed, P_{R1} will _____.

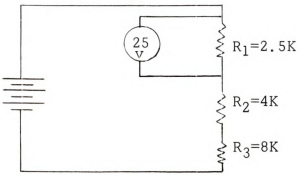


15. In the circuit below, the current through R_1 is _____.



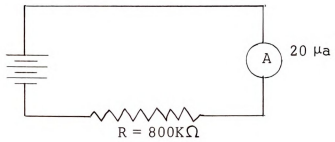
16. In the circuit below, I_t is

1. 1.00 ma.
2. 1.72 ma.
3. 10.00 ma.
4. 17.20 ma.



17. In the circuit below, E_t =

1. 1.5 v.
2. 16.0 v.
3. 1500.0 v.
4. 16,000.0 v.



18. If 4 basic units are divided by 2 micro units the answer would be

1. 2 kilo units.
2. 2 milli units.
3. 2 meg units.
4. 2 basic units.

19. 155 picoamps = _____ kiloamps.

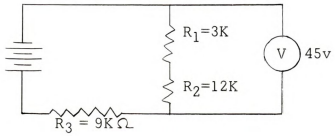
1. 1.55×10^{-10}
2. 1.55×10^{15}
3. 1.55×10^{-7}
4. 1.55×10^{-13}

20. 20 microvolts times 10^{12} is equal to

1. 2×10^{7} volts.
2. 20×10^{7} volts.
3. 2×10^{19} megavolts.
4. 2×10^{-7} microvolts.

21. In the circuit below, the voltage across R_3 is equal to

1. 72 volts.
2. 45 volts.
3. 27 volts.
4. 3 volts.

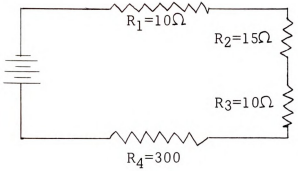


22. What is the relationship between power, current and resistance?

    1. Power is inversely proportional to current and resistance squared
    2. Power is directly proportional to current squared and resistance
    3. Power is directly proportional to resistance and inversely proportional to current
    4. Power is directly proportional to current and inversely proportional to resistance

23. In the circuit below, I_{R1} is equal to

    1. I_{R2}.
    2. I_{R3}.
    3. I_{R4}.
    4. all the above.

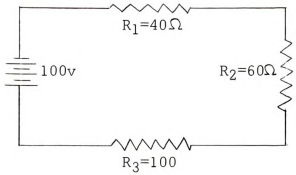


24. How much power is dissipated by a 500Ω resistor which drops 30 volts?

    1. 60.00 mw
    2. .18 w
    3. 1.80 w
    4. 15.00 kw

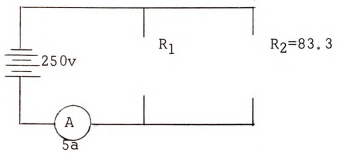
25. In the circuit below, P_{R2} is

    1. 10 watts.
    2. 15 watts.
    3. 25 watts.
    3. 50 watts.



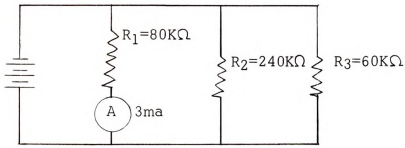
26. In the circuit below, R_1 equals

1. 50
2. 83.3
3. 125
4. 186.6



27. In the circuit below, I_t =

1. 30 ma.
2. 8 ma.
3. 5 ma.
4. 3 ma.

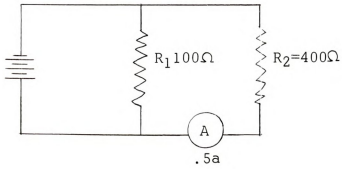


28. Adding a resistor in parallel with another resistor will cause a decrease in

1. R_t.
2. P_t.
3. E_t.
4. I_t.

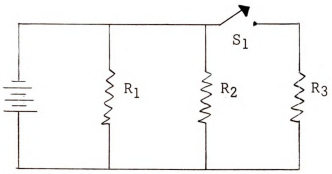
29. In the circuit below, what is P_{R1}?

1. 2 watts
2. 100 watts
3. 400 watts
4. 20,000 watts



30. In the circuit below, if S_1 is closed

1. I_{R2} decreases.
2. E_{R2} decreases.
3. E_{R1} decreases.
4. I_t increases.



APPENDIX G

RAW DATA: SCORES ON ALL VARIABLES FOR ALL SUBJECTS

TABLE G

RAW DATA: SCORES ON ALL VARIABLES FOR ALL SUBJECTS

Set 1

Program	Class	IO	RC	RS	PRT mc	PRT fi	PRT tot	PTT mc	PTT fi	PTT tot	RT mc	RT fi	RT tot	WK 1	WK 2	WK 3	WK 5	T
1	1	116	69	66	59	19	40	59	59	60	86	72	79	62	54	74	73	000
1	1	109	65	66	39	12	26	52	46	50	72	72	73	62	57	68	51	000
1	1	116	64	73	59	26	43	79	66	73	72	79	76	71	50	72	71	000
1	1	111	68	71	39	26	33	46	66	56	79	66	73	53	37	70	62	000
1	1	130	78	76	66	79	73	86	72	79	86	72	79	67	57	82	66	000
1	1	116	67	71	52	32	43	66	39	53	59	39	50	81	57	66	58	000
1	1	110	71	69	32	39	36	72	72	73	79	52	66	62	50	72	80	000
1	1	108	66	67	66	72	69	79	66	73	79	72	76	81	57	80	75	000
1	1	123	65	67	72	39	56	72	39	56	66	52	60	71	57	77	77	000
1	1	116	66	67	46	46	46	72	39	56	92	72	83	86	57	74	78	000
1	1	128	80	85	72	52	63	79	79	79	59	59	60	55	41	76	62	000
1	1	119	69	67	66	59	63	66	59	63	86	72	79	55	57	70	54	000
1	1	118	67	73	72	52	63	72	59	66	72	79	76	90	57	58	77	000
1	1	125	74	72	52	66	60	66	52	60	86	66	76	81	57	70	77	000
1	1	115	69	67	32	26	30	32	46	40	66	66	66	81	57	62	53	000
1	1	120	62	64	46	32	40	59	46	53	72	52	63	85	50	44	60	000
1	1	117	73	73	72	12	43	72	46	60	72	59	66	55	57	70	73	000
1	1	109	71	68	32	12	23	52	39	46	32	32	33	71	46	44	43	000
1	1	114	70	73	66	32	50	72	46	60	59	39	50	62	41	66	53	000
1	1	114	73	74	19	32	26	92	52	73	86	99	92	62	57	74	69	000
1	1	106	65	68	52	32	43	72	46	60	79	59	69	67	54	72	58	000
1	1	114	75	75	46	12	33	19	32	26	32	52	43	71	50	66	54	000
1	1	117	68	71	79	66	73	79	59	69	79	72	76	67	57	85	80	000
1	10	118	62	62	46	26	36	66	39	53	59	52	56	67	67	78	58	000
1	10	112	74	70	66	52	60	66	66	66	66	66	66	67	52	78	71	000
1	10	123	66	65	39	19	30	26	12	20	52	32	43	34	43	66	53	000
1	10	104	60	61	32	26	30	46	39	43	72	52	63	48	57	66	73	000
1	10	122	69	71	52	46	50	59	46	53	66	59	63	71	58	74	42	000
1	10	123	72	70	39	19	30	52	32	43	32	52	43	48	51	60	49	000
1	10	125	74	78	32	19	26	19	12	17	46	39	43	67	40	58	66	000
1	10	116	65	65	66	52	60	72	52	63	72	66	69	76	38	76	71	000
1	10	120	75	78	72	46	60	66	59	63	59	59	60	67	62	76	69	000
1	10	124	72	71	39	59	50	52	59	56	59	59	60	39	58	66	67	000
1	10	125	70	71	52	32	43	39	46	43	72	46	60	57	58	66	45	000
1	10	127	75	79	72	72	79	92	92	92	92	72	83	81	62	78	71	000
1	10	118	73	73	66	12	40	66	59	63	66	59	63	57	58	72	60	000
1	10	109	64	64	32	19	26	59	26	46	66	12	40	62	62	64	56	000
1	10	112	71	70	39	66	53	72	66	69	86	59	73	62	43	72	67	000
1	10	125	81	78	39	12	26	46	52	50	59	59	60	67	58	78	62	000
1	10	119	66	66	66	46	56	59	66	63	79	79	80	48	62	74	47	000
1	10	123	70	75	59	39	50	79	46	63	79	72	76	67	62	64	62	000

1	22	119	71	72	59	52	56	66	79	73	72	79	76	57	57	72	69	000
1	22	116	75	73	46	19	33	52	39	46	72	79	76	62	46	72	69	000
1	22	112	70	68	46	72	60	92	72	83	59	66	63	62	46	64	64	000
1	22	120	77	78	46	59	53	59	66	63	59	66	63	71	62	68	62	000
1	22	124	69	76	66	19	43	86	66	76	86	66	76	81	62	66	73	000
1	22	113	68	69	66	39	53	79	52	66	79	66	73	71	57	62	64	000
1	22	126	75	78	66	46	56	59	39	50	59	32	46	71	54	74	64	000
1	22	110	73	73	46	66	40	32	26	30	59	39	50	44	54	48	40	000
1	22	115	74	77	46	26	36	59	66	63	52	32	43	71	50	64	69	000
1	22	120	66	67	72	72	73	92	66	79	60	72	66	85	57	74	71	000
1	22	120	75	75	39	32	36	32	66	50	59	66	63	71	50	70	62	000
1	22	117	73	77	59	46	53	86	59	73	66	72	69	76	62	74	67	000
1	22	115	67	76	52	52	53	79	32	56	52	66	60	62	46	66	60	000
1	22	115	76	78	19	59	40	66	52	66	86	66	76	53	62	84	62	000
1	22	111	75	78	59	59	60	86	66	76	79	86	83	71	62	77	69	000
1	22	115	71	73	52	32	43	59	39	50	66	39	53	57	37	70	67	000
1	22	120	74	76	59	52	56	32	39	36	52	59	56	76	46	58	64	000
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1	22	124	65	69	66	66	66	59	59	60	46	66	56	67	46	70	67	000
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1	22	109	76	73	66	59	63	86	59	73	86	79	83	71	62	74	75	000
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1	24	122	65	68	46	66	56	59	19	40	79	66	73	67	51	64	51	000
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1	24	113	78	80	32	39	36	72	46	60	86	46	66	62	51	66	62	000
1	24	104	69	67	66	26	46	52	52	53	72	46	60	48	51	56	36	000
1	24	129	72	69	39	32	36	32	39	36	66	59	63	53	47	58	53	000
1	24	110	73	71	39	39	40	72	32	53	79	46	63	67	47	68	66	000
1	24	111	65	70	12	26	20	66	39	53	52	32	43	34	40	54	49	000
1	24	116	72	77	39	26	33	86	72	79	99	32	66	30	51	58	58	000
1	24	113	65	69	52	26	40	72	39	56	72	59	66	71	58	70	53	000
1	24	109	66	65	39	52	46	46	26	36	66	66	66	62	51	68	47	000
1	24	117	72	72	46	46	46	66	32	50	59	39	50	48	55	60	56	000
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1	24	117	78	77	72	72	72	86	79	83	86	79	83	76	55	77	71	000
1	24	130	82	82	86	79	83	79	72	76	86	86	83	58	70	77	000
1	24	121	83	80	59	52	56	39	26	33	79	59	69	71	43	66	60	000
1	24	118	74	69	59	32	46	52	66	60	86	66	76	67	51	70	56	000
1	24	124	68	74	59	52	56	66	52	56	56	59	56	46	51	58	53	000
1	24	120	66	65	19	26	23	39	12	26	59	60	59	34	40	46	51	000
1	24	116	73	74	32	39	36	39	19	30	66	59	63	57	40	54	51	000
1	24	116	69	67	32	52	43	46	32	40	46	72	60	71	55	70	54	000
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1	24	119	69	67	19	06	13	59	39	50	12	39	26	44	51	60	60	000
1	24	136	75	84	59	59	60	59	66	63	92	66	79	85	55	64	62	000

2	3	112	72	68	52	59	56	59	59	60	59	59	60	46	47	66	64	240
2	3	116	72	80	66	66	66	72	66	69	86	86	86	67	58	76	78	185
2	3	124	87	85	46	59	53	79	59	69	79	66	73	78	58	83	86	286
2	3	116	65	68	72	59	66	79	59	69	72	46	60	67	47	78	62	240
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2	3	110	71	70	46	46	46	52	52	53	86	39	63	51	47	76	56	235
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2	12	119	68	75	59	26	43	46	39	43	39	59	50	73	65	54	64	260
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2	9	128	71	78	66	72	69	26	39	33	72	66	69	62	62	82	64	242
2	9	105	66	70	46	39	43	26	32	30	39	26	33	51	57	60	53	258
2	9	120	74	69	66	52	60	72	46	60	79	39	60	62	62	64	60	301
2	9	114	72	71	66	59	63	66	72	69	59	59	60	73	54	72	82	209
2	9	100	61	63	66	19	43	66	39	53	92	66	79	51	37	54	60	314
2	9	116	76	70	52	52	53	66	59	63	66	50	60	57	54	76	73	358
2	9	117	70	69	66	59	63	52	46	50	59	72	66	41	50	58	71	269
2	9	112	68	68	52	32	43	32	59	46	39	50	46	67	54	64	73	289
2	9	120	68	71	26	39	33	39	39	40	59	52	56	62	54	72	64	291
2	9	119	72	71	19	39	30	66	52	60	66	39	53	51	50	62	64	307

2	15	117	72	75	46	12	30	79	59	69	79	39	60	57	55	62	66	240
2	15	118	70	77	59	46	53	52	46	50	66	52	63	57	51	71	71	299
2	15	114	77	82	72	66	69	59	46	53	92	59	76	62	62	58	58	248
2	15	122	76	81	59	72	32	46	66	56	92	52	73	57	40	73	69	205
2	15	123	71	67	72	46	60	66	72	69	72	66	69	71	62	66	69	285
2	15	116	71	71	66	66	66	79	46	63	72	66	69	67	65	77	73	295
2	15	115	64	66	26	12	20	39	26	33	46	19	33	67	65	51	42	322
2	15	126	74	77	72	72	73	79	92	86	92	72	83	67	58	84	69	250
2	15	109	72	71	59	52	56	52	52	53	52	66	56	71	65	60	64	243
2	15	124	82	80	79	72	76	72	72	73	79	52	66	81	55	69	67	211
2	15	117	66	68	92	66	79	72	79	76	92	59	76	57	65	77	78	203
2	15	114	67	67	59	39	50	59	46	53	66	59	63	57	65	71	47	294
2	15	124	74	79	46	39	43	26	39	33	72	26	50	67	62	55	67	210
2	15	120	74	76	46	12	30	46	26	36	52	26	40	39	55	66	47	205
2	15	120	71	75	46	19	33	46	32	40	39	26	33	57	40	49	56	250
2	15	113	70	72	59	59	60	79	32	53	79	66	73	76	62	73	69	245
2	15	111	65	65	59	26	93	72	66	69	79	52	66	57	58	64	66	257
2	15	132	86	73	79	66	73	66	72	69	92	59	76	81	55	62	73	270
2	15	120	73	81	46	26	36	39	19	30	39	46	43	81	43	60	71	235
2	15	139	80	84	86	79	83	92	79	86	92	79	86	67	62	84	78	180
2	15	115	65	70	79	66	73	46	46	46	72	39	56	53	62	71	69	240
2	15	110	63	62	39	32	36	66	59	63	72	72	73	57	47	71	62	258
2	15	112	63	67	72	46	60	59	39	50	86	59	73	67	65	77	75	285
2	15	120	67	71	52	26	40	46	59	53	79	46	63	62	58	68	54	270
2	15	118	74	75	52	46	50	46	52	50	52	52	53	76	62	68	67	235
2	15	125	72	70	52	32	43	39	59	50	66	59	63	67	40	60	66	260
2	15	115	72	73	59	72	66	66	59	63	72	52	63	67	62	52	71	227
2	15	125	67	69	66	39	53	59	46	53	66	66	66	81	58	68	51	263
2	21	126	80	72	46	26	36	46	39	43	46	39	43	62	41	60	66	272
2	21	128	80	84	66	52	60	66	46	26	36	66	72	69	62	57	79	69	250
2	21	119	75	75	26	59	43	52	59	56	72	59	66	78	57	79	66	267
2	21	114	72	75	52	72	63	72	32	53	72	72	53	88	66	82	75	188
2	21	110	68	66	19	26	23	32	39	36	39	59	50	62	50	62	45	300
2	21	110	72	71	19	46	33	52	52	53	66	52	60	78	62	79	75	278
2	21	108	66	65	66	52	60	39	46	43	52	59	56	51	54	79	73	234
2	21	119	78	80	32	32	33	32	19	26	72	59	66	62	50	66	47	239
2	21	116	75	74	52	26	40	59	26	43	39	26	33	73	46	62	43	290
2	21	117	72	76	46	32	40	46	52	50	32	59	46	67	62	71	53	255
2	21	126	72	68	52	59	56	66	46	56	59	52	56	83	41	68	60	288
2	21	126	68	75	79	26	53	66	52	60	92	72	83	78	62	71	62	240
2	21	117	71	69	86	79	83	72	32	53	92	52	73	73	66	68	78	224
2	21	125	65	69	79	39	60	86	66	76	79	86	83	62	66	62	66	253
2	21	114	66	66	32	12	23	59	32	46	32	26	30	62	66	51	58	272
2	21	122	73	77	72	32	53	52	52	53	72	39	56	78	57	79	62	207
2	21	120	74	78	39	19	30	39	19	30	46	39	43	73	46	75	51	291
2	21	120	68	67	59	52	56	52	52	53	59	52	56	88	41	68	67	275
2	21	119	66	71	59	52	56	59	59	60	59	66	63	51	50	79	66	203
2	21	119	69	72	52	52	53	66	26	46	66	52	60	62	50	58	42	178
2	21	116	68	66	72	52	63	52	46	50	92	66	79	62	57	68	43	252
2	21	125	76	79	39	46	43	32	19	26	52	52	53	57	50	58	58	265
2	21	123	67	70	59	59	60	72	66	69	89	72	76	83	46	95	71	253
2	21	105	67	65	39	06	23	32	39	36	46	39	43	83	46	64	62	300
2	21	107	67	66	59	32	46	59	59	60	86	59	73	73	46	77	71	247
2	21	122	76	74	66	46	56	59	59	60	59	52	56	78	54	64	73	293
2	21	091	66	66	26	12	20	32	26	30	46	12	30	51	57	62	58	259

3	2	113	73	74	52	32	43	79	66	73	72	66	69	51	51	79	66	331
3	2	109	66	66	52	79	66	86	66	76	86	66	76	83	55	88	82	324
3	2	116	71	79	52	66	60	72	79	76	59	59	60	73	43	66	71	313
3	2	117	84	83	59	52	56	32	39	36	79	52	66	73	57	66	67	232
3	2	110	74	69	52	32	43	39	46	43	39	26	33	62	51	62	69	262
3	2	113	70	72	46	32	40	46	32	40	59	52	56	67	36	66	47	238
3	2	109	63	61	26	32	30	46	32	40	26	26	26	41	47	53	36	230
3	2	111	71	73	79	39	60	32	46	40	32	39	36	51	43	58	45	254
3	2	118	66	67	59	59	60	66	59	63	66	66	66	73	58	66	66	269
3	2	122	78	75	66	46	56	46	52	50	52	79	66	67	58	62	60	387
3	2	133	66	69	72	59	66	59	66	63	52	59	56	83	55	75	86	287
3	2	117	68	68	89	52	66	92	66	79	86	86	86	83	55	82	82	310
3	2	124	75	80	86	59	73	79	59	69	52	59	56	67	58	82	67	241
3	2	140	76	73	79	32	56	86	86	86	79	86	83	78	58	77	82	297
3	2	102	69	73	32	26	30	66	39	53	59	52	56	25	36	62	42	275
3	11	132	87	86	72	52	63	86	52	69	92	59	76	95	62	84	86	280
3	11	118	81	80	59	39	46	66	52	60	52	59	56	76	50	60	64	320
3	11	104	73	70	32	32	33	46	39	43	59	46	53	62	37	62	58	235
3	11	117	74	74	46	39	43	72	52	63	39	52	46	90	66	75	51	245
3	11	107	69	70	66	39	53	52	39	46	66	59	63	57	57	60	71	290
3	11	114	70	76	52	79	66	72	66	69	66	52	60	71	62	71	75	173
3	11	117	74	74	52	59	56	52	39	46	39	39	40	81	50	66	67	192
3	11	107	70	71	26	12	20	79	19	40	46	46	46	76	33	58	40	264
3	11	111	73	70	59	59	60	46	32	40	66	59	63	71	37	60	67	295
3	11	125	74	74	46	59	53	59	52	56	59	39	50	85	62	66	60	225
3	11	134	74	74	52	32	43	19	19	20	66	59	63	81	46	51	69	351
3	11	123	80	76	52	59	56	79	59	67	59	52	56	76	50	71	67	296
3	11	128	78	80	66	32	50	72	46	60	59	59	60	85	46	84	77	250
3	11	132	74	76	79	72	76	92	86	89	86	86	86	90	66	92	84	167
3	11	109	65	65	79	66	73	72	66	69	72	79	76	90	66	79	80	382
3	11	116	75	76	59	59	60	79	52	66	66	66	66	67	57	62	62	231
3	11	131	73	76	79	66	73	66	52	60	86	92	89	85	50	86	75	245
3	11	137	81	79	39	39	40	59	72	66	66	52	60	81	50	71	67	185
3	11	131	80	79	39	52	46	32	06	20	46	32	40	67	57	66	64	260
3	11	121	75	76	66	39	53	66	32	50	52	52	53	81	62	66	53	210
3	11	127	83	83	59	12	36	59	26	43	06	32	20	71	54	73	51	505
3	11	122	83	84	66	59	63	72	59	66	66	86	76	67	46	68	86	280
3	11	111	63	63	52	66	60	72	66	69	72	72	73	76	62	66	78	249
3	11	114	71	75	52	52	53	79	59	69	79	59	69	81	50	84	58	184
3	11	131	71	74	72	72	73	79	92	86	72	59	66	76	62	75	53	215
3	11	119	69	73	39	26	33	32	32	33	46	46	46	62	46	66	64	220
3	11	124	74	80	46	19	33	32	46	40	46	39	43	71	50	58	69	273
3	11	127	69	75	39	46	43	39	46	43	66	52	60	71	57	55	58	285
3	11	132	88	86	72	59	66	59	46	53	66	66	66	90	57	62	71	215
3	11	117	65	68	52	26	40	26	52	40	52	46	50	62	54	62	56	260

3	19	132	71	73	72	72	73	59	52	56	86	59	73	90	66	85	62	205
3	19	120	72	74	39	26	33	19	26	23	32	32	33	53	33	60	42	241
3	19	112	63	65	59	39	50	79	52	66	79	59	69	53	54	83	75	272
3	19	115	71	72	86	46	66	72	59	66	86	72	79	81	66	85	67	191
3	19	120	71	68	32	32	33	26	39	33	52	79	66	62	66	87	66	237
3	19	124	82	75	39	12	26	39	59	50	39	59	50	39	50	66	69	271
3	19	117	74	69	79	59	69	66	59	63	79	46	63	81	66	87	86	133
3	19	110	64	67	59	39	50	72	46	60	79	72	76	67	66	76	67	182
3	19	117	66	69	72	52	63	52	52	53	66	59	63	62	57	74	66	212
3	19	102	67	66	39	39	40	46	52	50	52	66	60	71	46	80	80	300
3	19	115	68	73	32	39	36	39	12	26	52	39	46	44	46	58	53	222
3	19	107	68	69	46	36	36	32	12	26	39	39	40	53	25	68	53	219
3	19	118	76	72	46	39	43	52	39	46	39	46	43	53	50	74	66	276
3	19	149	80	83	79	72	76	79	52	66	66	86	76	81	66	87	84	175
3	19	120	72	78	46	19	33	59	32	46	32	72	53	62	50	70	56	216
3	19	129	69	74	92	86	89	86	79	83	72	72	73	81	62	91	82	203
3	19	118	72	74	72	86	79	66	66	59	66	63	67	57	70	66	208	
3	19	117	66	69	86	59	73	72	72	73	79	79	79	60	66	93	62	171
3	19	120	67	68	26	19	23	39	26	33	39	26	33	53	46	64	38	255
3	19	111	68	68	66	46	56	66	52	60	66	39	53	85	50	68	56	244
3	19	114	65	71	59	59	60	72	39	56	59	59	60	76	66	87	80	180
3	19	122	69	71	59	46	53	52	52	53	72	59	66	62	54	68	66	253
3	19	133	74	82	46	52	50	39	26	33	32	39	36	67	66	74	53	165
3	19	126	72	73	92	59	76	79	79	79	72	72	73	85	57	72	64	220
3	19	113	61	63	46	32	40	52	39	46	52	39	46	71	37	83	64	162
3	19	110	75	71	32	12	23	12	12	13	26	32	30	76	29	54	45	300
3	19	116	63	64	32	12	23	19	32	26	39	26	33	39	33	74	56	290
3	23	120	81	81	59	79	69	59	59	60	39	39	40	76	58	78	58	274
3	23	118	74	76	66	79	73	86	79	83	92	86	89	81	65	78	82	194
3	23	124	71	75	59	46	53	79	79	79	59	79	79	95	69	80	77	254
3	23	138	74	73	46	32	40	66	86	76	46	39	43	81	69	66	62	230
3	23	116	66	67	59	46	53	66	66	66	79	52	66	81	65	70	75	241
3	23	115	75	76	46	19	33	36	19	30	66	52	60	67	62	60	64	275
3	23	126	64	72	59	79	69	66	52	60	39	32	36	62	69	85	62	188
3	23	124	71	73	46	26	36	39	32	36	46	76	60	67	60	64	49	310
3	23	112	65	64	39	32	36	46	46	46	39	32	36	53	58	85	45	199
3	23	114	70	68	52	66	60	59	46	53	32	26	30	90	47	66	53	281
3	23	113	75	72	79	66	73	66	46	56	72	66	69	62	62	87	80	200
3	23	120	69	70	52	46	50	86	66	76	72	59	66	85	65	62	71	235
3	23	115	63	68	52	66	60	66	52	60	66	59	63	76	62	83	58	175
3	23	126	76	81	52	19	36	59	39	50	52	39	46	67	51	56	47	252
3	23	118	65	65	92	52	73	86	66	76	72	72	73	81	69	70	78	240
3	23	115	77	78	39	26	33	39	12	26	26	32	30	81	36	64	56	187
3	23	124	71	71	79	32	56	59	59	60	59	79	69	71	69	70	47	279
3	23	119	66	64	59	52	56	79	79	79	92	72	83	95	62	72	69	242

[1] 1=Lecture, 2=Skinner, 3=Crowder

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