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ABSTRACT

The purpose of this study was to develop a taxonomy which would categorize high level physics problem-solving behaviors, and to examine the usefulness of such a classification system. This classification of learning objectives is based on complexity, a nonarbitrary measure which does not rely upon comparison between students but rather is based on the number of computational steps required. An experiment was conducted to compare the results of criterion referenced items based on the classification scheme with problem difficulty. Significant differences indicated that performance on more complex problems could not be predicted on the basis of zero or one step problems. Included are samples of zero-step, one step and multiple step criterion test items. The computer programs used to analyze the data are also included. The project was carried out by the New York Institute of Technology and was funded by the U. S. Office of Education. (TS)

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DOCUMENTATION REPORT

UNITED STATES NAVAL ACADEMY

Self-Paced

PHYSICS

5.8 CLASSIFICATION OF LEARNING OBJECTIVES

TECHNICAL REPORT 5.8

CLASSIFICATION OF LEARNING OBJECTIVES

Physics Program

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SECTION I: Introduction

Writing learning objectives for highly quantitative hard science courses requires careful specification of an elusive measure of level. For example, high school and college physics courses may cover essentially the same topical material, but with a profound difference in requirements and expected performance. The purpose of this study was to develop a taxonomy which would categorize high level physics problem-solving behaviors, and to examine the usefulness of such a classification system.

Our classification of learning objectives is based on complexity, a nonarbitrary measure which does not rely upon comparison between students. Basically, the scheme is to count the number of computational steps required. We examine the consistency between the proposed classification of complexity and the more familiar measure of student difficulty. By using the system to determine the significance of complexity as a variable in absolute and relative student performance, we intend to investigate the relationships between student performance and levels of complexity.

The classification system, as presented in this paper, evolved as a pragmatic consequence of an attempt to categorize the objectives of a physics program developed by educators for the U. S. Naval Academy. Originally the objectives were defined by verbal descriptions of the intended behavior, but various difficulties indicated a need to present objectives in more precise terms, as discussed in Section II. Objectives were therefore translated into problem form. The effort required for classifying was thus reduced to one of categorizing physics problems.

Once the objectives were defined in problem form, a classification scheme had to be developed. An objective measure of problem complexity, the number of computational steps required to solve the problem, was adopted. "A taxonomy must be validated by demonstrating its consistency with the theoretical views in research findings of the field it attempts to order."[1] A general discussion of taxonomies is presented in Section III.

The classification scheme proposed in Section IV fits the definition of taxonomy, as determined empirically. This procedure of counting mathematical steps is objective and a majority of physics questions fall uniquely and unambiguously into one of three categories. These categories have a clear hierarchal structure and can be assigned a numerical measure so that complexity can be viewed as an independent variable in student performance.

We tested the classification system at the Naval Academy. The subjects in the experiment were sophomore midshipmen, well above average in verbal and mathematical skill. Section V describes the experiment.

The results and conclusions are discussed in Section VI, and implications are drawn in Section VII.

[1]Benjamin S. Bloom, J. Thomas Hastings, and George F. Madaus, Handbook on Formative and Summative Evaluation of Student Learning (New York, 1971), p. 17.

SECTION II: Defining Learning Objectives

The need for defining objectives cannot be overemphasized. Leonard Blackman, in Frontiers in Education, feels: "The development of education as a science rather than an art form will be wholly dependent on concrete and measurable statements of educational objectives coupled with the highly specific delineation of instructional procedures leading toward those objectives."[2] Creating and constructing a detailed and comprehensive set of behavioral objectives is, then, a first major step in the process of course development. The objectives, taken collectively, define the content, scope, and organization of the course. They specify for both the student and the teacher the content and processes to be learned, and indicate the intended behavior of the student upon completion of the course.

In addition to defining the course, the objectives provide the course instructor or designer with a basis for evaluating student performance and course materials, and a basis upon which revision processes can be based. In a recent handbook by Benjamin Bloom, Leopold Klopfer promoted another use for objectives.

> In numerous science evaluation situations when observations of a student's performance are called for, there is a substantial degree of uncertainty in deciding how well he has done and how to guide him to do better. . . . The problem, then, is to find ways of developing much more detailed and precise specifications than have heretofore been attempted of the behaviors that the student is to attain. These specifications

[2]"The 'Brave New World' of Special Education," ed. Morey R. Fields (New York, 1967), p. 17.

> would also delineate the prerequisite behaviors leading to the desired criterion behaviors, so that the student who has not attained mastery may be given soundly based guidance.[3]

Because the objectives "identify the kind of behavior that will be accepted as evidence that the learner has achieved them,"[4] we can determine exactly how much of what was taught was actually learned. Data obtained by analysis of test items related to the objectives can provide us with information as to which objectives have not been successfully attained.

Still more can be provided by well defined objectives. They perform an important organizational task for the student. As "advance organizers" they provide a label under which the learner can store new knowledge and concepts. Too, they can work as synthesizing agents, relating separate items to form a larger whole. "The usefulness of a structure for learning has to do with the ability of students . . . to use it as an organizing factor in their learning."[5]

Much of Robert Mager's work has attempted to impress the educational community with the need to define objectives specifically. A meaningful objective is one that communicates to the reader the writer's instructional intent; the best statement is one that excludes the greatest number of possible alternatives, which succeeds in describing

[3]"Evaluation of Learning in Science," Handbook on Formative and Summative Evaluation of Student Learning, Benjamin S. Bloom, et al. (New York, 1971), pp. 637-638.

[4]Barbara E. Schure, "The Computer: An Adaptive Teacher," Some Essays on Computers in Education, ed. Margaret E. Pincus (Cambridge, Mass., Spring 1967), p. 51.

[5]Bloom, Handbook, p. 12.

the terminal behavior of the learner well enough to preclude misinterpretation. Others agree with Mager's requirement that the objectives be specific.

> A statement of an objective is an attempt by the teacher or curriculum maker to clarify within his own mind or communicate to others the sought-for changes in the learner. To accomplish this, the educator must choose words that convey the same meaning to all intended readers. Statements of objectives that can be interpreted differently by different readers give them no direction in selecting materials, organizing content, and describing obtained outcomes, nor do they provide a common basis for instruction or evaluation.[6]

The definition of an objective should include three facets. First, it must specify the behavior that a learner must elicit, preferably in terms that are understandable to both the instructor and the learner. Because we cannot see learning directly, we must base our analysis of learning on something more evident. "The change in performance is what leads to the conclusion that learning has occurred."[7]

> The short-term objectives must be stated in an unambiguous way so that they are clear not only to the teacher himself. . . . In order to communicate objectives precisely and unambiguously, it is not enough to specify independently the content to be covered or the abilities and skills the student is expected to acquire. Communicability requires accurate statements of the expected behavioral changes related to a particular content area.[8]

Second, the conditions under which this learning is to be demonstrated should be specified. If textbooks, slide rules, and other information sources can be consulted, the objective should so state. If the objective is to be achieved within a time limit, or if any other operating constraints are imposed, these should also be specified.

[6]Bloom, Handbook, p. 20.

[7]Robert M. Gagne, The Conditions of Learning (New York, 1965), p. 6.

[8]Bloom, Handbook, p. 23.

The criteria of acceptable performance is another aspect which should be included in the process of defining objectives. The student and instructor must both know what degree of competency is required and what measurable evidence of this achievement will be acceptable.

> One way of making the objectives more detailed is to specify the behaviors the student should possess or exhibit if he has attained the objectives. . . . Another way of giving further clarity to the specifications of outcomes is to represent them in the form of the problems, questions, tasks, and the like which the student should be able to do or the kinds of reactions he should give to specific questions or situations.[9]

By developing criterion test items to clarify acceptable behavior at the time the objectives are defined, we have a basis for measuring the achievement of an objective, and, at the same time we avoid the possibility of making the objectives depend on relative performance. Measurement of achievement, Branson emphasizes, must be on an absolute standard, "since each person in the class has the opportunity to meet the prescribed specifications, regardless of how well or poorly his classmates do."[10] Relative achievement of one student against another defers establishment of levels of acceptable competence until we grade student papers.

Thus we build the term "Measurable Behavioral Objective" (MBO). Since not all objectives are equivalent in importance, scope, or complexity, we can group these MBOs into terminal and enabling objectives. Terminal objectives are the desired final behaviors and enabling objectives are the more specific smaller blocks leading toward the terminal objectives.

[9]Bloom, Handbook, p. 15.

[10]Robert K. Branson, "The Criterion Problem in Programmed Instruction," Educational Technology, July 1970, 36.

Enabling objectives represent the transitional type of skill or knowledge which is believed to be a precondition for success on the terminal objective. Not all the enabling objectives are of equal importance, nor do we assume they are of equal degree of difficulty to attain. Enabling objectives may or may not "build" upon each other; it is sufficient only that they facilitate the mastery of their associated terminal objectives. We have, then, distinct simpler behaviors as components of more complex behaviors.[11]

Intuition suggests that not all learning is the same, and observation and research concur. "A serious attempt to describe learning must take all these varieties into account. Naturally, it must make differentiations among them, and classifications of them, if these are possible."[12] What we attempt to do with defined objectives, then, is "to order phenomena in ways which will reveal some of their essential properties as well as the interrelationships among them."[13]

In the physics project, we began with verbal statements of objectives. Their lack of precision, however, resulted in a lack of clarity. Students were not able to assess the objective's level and scope, and so were not certain exactly what was expected of them. Professors with little specific classroom experience, regardless of their subject matter expertise, could not be sure to what extent any content was to be covered. Although there was professorial consensus

[11]Benjamin S. Bloom, et al., Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook I: The Cognitive Domain (New York, 1956), p. 16.

[12]Gagne, Conditions, p. 20.

[13]Bloom, Taxonomy, p. 17.

on a list of objectives, there was little agreement on whether the objectives were achieved: evaluation of student progress was less than standardized.

Use of verbal objectives revealed another more serious, though less obvious, hazard. Enabling objectives are clearly discerned by the course instructor or designer only when he executes the behavior called for in the terminal objective. Each necessary step toward terminal behavior is then, by definition, an enabling objective. When a terminal objective is "fuzzy" the requisite steps for its achievement are even less clear. Our experience has been that this situation leads to poor ordering of enabling objectives under a terminal objective, a number of redundant enabling objectives, and a few omissions of enabling objectives.

We reformulated the objectives into problem form to eliminate these difficulties. With a precise problem to represent a terminal objective, any subject matter expert can perform the steps for its solution and identify the individual steps as enabling objectives. Moreover, specifying objectives in problem form indicates to students what behavior will be considered acceptable and under what constraints their behavior must be evidenced.

When acceptable performance is defined as correctly solving a problem, relative performance measures are obviated. Relative grades depend not on success in achieving the objectives but on achieving more or fewer than other students.

> We have become accustomed to classifying students in about five levels of performance and assigning grades in some relative fashion. It matters not that the failures of one year performed at about the same level as the C students of another year. Nor does it matter that the A students of one

> school do about as well as the F students of another. . . . There is nothing sacred about the normal curve. It is the distribution most appropriate to chance and random activity. Education is a purposeful activity, and we seek to have the students learn what we have to teach. If we are effective in our instruction, the distribution of achievement should be very different from the normal curve. In fact, we may even insist that our educational efforts have been unsuccessful to the extent that the distribution of achievement approximates the normal distribution.[14]

The concept of casting objectives into problem form follows closely from developing test questions with which to measure achievement of those objectives.

> As objectives are developed and approved by the subject matter expert, test questions will be developed to cover these objectives. . . . In this way, one can determine from test items missed which educational objectives are not being met.[15]

By making the test items synonymous with the objectives we have an indication of attainment of the objectives which is more closely related to the objective. "This represents the most detailed and precise definition . . . since it indicates the tasks the student is expected to perform and the specific behavior he is expected to exhibit."[16]

[14] Bloom, Handbook, p. 45.

[15] Donald T. Tosti, Research and Evaluation Plans, Part I (Westinghouse Learning Corporation, Palo Alto, Calif., January 1969), p. 12.

[16] Bloom, Taxonomy, pp. 44-45.

SECTION III: Classifying Learning Objectives

There is no definitive system for classifying learning behaviors in a way which is suitable to all fields and levels of learning. Nor do the experts--educators, researchers, subject matter specialists--suggest that an ultimate model is necessary. Instead, in an attempt to classify learning conditions, general guidelines have been advanced which can be altered to suit specific courses of study.

Generally accepted is the notion that we store information in a hierarchal manner, building upon simple facts and skills to develop more complex principles and concepts. Classification of behaviors into terminal and enabling forms implies a recognition that some behaviors are subordinate to others.

> The clearest evidence that problem solving "can be conceived as a linear sequence of operations" is provided by the extensive work on simulation of cognitive processes. . . . This same work also provides clear evidence of the importance of hierarchal relations not only in problem solving but in other kinds of behavior.[17]

From that point of concurrence, independently developed taxonomies often vary, some based on difficulty, some on levels of abstractness, others on still other variables. This is no handicap, however, for there seems to be no reason to impose rigorous laws on the nature of learning. Rather, the ultimate purpose of any classification system is the need for more information about the learner and the task to be learned, and the relationship between these. As long as a taxonomy offers some insight to this end, it is a useful classification scheme.

[17]Donald W. Taylor, "Discussion of Papers by Adriaan D. de Groot and by Jeffery M. Paige and Herbert A. Simon," Problem Solving: Research, Method, and Theory, ed. Benjamin Kleinmuntz (New York, 1966), p. 124.

Benjamin Bloom finds that "there could be an almost infinite number of ways of dividing and naming the domains of education outcomes,"[18] since the determination of classes is in some ways arbitrary. He suggests a hierarchy of levels of behavior that relate to the difficulty and complexity of the learning process.[19] Bloom and his associates divided the cognitive domain into six major classes of educational objectives, each in turn subdivided into further specific behavior classifications. The subdivisions of these major categories are vaguely defined, some being distinct in content rather than in form. Only by studying the example test items offered can some of the ambiguity be cleared away.

> Although we have little difficulty in determining the major class within which a behavior falls, we still are not satisfied that there are enough clearly defined subclassifications to provide adequately for the great variety of objectives we have attempted to classify.[20]

Bloom's intention of comprehensiveness, that is, setting up a classification scheme which would provide for all cognitive behavior found in an educational setting, demanded a certain degree of generality. The categories Bloom offers present a good generalized model of learning activities in the classroom. Because they are so inclusive, covering "a greater range of educational objectives than is typical at the secondary or college level,"[21] some alteration of the basic scheme is necessary in order to apply it to any specific field.

[18]Bloom, Taxonomy, p. 13.

[19]Bloom, Handbook, p. 119.

[20]Bloom, Taxonomy, p. 21.

[21]Bloom, Taxonomy, p. 25.

One can be more specific about categorizing objectives by narrowing the variety under investigation. "It is evident that the use of a limited number of categories, or components of knowledge or skill, does not necessarily imply a limited numb. of kinds of knowledge or skill."[22] What we gain by focusing our attention more specifically on the higher level problem-solving categories is a classification system appropriate for ordering physics problem complexity.

Complexity, to distinguish it from difficulty, is a nonarbitrary objective standard. It is a quality inherent in the task. Depending upon one's qualifications, it may be easy or not to achieve. In either case, complexity level can be determined in the absence of performance measures and does not require knowledge of preceding learning experience.

Difficulty, on the other hand, is both a more relative and more subjective measure. It is often determined by professorial experience with prior student performance on similar items, or by analysis of student performance, often long after it would be useful for formative evaluation. When Bloom says that a reader "must know . . . the learning situations which have preceded the test,"[23] we are reminded that he does not clearly distinguish between difficulty and complexity (see n. 19, above). We expect a high correlation between these two measures, but we cannot assume their equivalence.

[22]Francis Mechner, "Behavioral Analysis and Instructional Sequencing," Programmed Instruction, ed. Phil C. Lange (Chicago, 1967), p. 83.

[23]Bloom Taxonomy, p. 51.

By comparing problem complexity with student difficulty, we should find evidence of the appropriateness of our hierarchy. "If this is the real order from simple to complex, it should be related to an order of difficulty such that problems requiring behavior A alone should be answered correctly more frequently than problems requiring AB."[24] It is believed that difficulty, too, follows a hierarchal order:

> That is, the test items for knowledge of specific facts or terms should be passed by more students than those for knowledge of rules and principles or skill in the use of processes. Also, the test items involving translation and application are likely to be more difficult, and thus to be passed by fewer students.[25]

If correlations between these two measures are high, it would suggest a validity in our taxonomy.

[24] Bloom, Taxonomy, p. 23.

[25] Bloom, Handbook, p. 129.

SECTION IV: The Hierarchy Defined

Earlier classification systems advanced were inappropriate for one or more reasons: too general, covering more kinds of behavior than were apparent or necessary to test in a physics problem-solving course; too ambiguously or nonobjectively defined, requiring suppositions about internal thought processes or arbitrary assignment to subclassifications; too history dependent, requiring previous learning experiences as a base. For these reasons it was decided to adopt an objective measure of problem complexity for categorization purposes. This was taken to be the number of computational steps required to solve the problem in question; in short, a measure of complexity determined by counting mathematical steps.

For this initial investigation, three categories of objectives were identified, and a catch-all gray category was invented. They are listed in order of increasing complexity.

(1) Zero Step Problems: Those questions which do not require any mathematical manipulation. Recall of a fact or definition, or the recognition of an object, fact, or definition fall into this category. Even difficult conceptual problems or associations are categorized as zero step questions whenever there are no algebraic steps involved. All word problems; that is, problems which are nonnumerical and nonsymbolic, are zero step problems.

(2) One Step Problems: Those problems which require the solution of one algebraic equation for one unknown, or a single calculus operation (differential or integration).

(3) Multiple Step Problems: All problems which require the solution of more than one algebraic equation, or more than one calculus operation.

We do not distinguish between two, three, or more step problems, since we can analyze the number of steps only in the intended behavior, not the actual behavior. "We do not expect all students to use the skills acquired in a course in exactly the same way. The higher one proceeds up the education ladder, the more apparent this becomes."[26] By eliminating the distinction between, say, two and three step problems, we minimize the difference between intended and actual behavior.

In addition, when more than a single operation (step) is required to solve a problem, even experts frequently disagree as to the "best" way to solve it and the number of steps required.

> Many problems give no clue as to how many, or what, intermediate steps must be taken. . . . And if the operation is not a formal analytic tool, like arithmetic addition, two solvers may apply the same operation with different numbers of steps.[27]

Clearly, ambiguities in the step counting process are much more likely to occur in multiple step problems.

A fourth catch-all category included all problems which were judged not valid or which did not fall precisely into one of the three categories. Problems which had errors, insufficient information, or ambiguities were relegated to this category, as were many graphical problems which require geometrical steps rather than algebraic steps.

[26]Bloom, Handbook, p. 26.

[27]Helen I. Snyder, Contemporary Educational Psychology: Some Models Applied to the School Setting (New York, 1968), p. 66.

A majority of problems lacking clear definition required simple arithmetic operations; we did not want to equate trivial arithmetic computations with algebraic steps.

Of course, all the valid problems can still be assigned to categories by making the above definitions more exhaustive and detailed. More inclusive categories will be developed in the future; at present we wish to examine the most elemental scheme without including all possible ramifications.

A complete listing of the items in each category used in the analyses can be found in Appendices A, B, and C.

SECTION V: The Experiment

The course materials and procedures discussed below describe, in part, the physics course delivered under Contract No. N00600-68C-0749 to the U. S. Office of Education for development, validation, and installation at the U. S. Naval Academy. The course, as delivered, is self-paced, independent study, multimedia, computer or manually managed, introductory classical physics.

There were 513 students available for taking the required course at the Academy in the Fall 1969 semester. All had finished one year of college at the Academy and were generally engineering and applied science majors. Their college experience included one year of chemistry and introductory calculus. Understandably, this is a highly select and homogeneous group of subjects. The students were randomly assigned to one of three groups. Control Group I consisted of students taking the conventional course, as it had been developed and taught by the Academy Physics staff. Control Group II consisted of students also taking the conventional course, but, in addition, being given the criterion tests developed for the multimedia course.

The Experimental Group was made up of those students taking the multimedia course developed by N.Y.I.T. under contract to the Office of Education. Each week the students were required to complete a Study Guide in the form of a scrambled text, which consisted of 45 to 72 problems. The students responded to these multiple choice problems on IBM punch cards, which served as recording and directing devices, since the student had to punch his card to find out where to go for the next question and to find out if he had made the correct answer selection. As he progressed through the Study Guide, he was directed to media presentations, readings, homework assignments, and the various other course components. The students worked at their own rates throughout the week, but were required to take the criterion test together at the end of each week.

Each student was given a copy of the test, and wrote his answers on separate answer forms, which were then scored by comparing responses to those listed on a preestablished answer key. In order to encourage the students to work consistently throughout the semester, it was recommended that the criterion tests be weighted as 60% of the total grade.

Criterion test questions were prepared from the verbal objectives of the development phase of the project by the same team of physicists who developed the course materials. The test questions were then sent to Annapolis for approval by those members of the Navy Physics staff who were involved in the multimedia project. The approved problems, with any alterations, additions, or deletions, were then returned to the project team at N.Y.I.T., where the questions were analyzed and assigned to one of three problem categories: zero step, one step, and multiple step. Those problems which could not be uniquely classified into one of these categories were assigned to a fourth category, gray. Later, if errors which would affect performance were found in a problem, it too was reclassified as gray, and excluded from the analyses.

The criterion test for the week's work was given on Saturday morning to the midshipmen at the Academy who participated in the multimedia course. Tests varied in length from seven to ten problems, most having ten. A total of 79 of the 126 problems were acceptably classified in this initial effort.

Those students absent from a group session when the weekly tests were given had the opportunity for a make-up exam at a later date. Because the exact nature of the make-up test could not be controlled at N.Y.I.T., only those students having taken all 79 criterion test questions used for analysis were included in the present study. Of 197 students in the Experimental Group, only 41 students fulfilled this requirement.

Analyses were conducted on the set of 41 subjects who had complete data on all criterion test questions determined to be nonarbitrary. The problems were sorted by learning category, and percentage correct in each category was computed for each student.

SECTION VI: Calculations and Results

Our analysis of the data is directed toward three interrelated questions:

(1) Is categorizing by complexity consistent with more familiar measures of performance?

(2) What is the relationship between complexity and absolute student performance; is complexity a good predictive variable?

(3) What is the relationship between complexity and relative student performance; is complexity a good predictive variable?

Intuition dictates that problem solving difficulty should be well correlated with any reasonable measure of problem complexity. As an objective standard of student performance difficulty, we take the percentage incorrect for each student in each category. (See Appendix D for the individual performance graphs.) By assigning numerical measures to the complexity categories; 0, 1, and 2 to zero step, one step, and multiple step, respectively, we find the relationship between the categories of complexity and student difficulty. The correlation coefficient we obtain is

$$r = .94$$

which is significant at the .01 level. Clearly, difficulty and complexity are well correlated, and we conclude that our measure of complexity is consistent with the more familiar measure of student difficulty. The special advantage, of course, of the complexity hierarchy is that it can be determined

<u>before</u> testing takes place; whereas an objective measure of student difficulty can only be obtained after a performance check.

The data indicate that complexity as defined in this paper is an important variable for absolute student performance in problem solving. Remarkably, average percentage correct for all students in each category (71%, 61%, 49%), is virtually a perfect linear function of complexity, as illustrated in Figure 1. The decline of absolute performance with increasing complexity is completely expected.

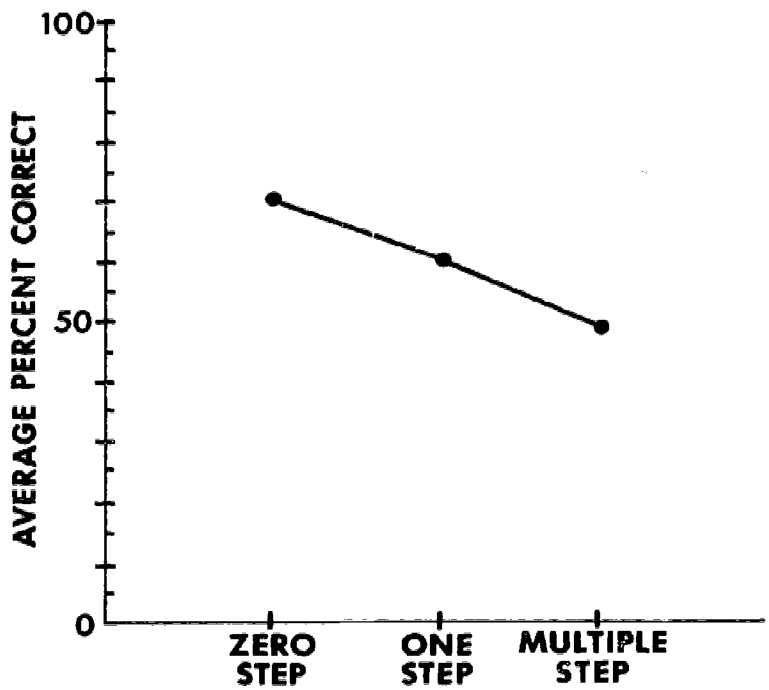

Figure 1 Average percentage correct for all students in each category.

Correlations of student performance scores for the three pairs of categories were calculated. (Figures 2, 3, and 4 represent these correlations graphically.)

Zero step/Multiple step	r = .35
Zero step/One step	r = .44
One step/Multiple step	r = .65

The first correlation is significant to the .05 level; the other correlations are significant to the .01 level.

These correlations show clearly that absolute performance in zero step problems is not an accurate predictor of performance in one or multiple step problems. Even the higher correlation between one and multiple step (.65) is insufficient to make a definitive prediction of performance in multiple step problems based upon performance in one step problems. This conclusion may have important consequences for the physics graduate record examinations which are generally limited to zero and one step problems. When it is important to measure high capabilities for synthesizing complex problem elements, multiple step performance must still be tested.

We note that the correlations indicate a closer relation between the two categories which require mathematical manipulation (.65) than between the nonmathematical zero step category and the one step mathematical category (.44).

A perfect correlation of student performance in any pair of categories would indicate that performance does not depend upon complexity at all since a change in complexity (change in category) causes no change in performance. The larger correlations between the one step and multiple step categories indicate that performance is less sensitive to changes at the high end of the complexity scale.

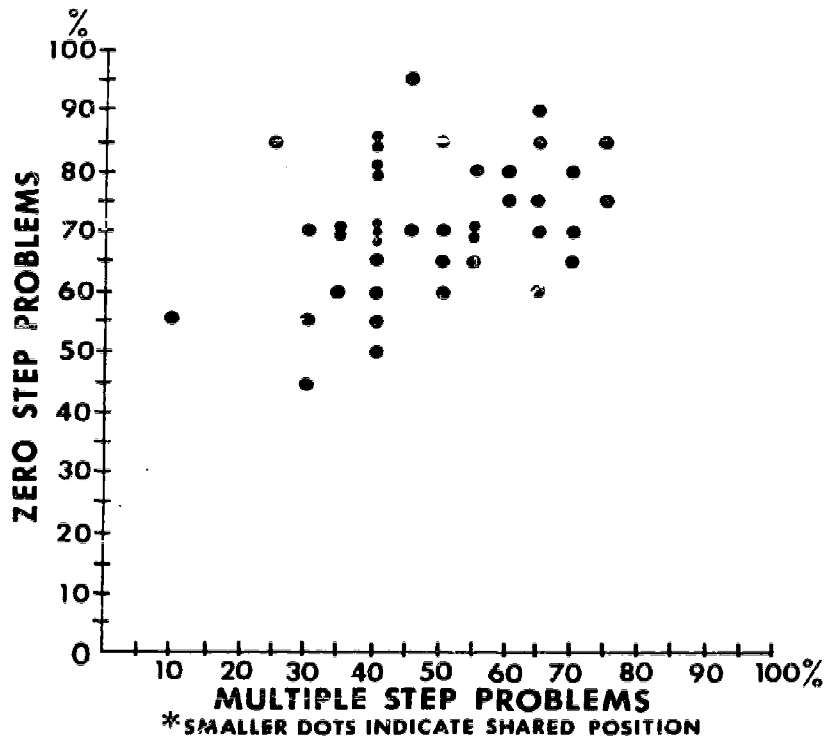

Figure 2 Correlation between zero step and multiple step problems.

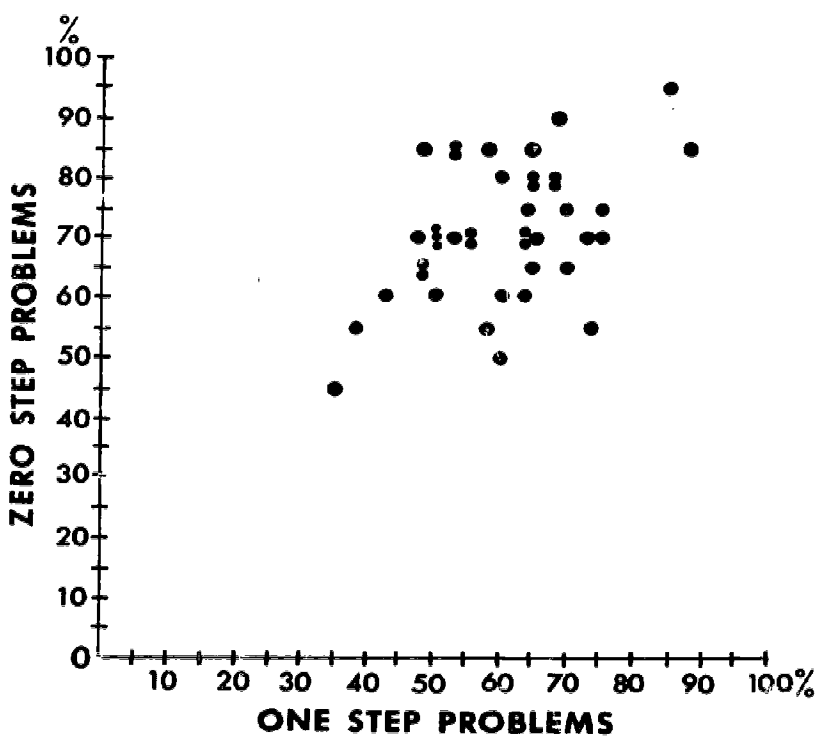

Figure 3 Correlation between zero step and one step problems.

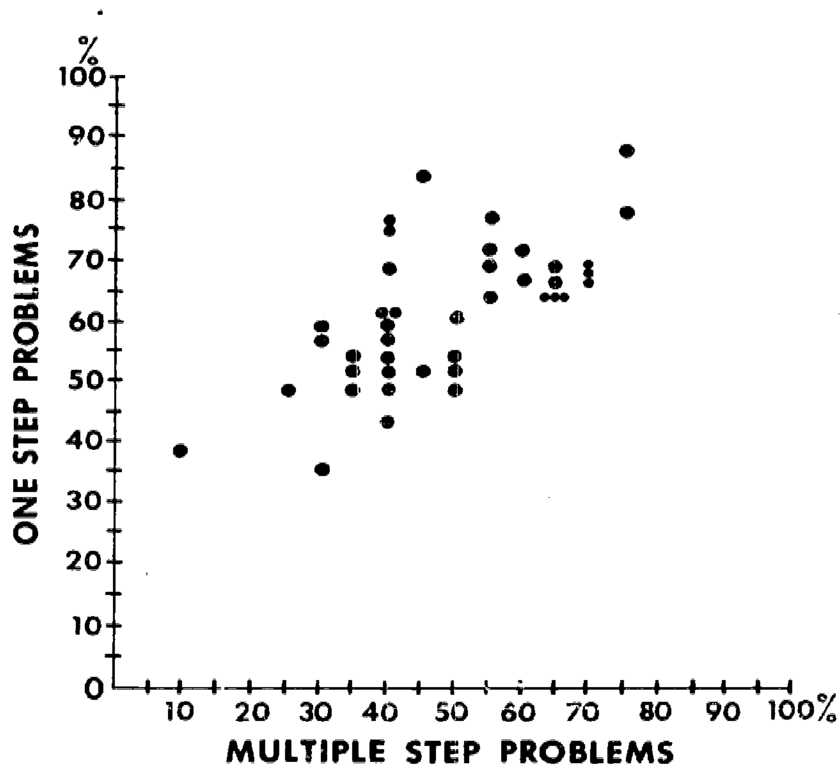

Figure 4 Correlation between one step and multiple step problems.

To ascertain whether relative performance in one category is related to relative performance in other categories, we computed the Kendall W. This is a measure of concordance of student rank across all three categories. The result is

W = .63

which is significant at the .01 level. This agreement between ranks is not unexpected. The high correlation indicates that students roughly maintain their relative problem solving ability across all categories.

This finding tends to support the attitude that "a 'B' student is a 'B' student whatever the test." The correlation is still too low to be taken as anything more than a very rough indicator. In short, relative performance in two categories is a crude predictor of relative performance in a third category.

SECTION VII: Discussion

We have proposed a classification system for problem solving behavior based upon complexity. The basic method was to classify according to the objective measure of computational steps required for the solution of the problem.

When the categories were assigned a numerical value, complexity was regarded as a mathematical variable upon which performance was strongly dependent. An increase in complexity resulted in a decrease in absolute performance. The analysis indicated a closer correlation between one and multiple step performance than between zero and one or zero and multiple performance. Analysis of concordance of rank indicated that students roughly maintain their ranks across complexity categories.

The finding of less sensitivity at the complex end of the hierarchy further justifies our lack of distinction between different numbers of multiple step problems. Originally, we did not distinguish between levels of computational problems above two steps for a practical reason: determining how economical a student is in solving a multiple step problem is somewhat arbitrary. Experimental results are consistent with our categorizing these problems merely as multiple step.

Clearly, a prediction of student performance based solely on complexity would be questionable, but its utility as an index of problem difficulty cannot be minimized. Since a measurable objective must specify performance, and performance is highly dependent upon complexity, it follows that complexity should be specified for hard science objectives. Even if objectives are stated in problem form, the complexity category of the problem should be known in order that variations of the problem (for use on a final exam, or for comparison purposes) can have equivalent complexity.

> We are finally, slowly, painfully beginning to find better ways of measuring educational results, not just in terms of achievement in broad areas as measured by standardized tests and compared with group norms, but in terms of learning outcomes compared with objectives stated in behavioral terms.[28]

The taxonomy advanced by this paper should prove to be a useful systematizing agent. Defining classes of behavior suggests certain implications for the establishment of those behaviors[29] which guide our instructional procedures. As a result of this investigation, we would conclude that enabling objectives should not be more complex than the related terminal objective. Enabling objectives should facilitate success on the terminal objective; as the complexity of an enabling objective increases, it is likely to produce a decrease in performance.

The classification system investigated here presents a useful method of categorizing problem solving behavior. It is hoped that classification by complexity will contribute somewhat to our understanding of the educational process.

> A more adequate analysis and classification of the variety of the processes employed in thinking is prerequisite to the development of a more adequate theory of problem solving, or of thinking more generally. At this stage, it may well

[28]Robert W. Locke, "Has the Education Industry Lost its Nerve?" Saturday Review, January 16, 1971, 44.

[29]Robert Gagne, "The Analysis of Instructional Objectives for the Design of Instruction," Teaching Machines and Programmed Learning, II: Data and Directions, ed. Robert Glaser (Washington, D.C., 1965), p. 25.

be most fruitful to focus upon the development of limited theories of problem solving. . . . One would hope, however, that in the identification of processes in these limited areas, one might proceed to the construction of more general theories.[30]

[30]Taylor, p. 125.

BIBLIOGRAPHY

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Blackman, Leonard S. "The 'Brave New World' of Special Education," Frontiers in Education, ed. Morey R. Fields. New York, 1967.

Bloom, Benjamin S., et al. Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook I: The Cognitive Domain. New York, 1956.

Bloom, Benjamin S., J. Thomas Hastings, and George F. Madaus. Handbook on Formative and Summative Evaluation of Student Learning. New York, 1971.

Branson, Robert K. "The Criterion Problem in Programmed Instruction," Educational Technology. July 1970.

Bruner, Jerome S., Rose Olver, and Patricia Greenfield, eds. Studies in Cognitive Growth. New York, 1966.

Bruner, Jerome S. The Process of Education. New York, 1963.

Bruner, Jerome S., Jacqueline Goodnow, and George Austin. A Study of Thinking. New York, 1962.

Feigenbaum, Edward A. and Julian Feldman. Computers and Thought. New York, 1963.

Gage, N. L., ed. Handbook of Research on Teaching. Chicago, 1963.

Gagne, Robert M. The Conditions of Learning. New York, 1965.

Gagne, Robert M. "The Analysis of Instructional Objectives for the Design of Instruction," Teaching Machines and Programmed Learning, II: Data and Directions, ed. Robert Glaser. Washington, D. C., 1965.

Hunt, Earl B. Concept Learning: An Information Processing Problem. New York, 1962.

Kleinmuntz, Benjamin, ed. Problem Solving: Research, Method, and Theory. New York, 1966.

Klopfer, Leopold E. "Evaluation of Learning in Science," Handbook on Formative and Summative Evaluation of Student Learning, Benjamin S. Bloom, J. Thomas Hastings, and George F. Madaus. New York, 1971.

Lange, Phil C., ed. Programmed Instruction. The 66th Yearbook of the National Society for the Study of Education, Part II. Chicago, 1967.

Locke, Robert W. "Has the Education Industry Lost its Nerve?" Saturday Review, January 16, 1971.

Mager, Robert F. and Kenneth M. Beach, Jr. Developing Vocational Instruction. Palo Alto, Calif., 1967.

Mager, Robert F. Preparing Instructional Objectives. Palo Alto, Calif., 1962.

Mechner, Francis. "Behavioral Analysis and Instructional Sequencing," Programmed Instruction, ed. Phil C. Lange. Chicago, 1967.

Schure, Barbara E. "The Computer: An Adaptive Teacher," Some Essays on Computers in Education, ed. Margaret E. Pincus. Cambridge, Mass., Spring 1967.

Skinner, B. F. The Technology of Teaching. New York, 1968.

Snyder, Helen I. Contemporary Educational Psychology: Some Models Applied to the School Setting. New York, 1968.

Taber, Julian, Robert Glaser, and Halmuth Schaefer. Learning and Programmed Instruction. Reading, Mass., 1965.

Taylor, Donald W. "Discussion of Papers," Problem Solving: Research, Method, and Theory, ed. Benjamin Kleinmuntz. New York, 1966.

Tosti, Donald T. Research and Evaluation Plans, Part I. Westinghouse Learning Corporation, Palo Alto, Calif., January 1969.

APPENDICES

APPENDIX A

Criterion Test Items: Zero Step

1. At time t = 0, a puck is observed to move on a frictionless horizontal table with a speed of 40 ft/sec. After two seconds the speed f the puck is:

2. If the work done by a force on an object in moving the object through a closed path is zero, the force is called:

3. f the following statements select the one which does not represent one of Kepler's three laws of planetary motion

A. A line joining any planet to the sun sweeps out equal areas in equal times.

B. The square of the period of any planet about the sun is proportional to the cube of the planet's mean distance from the sun.

C. All planets move in elliptical orbits having the sun as one focus.

D. The force of attraction between the sun and each planet is along the line joining the two and has magnitude which is proportional to the product of their masses and inversely proportional to the square of the distance between them.

4. Experiments performed on the surface of the Earth give a value for the universal gravitational constant

$$G = 3.44 \times 10^{-8} \text{ lb-ft}^2/\text{slug}^2$$

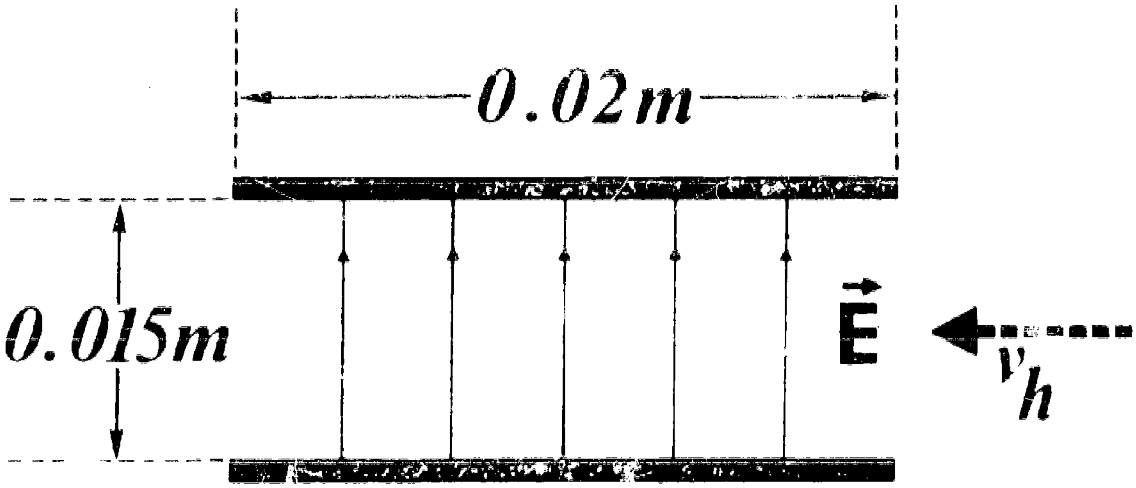
The mass of the moon is 1.23×10^{-2} that of the Earth and its radius is 0.27 times the Earth's radius. If an astronaut performed the same experiments on the surface of the moon, what value would he find for G?

5. From the following expressions select the <u>one</u> in which "m" (or "M") stands for inertial mass (as opposed to gravitational mass).

A.	weight of a body	$w = GmM/R^2$
B.	escape velocity	$v_o = \sqrt{2GM/R}$
C.	centripetal force	$F = mv^2/R$
D.	centripetal acceleration of a satellite	$a = GM/r^2$

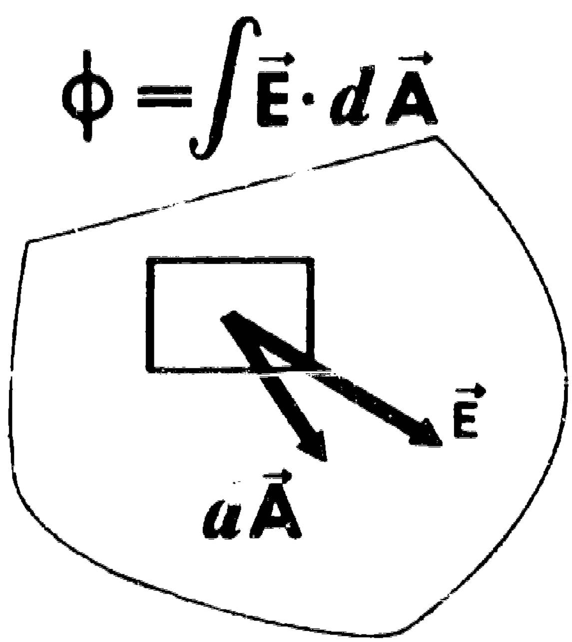
6. The charge developed on an insulated glass rod rubbed with a silk cloth is designated:

7.



An electron enters the space between two parallel plates with a horizontal velocity v_h = 100 km/sec (see diagram above). If the net electric field between the plates is $|E| = 10^{-1}$ nt/coul, what will be the horizontal velocity of the electron as it leaves the space between the plates on the left side? (The charge on an electron is $q_e = -1.6 \times 10^{-19}$ coul.)

8.



In the diagram above, the symbol ϕ is defined and it is called:

9. Which of the following can be considered a Gaussian surface? (There may be more than one.)

A. Spherical shell

B. Open-ended cylindrical shell

C. Six-sided cubical shell

D. A plane, 3 m × 4 m

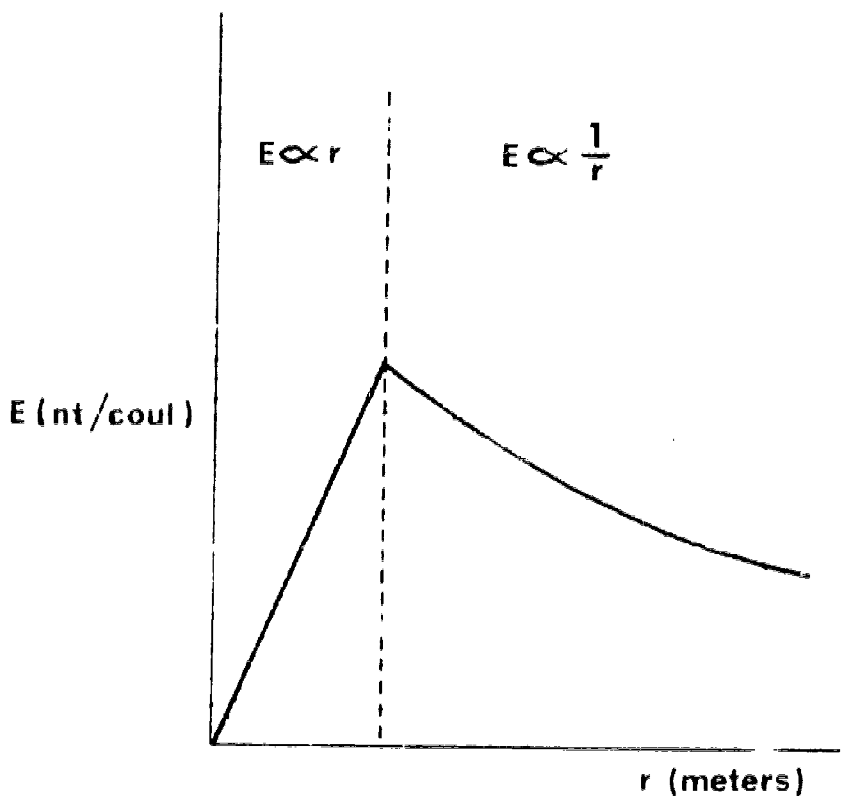
10. The diagram below shows the magnitude of the electric field plotted as a function of distance. The dependence of E upon r is given by the equation shown on the diagram. Which of the following objects could produce such an electric field?

A. A uniformly charged, non-conducting cylinder

B. A charged conducting sphere

C. A charged conducting cylinder

D. Either B or C



11. In the equation for Gauss's law

$$\oint \vec{E}\cdot dA = \frac{q}{\epsilon_o}$$

the q term indicates:

A. The charge enclosed by the Gaussian surface

B. The net charge enclosed by the Gaussian surface

C. The net charge enclosed by the Gaussian surface and any other charges in proximity to the Gaussian surface

D. The absolute value of the net charge enclosed by the Gaussian surface

12. You may need the following constant:

$$\frac{1}{4\pi\epsilon_o} = 9 \times 10^9 \text{ nt-m}^2/\text{coul}^2$$

Choose one or more of the following statements. An electric potential, $V_B - V_A$ is:

A. directly proportional to W_{AB}

B. indirectly proportional to $-W_{BA}$

C. indirectly proportional to q_o

D. directly proportional to q_o

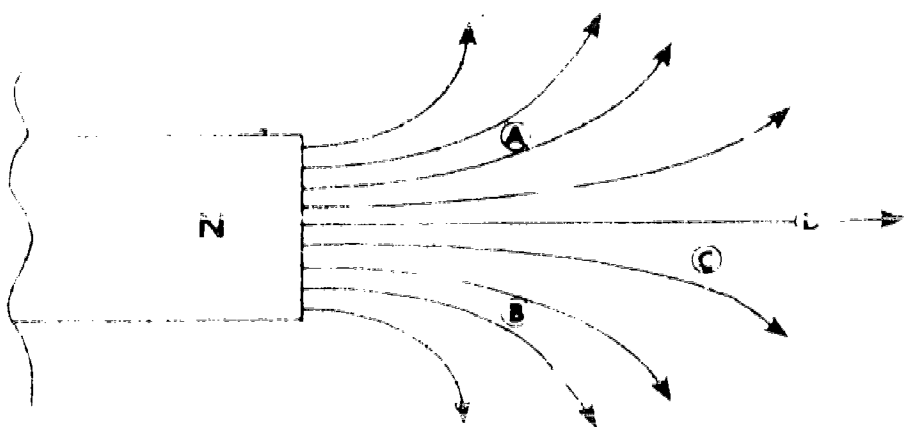
13. Which of the following is true about a uniform magnetic field? (There may be more than one, or there may be none.)

A. A charged particle will have a greater velocity after passing through a magnetic field.

B. A charged particle will have a smaller velocity after passing through a magnetic field in the direction of the field.

C. The kinetic energy of an electron cannot be changed by a magnetic field regardless of its position or its velocity.

14.



From the above diagram, which of the following is true? (There may be more than one, or there may be none.)

A. The magnetic field at points A and B has the same magnitude and direction.

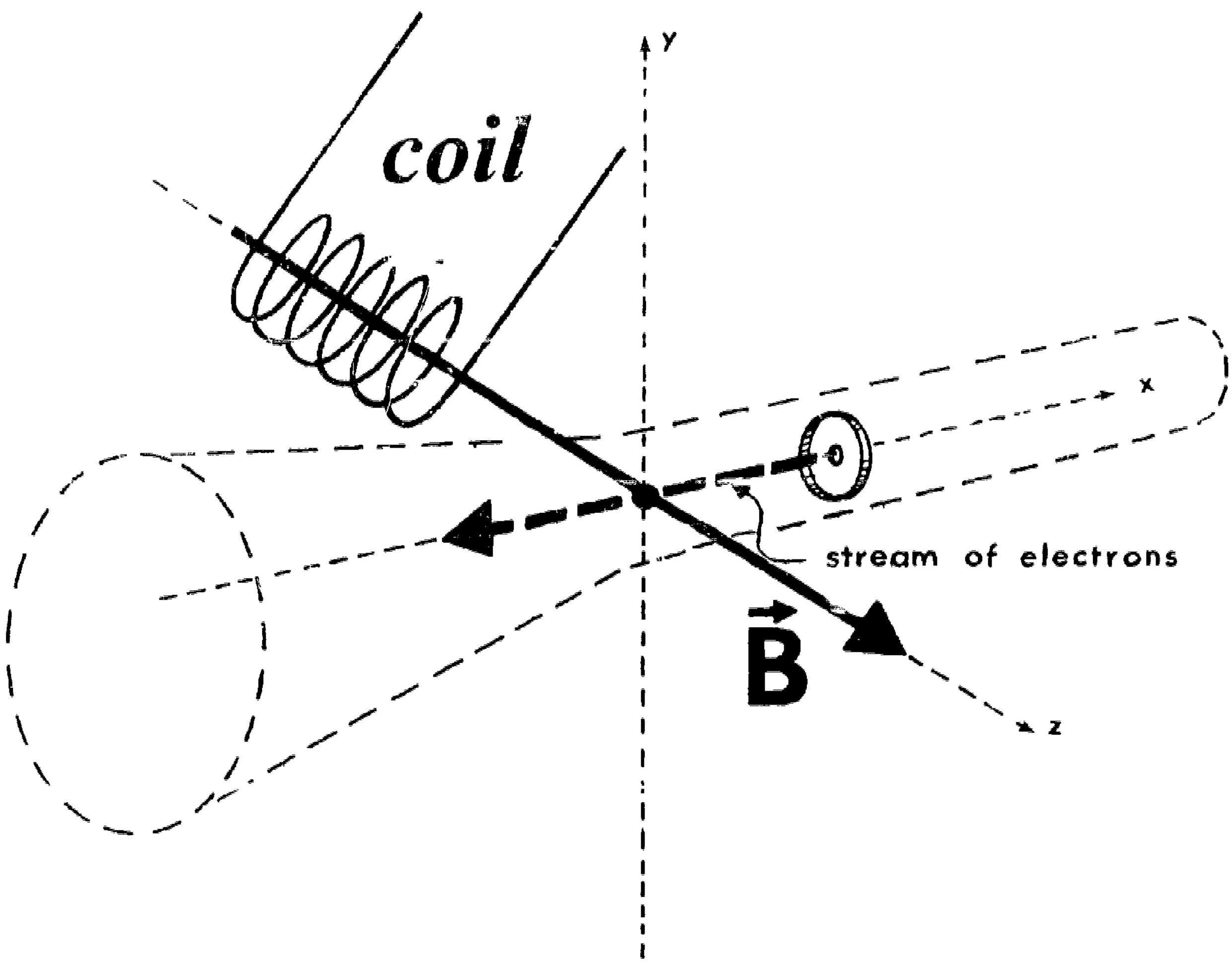
B. The magnetic field at points A and C are equal in magnitude only.

C. The magnetic field at point D is the largest.

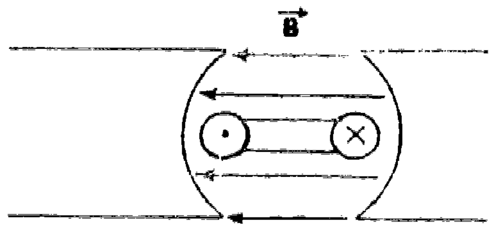
D. The magnitude of the magnetic field at point C is greater than the magnitude at point B.

15. The MKS unit of magnetic flux is the ______________ (one word).

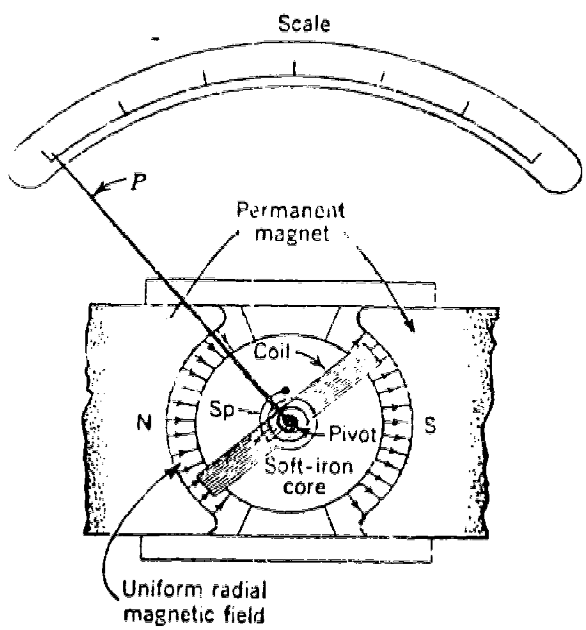
16. The diagram below shows the outline of a cathode-ray tube with electrons streaming out along the negative x-axis. A coil produces a magnetic field $\vec{B}$ in the positive z-direction. What must be the direction of an electric field in order to cause the electrons to pass through the tube <u>undeflected</u>?



17. The loop shown in the figure below would turn in the ____________ direction.



18. The diagram shows the elements of a device used to measure current. The device is called a ____________ (one word).



19. Which of the following statements are correct (there may be more than one).

A The direction of the magnetic induction lines produced by a current-carrying conductor is established by making use of the right-hand rule; i.e., with the thumb of the right hand pointing in the direction of the electron flow, the right-hand finger will curl in the same sense as the magnetic induction lines.

B. The direction of the magnetic induction lines produced by a current-carrying conductor is established by making use of the right-hand rule; i.e., with the thumb of the right hand pointing in the direction of the current, the right-hand finger will curl in the same sense as the magnetic induction lines.

C. The magnetic induction lines around a long, straight, current-carrying wire are circles whose centers are located at the axis of the wire and whose planes are normal to the axis of the wire.

D. The direction of the magnetic induction lines produced by a current-carrying conductor may also be determined by making use of the left-hand rule; i.e., with the thumb of the left hand pointing in the direction of the current, the left-hand finger will curl around the conductor in the same sense as the magnetic induction lines.

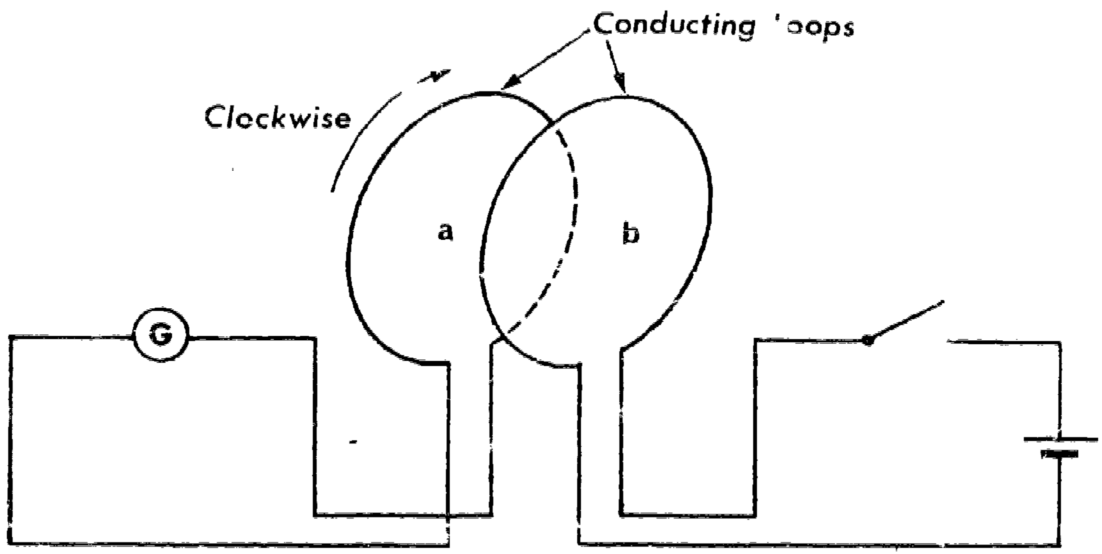
20. Immediately after the switch in circuit b is closed the current in loop a will be (select the appropriate one or more):

A. clockwise

B. counterclockwise

C. zero

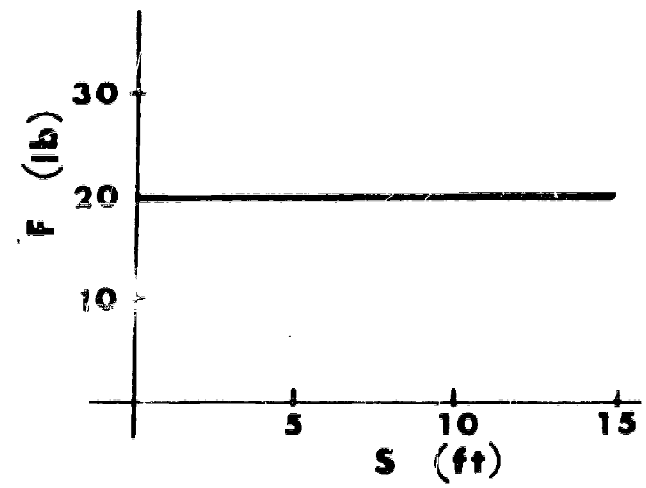
D. infinite



APPENDIX B

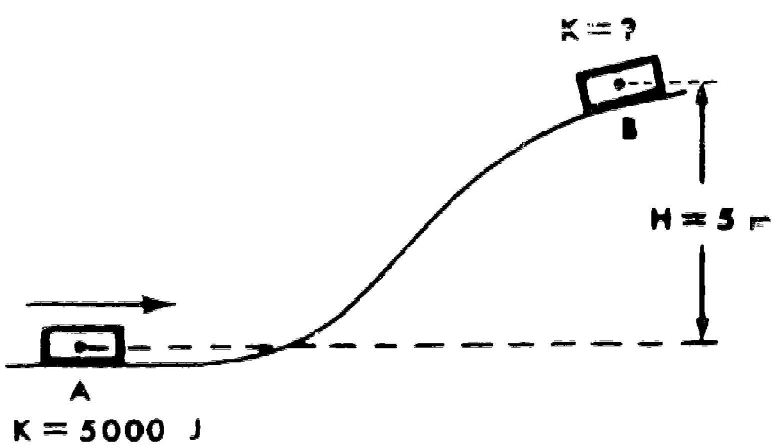
Criterion Test Items: One Step

1. The diagram shows how a force applied to a 5-lb object varies with the displacement of the object. Calculate the work done by this force in moving the object from the origin to s = 10 ft (include units).

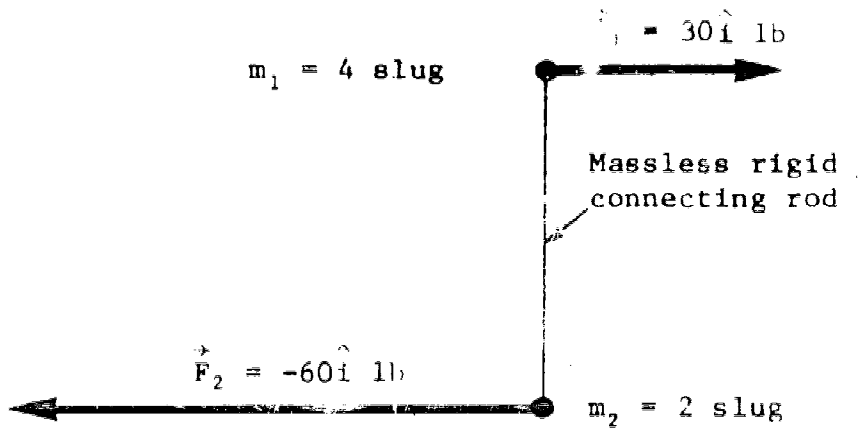


2. A constant force of magnitude 100 lb is required to move a block along a horizontal floor with constant speed of 4 ft/sec. The force is directed along the motion of the block. Calculate the power delivered by this force.

3. At point A a 100-kg roller coaster has a kinetic energy equal to 5000 J. What will be the kinetic energy of the coaster when it reaches a height of 5 m relative to the level of A (point B)? (Neglect friction.)

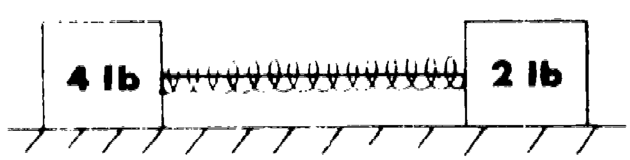


4. For the system of masses and forces shown in the diagram, the acceleration of the center of mass is:



5. A 4-kg body is moving toward the positive x-direction with a speed of 3 m/sec. What is the magnitude of the body's momentum? (Include units.)

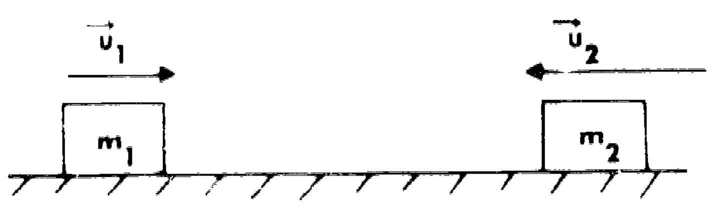
6. Two blocks weighing 4 lb and 2 lb, respectively, rest on a frictionless horizontal table. A compressed spring is placed between the two blocks but is not attached to either of the blocks. A string tied to the blocks keeps them from flying apart. Suddenly, the string breaks and the 4-lb block is observed to move to the left with a speed of 2 ft/sec. The 2-lb block is moving to the right with a speed of:



7. A 3-kg body is moving toward the <u>positive</u> x-direction with a speed of 2 m/sec. An impulsive force applied to this body causes it to change its velocity to 5 m/sec toward the <u>positive</u> x-direction. The magnitude of the impulse imparted to the body is (include units):

8. An impulsive force of constant direction and with average magnitude of 500 lb is applied to a body for a duration of 400 m sec ($1 \text{ m sec} = 10^{-3}$ sec). What is the magnitude of the impulse imparted to the body during this time interval?

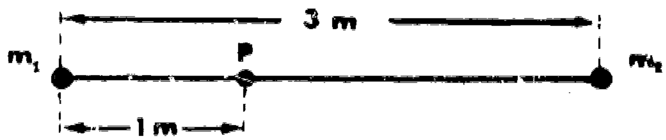
9. Two masses, $m_1 = 4$ slug and $m_2 = 2$ slug, move toward each other on a frictionless table with respective speeds of 4 ft/sec and 8 ft/sec.



They collide and after the collision m_1 moves directly to the left with a speed of 3 ft/sec. m_2 moves toward the right and has a speed of:

10. A 1000-kg car traveling due east with a speed of 30 m/sec collides with a 2000-kg truck traveling due north with a speed of 20 m/sec. The two vehicles lock together. The direction of the momentum of the two-vehicle body immediately after the collision is:

11. Two particles of masses $m_1 = 1$ kg and $m_2 = 4$ kg, respectively, are separated by a distance of 3 m. Neglecting the effect of all other masses in the universe, compute the magnitude of the gravitational field strength at a point (P) located on the line joining the two particles and at a distance of 1 m from m_1. ($G = 6.67 \times 10^{-11}$ nt-m^2/kg^2.)



12. For the two particles in problem 11 calculate the gravitational potential at point P. (Again neglect the effect of all other masses in the universe.)

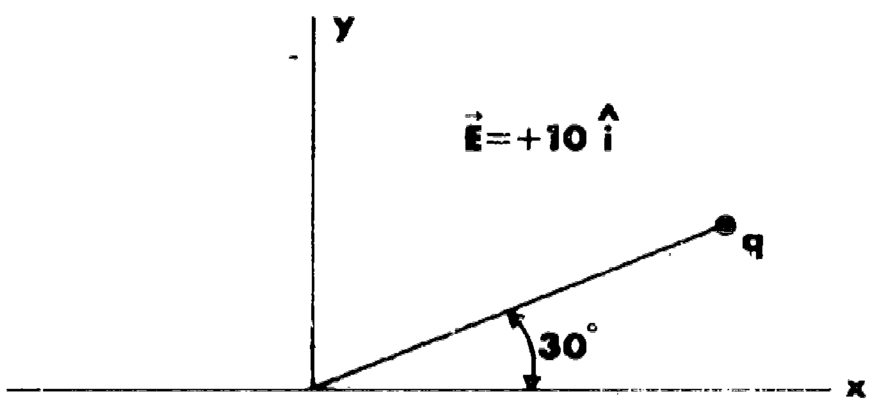
13. Two point charges are separated by a distance of one meter. The value of each charge is +1 coulomb. What is the magnitude of the force exerted by one charge on the other charge?

14. A charge q = +10 coulombs is located in an electric field. The force on the charge is measured to be 20 $\hat{i}$ newtons. What is the <u>magnitude</u> of the electric field at the point where the charge is located? (Include units.)

15. A charge $q = -1$ coul is exposed to an elect ic field $\vec{E} = 10\ \hat{i}$. What is the magnitude and direction of the force on the charge q? (Include units.)

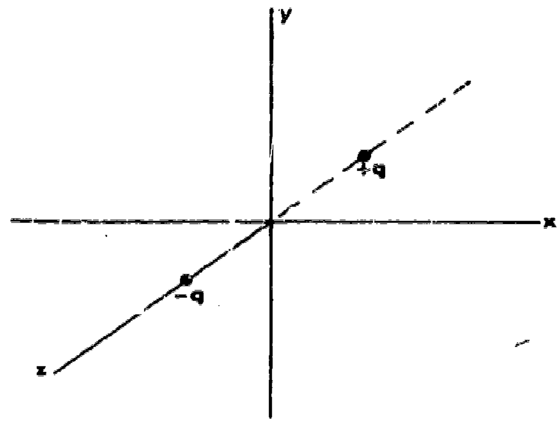
16. A negatively charged rubber rod is rubbed with fur and brought near the knob of an uncharged electroscope. If the leaves of the electroscope move apart due to the proximity of the rod, what is the sign of the charge on the leaves?

17.



A charge $q = +10$ coul is suspended from the end of an insulated rod of length $r = 1$ m. Calculate the torque about the origin due to the force on the charge. The uniform electric field is shown in the diagram.

18.



Suppose the dipole shown in the diagram is exposed to an electric field $\vec{E} = 10\ \hat{j}$. What is the magnitude of the net torque on the dipole?

19. Figure 1 shows an area of width W = 2 m and length L = 4 m at an angle of 30° with respect to the x-z plane. There is in this region an electric field $\vec{E}$ parallel to the y-axis with a magnitude of 10 nt/coul (see Figure 2, next page). What is the electric flux through the surface area LW?

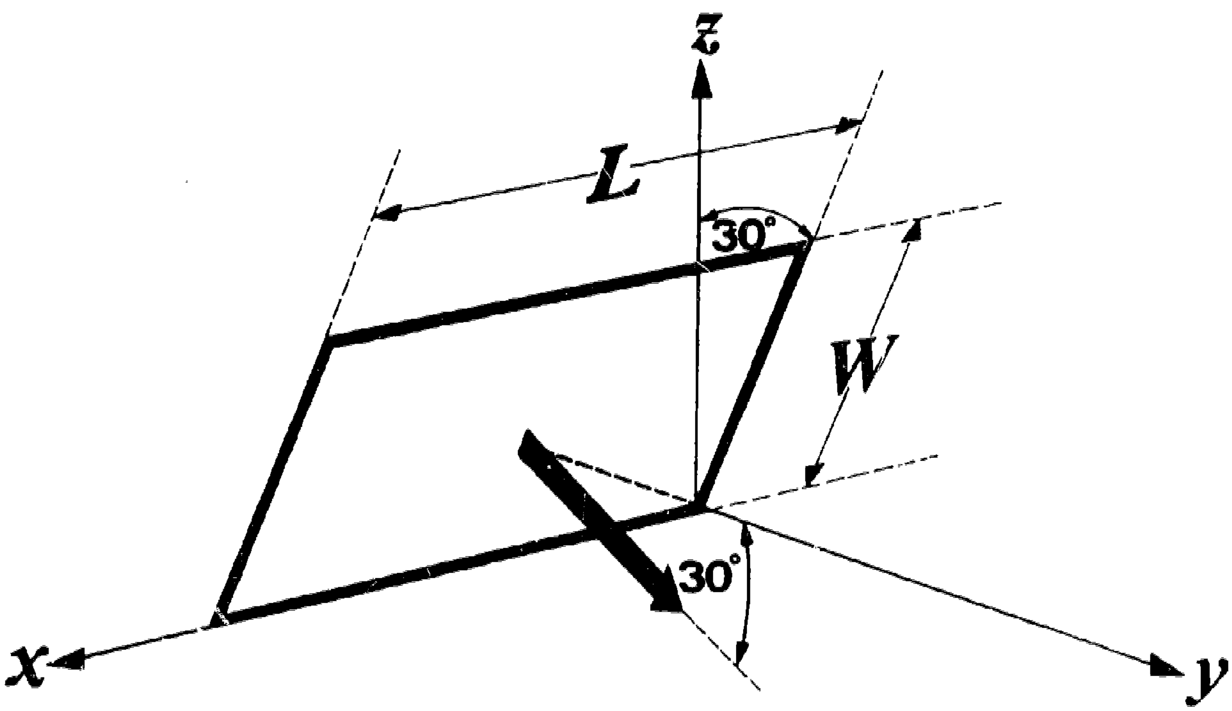


Figure 1

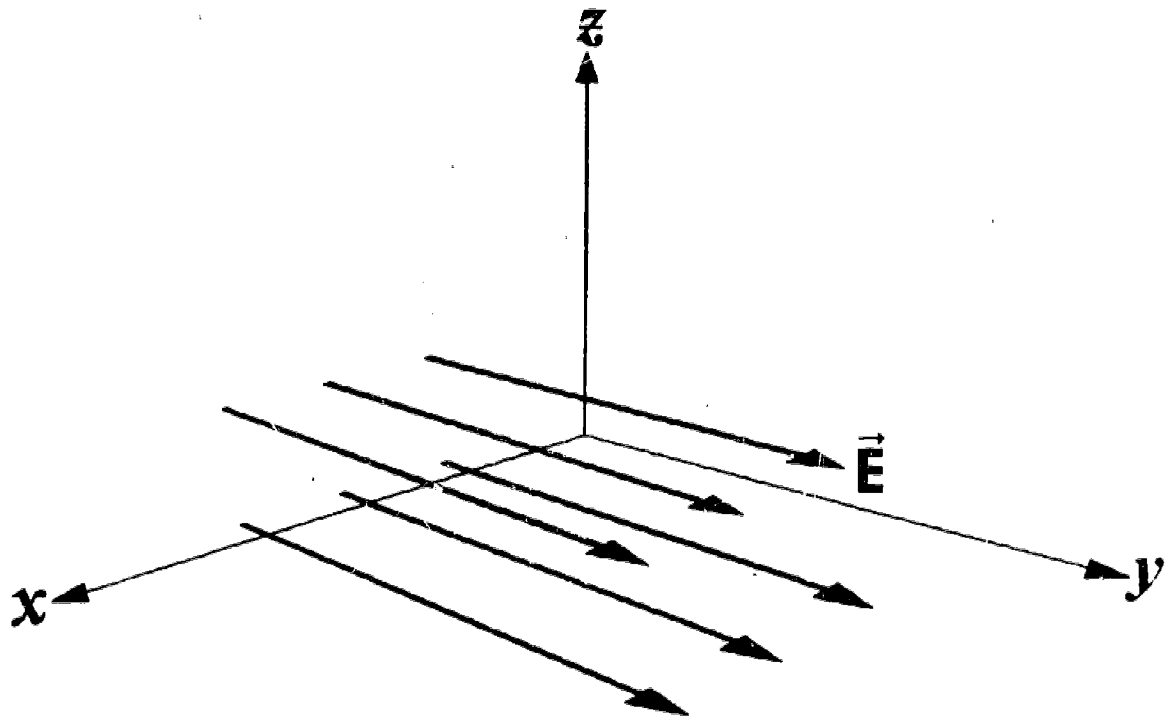


Figure 2

20. A non-conducting sphere is uniformly charged with a charge density $\rho = +3$ coul/m^3. The sphere has a radius of one meter. The sphere is plunged into a very cold, non-conducting liquid solution (temperature = 1° K) and transforms into a conductor. What is the surface charge, σ (coul/m^2), on the sphere? (The volume of the sphere is $4/3\ \pi r^3$ and the area is $4\pi r^2$).

21. What is the electric potential at a distance 3 m from a charge of 3 coul?

22. The electric potential at a point a distance r from a charge distribution is given by

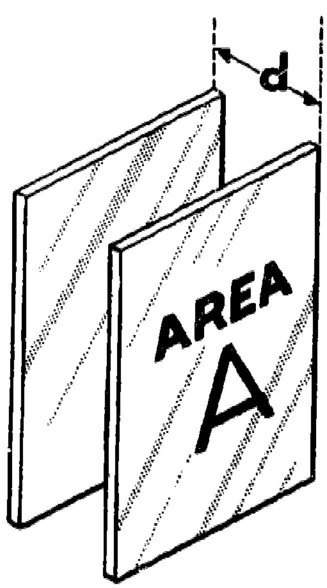
$$V\ (r) = 6r^5$$

In terms of the distance r, what is the magnitude of the field intensity at that point?

23. Two charges $q_1 = 2.0 \times 10^{-19}$ coul and q_2 3.0×10^{-19} coul are 6.0×10^{-15} m apart. How much energy was expended in gathering this system of charges?

24. A 20-microfarad capacitor is subject to a 3000-volt potential difference across its terminals. What is the charge on each plate of the capacitor?

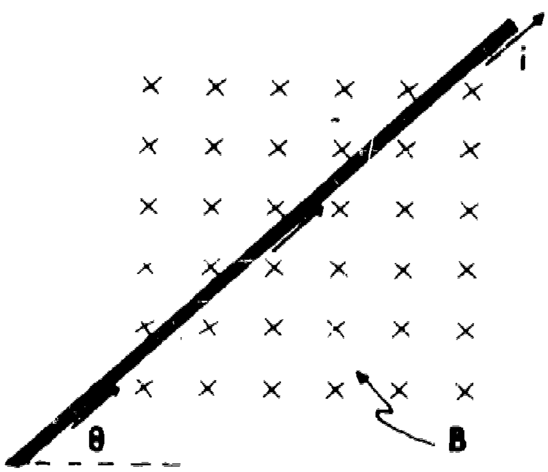
25. A parallel plate capacitor shown in the diagram below consists of two parallel conducting plates of area _A_ separated by a distance _d_. The charge density (charge per unit area) on each plate is $+\sigma$ and $-\sigma$ respectively. What is the capacitance of this capacitor?



26. What is the capacitance of an isolated sphere of radius $r = 1.8$ meters? (Include units.)

27. What is the potential at 1 m from the center of a non-conducting sphere of radius 10 m, charged uniformly with a charge density of 8.8×10^{-12} coul/m^3. (The volume of a sphere is $\frac{4}{3}\pi r^3$ and the area of a sphere is $4\pi r^2$.)

28.



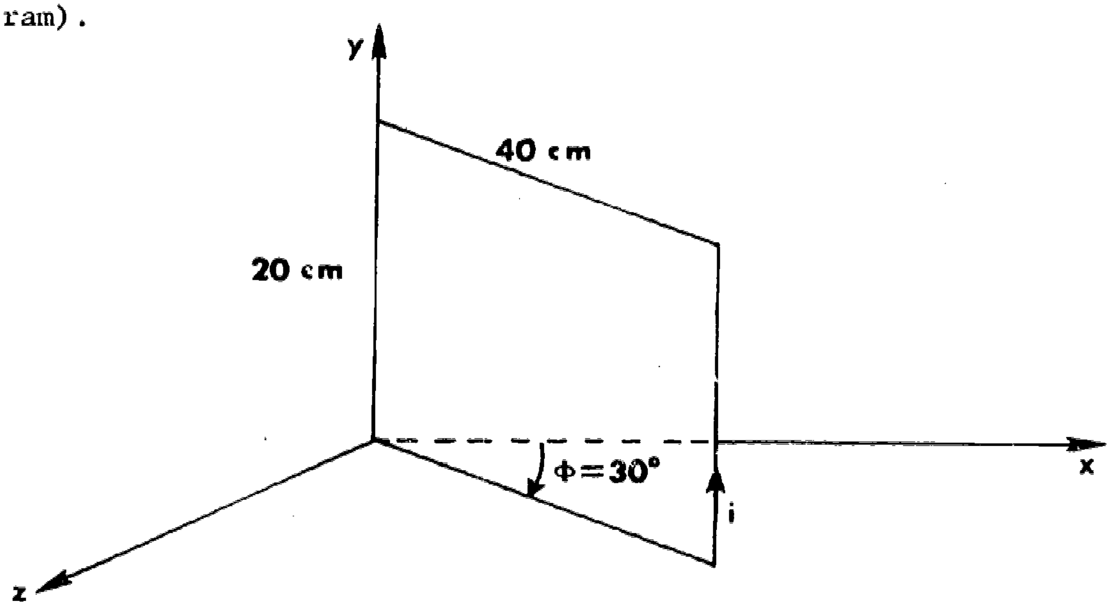
$\theta = 45°$

$B = 1$ tesla

$i = 1$ A

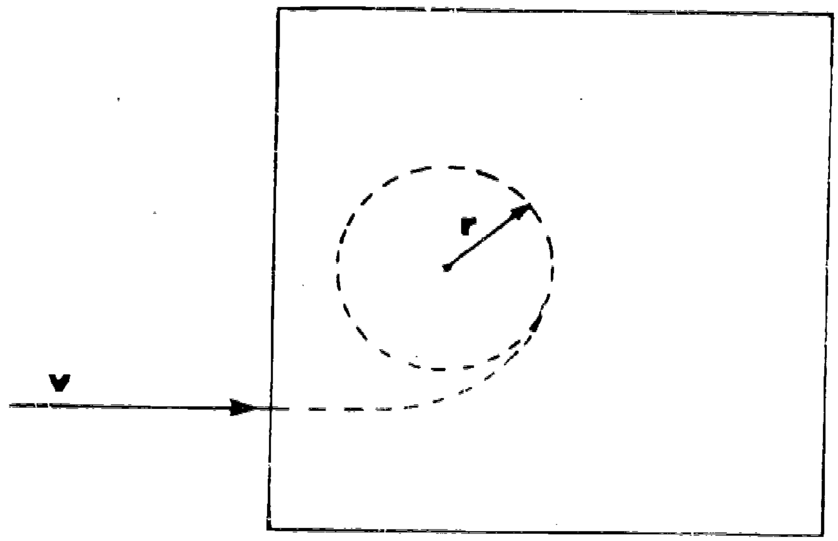
A current-carrying wire lies in the plane of the paper and is exposed to a magnetic field which is directed into the paper at all points (see diagram above). If only one meter of the wire is exposed, what is the magnitude of the force on the wire?

29. A rectangular coil has 50 turns and carries a current of 10 amp. It is hinged such that it is free to rotate about the y-axis (see diagram).



There is a uniform magnetic field in the region given by $\vec{B} = 3.8 \times 10^{-3}\ \hat{k}$ T. What is the magnitude of the torque on the coil at the instant the angle between the plane of the coil and the xy-plane is $\phi = 30°$?

30.



An electron is shot into the region shown with a velocity $v = 100$ m/sec. The electron's path becomes circular within the region as shown with $r = 0.001$ m. What is the magnitude and direction of the magnetic field in the region shown? ($e/m = -1.76 \times 10^{11}$ coul/kg).

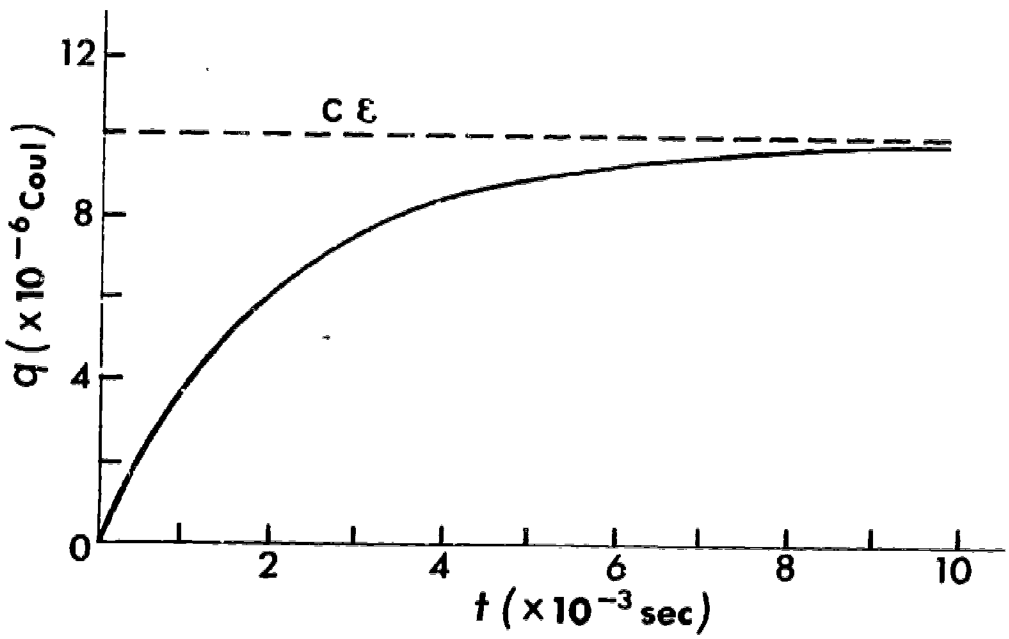
31. A direct current of 4 amp produces a flux of 5×10^{-4} weber in a coil of 100 turns. What is the self-inductance of the coil?

32. A long solenoid with a cross section 10^{-4} m^2 has 4×10^2 turns of wire per meter. What is the inductance per unit length for this solenoid?

33. A coil has self-inductance of 4×10^{-2} henry and resistance of 5 ohms. What is the instantaneous power delivered to this coil by an emf which causes a current of 5×10^{-3} amps to increase at the rate of 0.5 amps/sec?

34. What is the current in an RC circuit with a resistor (R = 5 ohms) due to a 100-volt emf two time constants after the voltage is applied? [e^{-1} = .37]

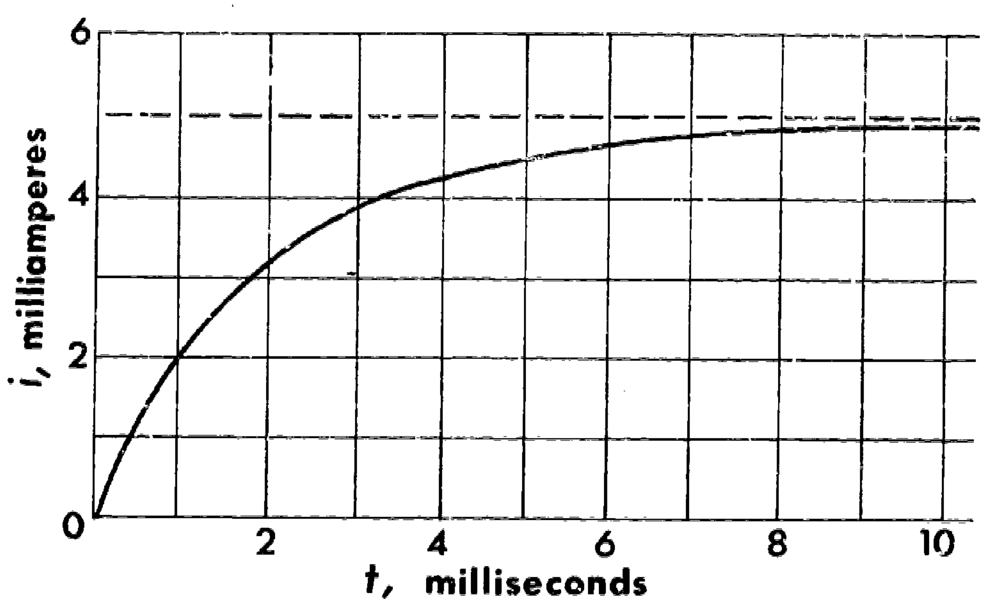
35. Find the time constant of an RC circuit if the charge in the capacitor varies with time as shown below.



36. A capacitor in an RC circuit has been charged at 100 volts. If the resistance is 20 ohms, what is the magnitude of the current in this circuit at the moment the capacitor begins discharging?

37. A coil with resistance of 20 ohms and inductance of 0.5 henry is connected to a 240-volt dc line. At what rate will the current in the coil be rising at the instant the current reaches 50% of its maximum value?

38. The curve given below shows the current versus time in an LR circuit. What is the time constant of the circuit?



39. The current in an LR circuit decays to 13.7% of its equilibrium value in 10 sec. What is the time constant of the circuit?

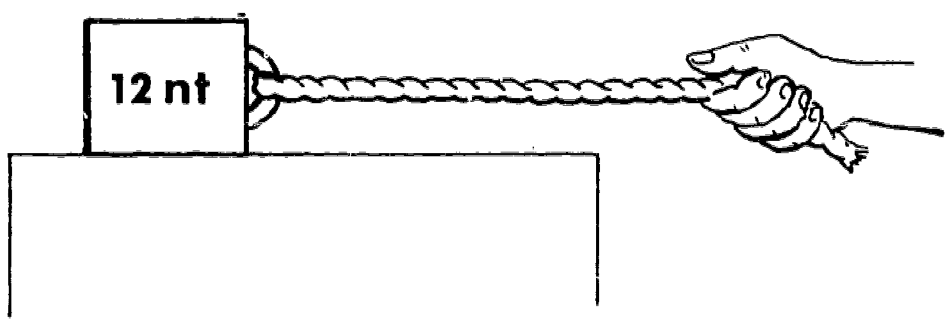
APPENDIX C

Criterion Test Items: Multiple Step

1. A force of 6 nt applied to a block causes it to accelerate at 5 m/sec^2. If the mass of the block is tripled and the same force is applied, what will be the acceleration of the block?

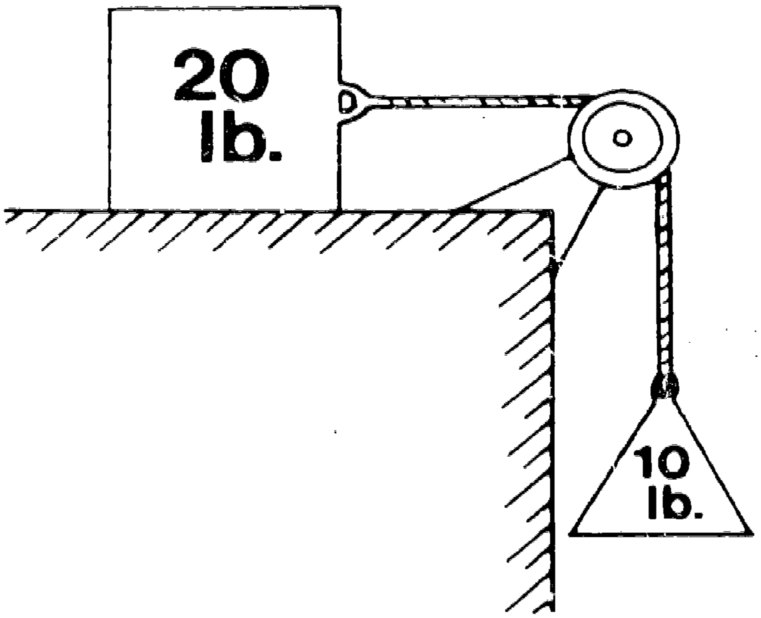
2. A section of level roadway has a radius of curvature of 100 m and is expected to handle traffic at 10 m/sec. What minimum coefficient of friction prevents skids at this speed?

3.



A 12-nt block rests on a horizontal surface. The block is tied to a rope and a horizontal force of magnitude 5 nt is applied to the other end of the rope by the shown hand. If the block remains stationary, what is the magnitude of the total reaction force applied by the horizontal surface on the block?

4. A 20-lb weight slides to the right along a table according to the arrangement shown in the diagram. The coefficient of kinetic friction between the table and the block is .10. What is the magnitude of the net force that accelerates the block on the table?

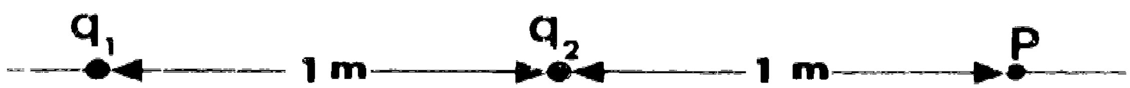


5. The magnitude of a force applied to a block is directly proportional to the magnitude of the block's displacement ($F = ks$, where k is a constant). Furthermore, the force is directed along the block's displacement ($F_s = F$). Derive an expression for the work done by this force in moving the block from position s_1 to position s_2.

6. Determine the weight of a 2-slug body at a distance of 4000 mi from the surface of the Earth. (Take the Earth's radius to be equal to 4000 mi, and the value of g at the Earth's surface equal to 32 ft/sec^2.)

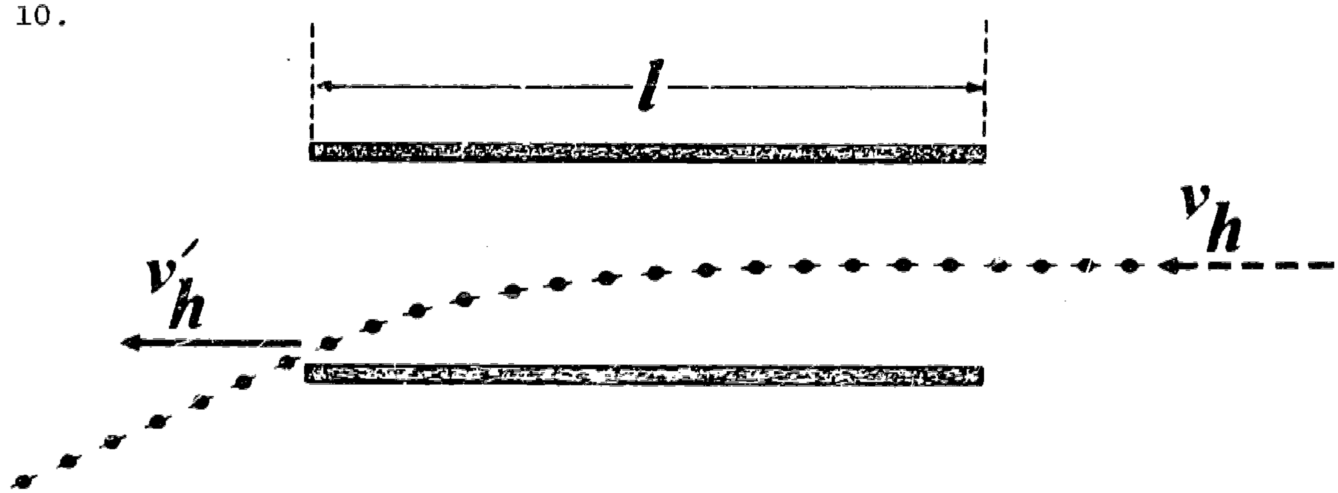
7. A satellite is in circular orbit around the Earth. Write down an expression giving the radius of the satellite's orbit in terms of the Earth's mass, M, the satellite's speed, v, and the constant of universal gravitation, G.

8. Two point charges q_1 and q_2 are one meter apart. If q_1 = -4 coul and q_2 = +1 coul, what is the magnitude and direction of the electric field at point P shown below?



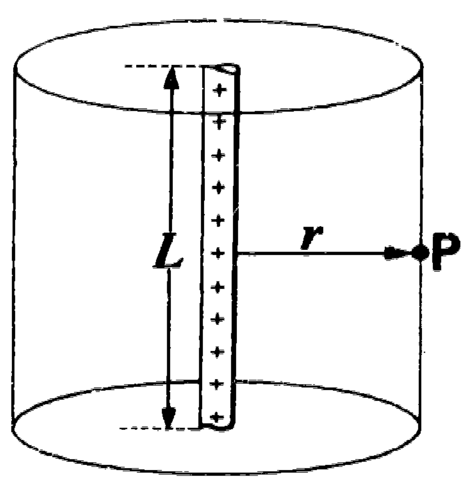
9. A charge q = 1 μcoul resides on a very small object of mass m = 1 μg. The charged object is placed in an electric field produced by an infinitely long wire that is uniformly charged (λ = 1 coul/m). The small object is 4 meters from the wire. What is the magnitude of the force on the small charged object?

10.

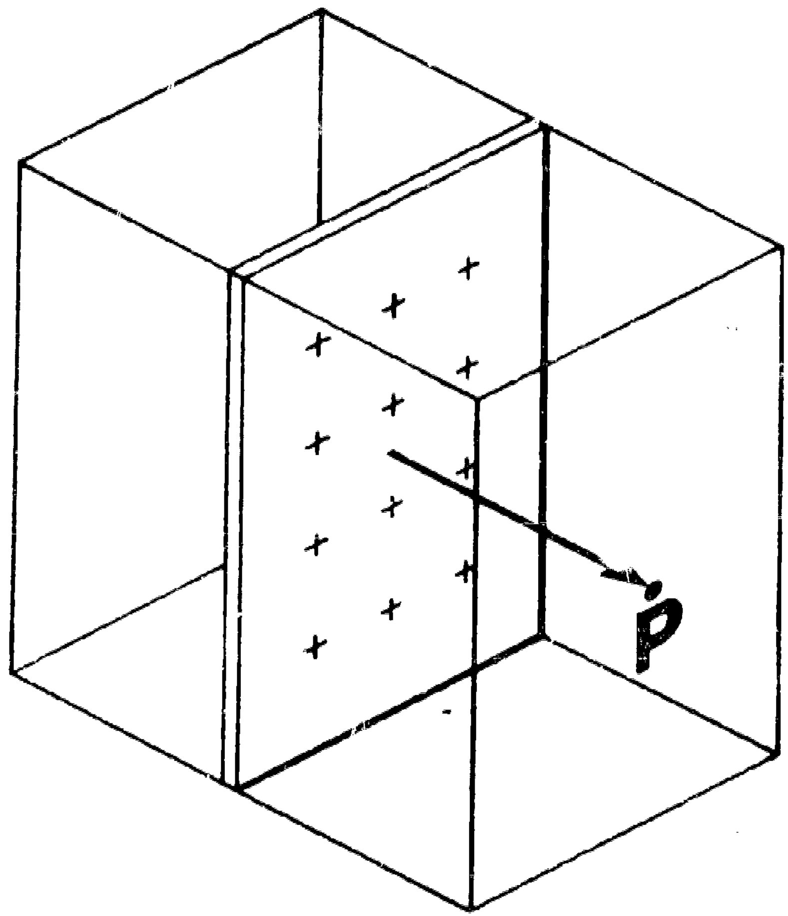


The above diagram shows the trajectory of an electron before, during, and after entering the space midway between two parallel plates. Suppose we know that ℓ = 0.05 m, and that the plates are 0.004 m apart. If the electron enters with a horizontal velocity of 4×10^7 m/sec, what must be the value of the electric field so that the electron just misses the edge of the bottom plate? (Include magnitude and direction.)

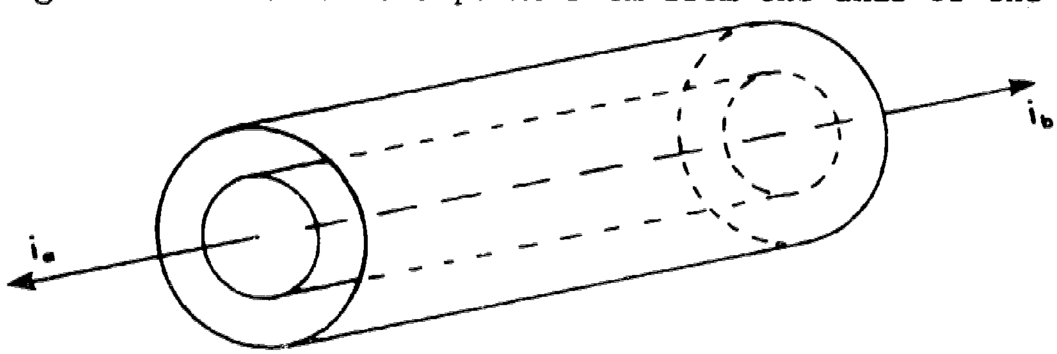
11. The figure below shows a portion of an infinitely long wire with a uniform charge λ = 1 coul/m. Use Gauss's law to determine the electric field at point P which is a distance of 2 m from the wire.



12. The figure below shows part of a very large plane sheet of charge with a uniform charge density σ = 180 coul/m^2. Use Gauss's law to determine the magnitude of the electric field at point P which is 2 m from the plane.

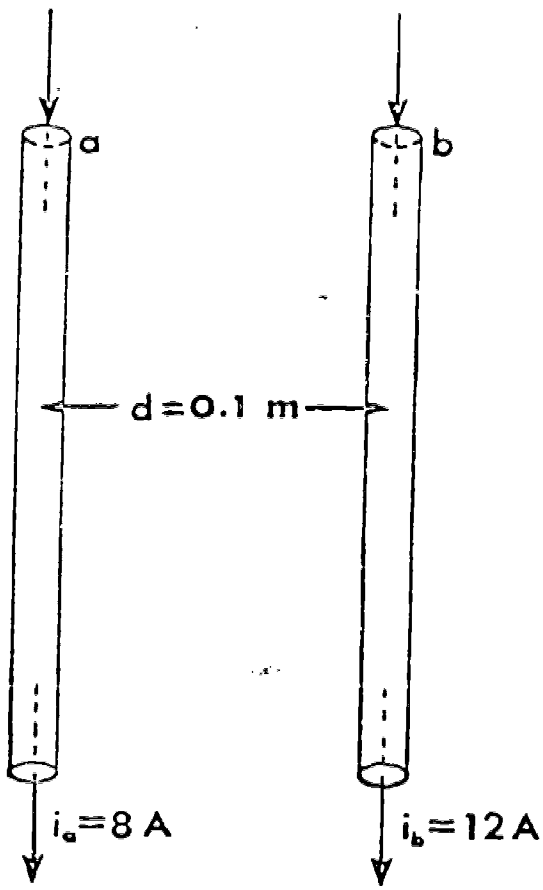


13. A long cable consists of two coaxial conductors, a solid inner wire of radius a = 5 mm and a thin outer shell of radius b = 1 cm. The two conductors carry equal currents ($i_a = i_b$ = 10 amps) but in opposite directions. Use Ampere's law to calculate the magnitude of the magnetic induction at a point 5 cm from the axis of the cable.



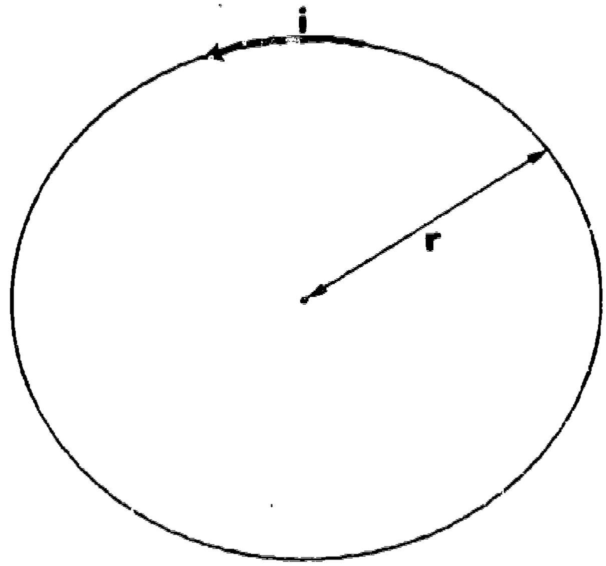
14. Use Ampere's law to calculate the magnitude of the magnetic induction at a distance of 2 mm from the center of an infinitely long cylindrical wire of diameter 10 mm which carries a current of 6 amps uniformly distributed over its cross section.

15. Two long parallel conductors separated by a distance $d = 0.1$ m carry parallel currents of $i_a = 8$ amps and $i_b = 12$ amps (see diagram). Calculate the magnitude of the (attractive) force per unit length on each conductor due to the current in the other conductor.

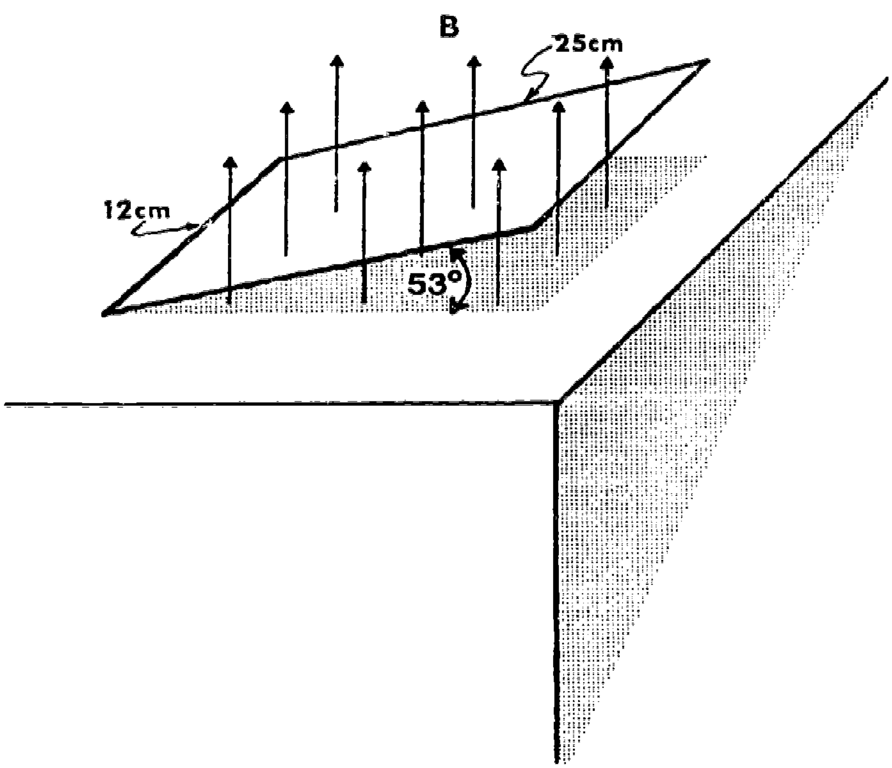


16. A current balance is an instrument for precise measurements of current. If the force between the two wires of a current balance is 2×10^{-7} nt/m of length and if the parallel wires are one meter apart, how much current flows through each wire?

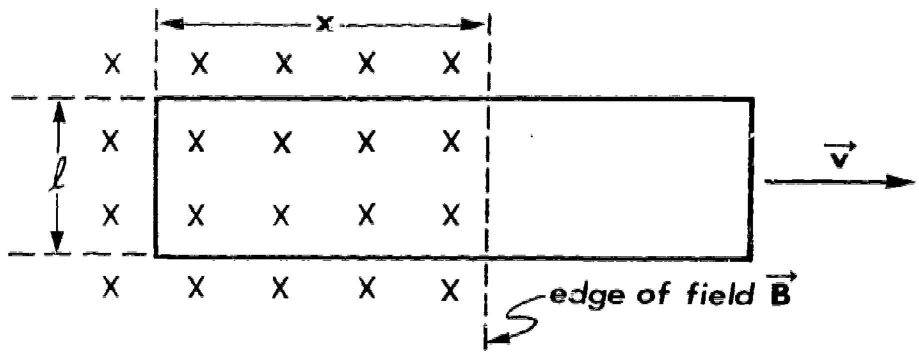
17. Use the Biot-Savart law to calculate the magnitude of the magnetic induction at the center of a circular loop of radius r = 20 cm carrying a current i = 2 amps.



18. A closely wound rectangular 50-turn coil has dimensions of 12 cm × 25 cm. It is located in a uniform magnetic field of B = 2 T, oriented as shown in the diagram. If the loop is brought from its position as indicated to the horizontal position in 0.1 sec, what is the magnitude of the average emf induced?



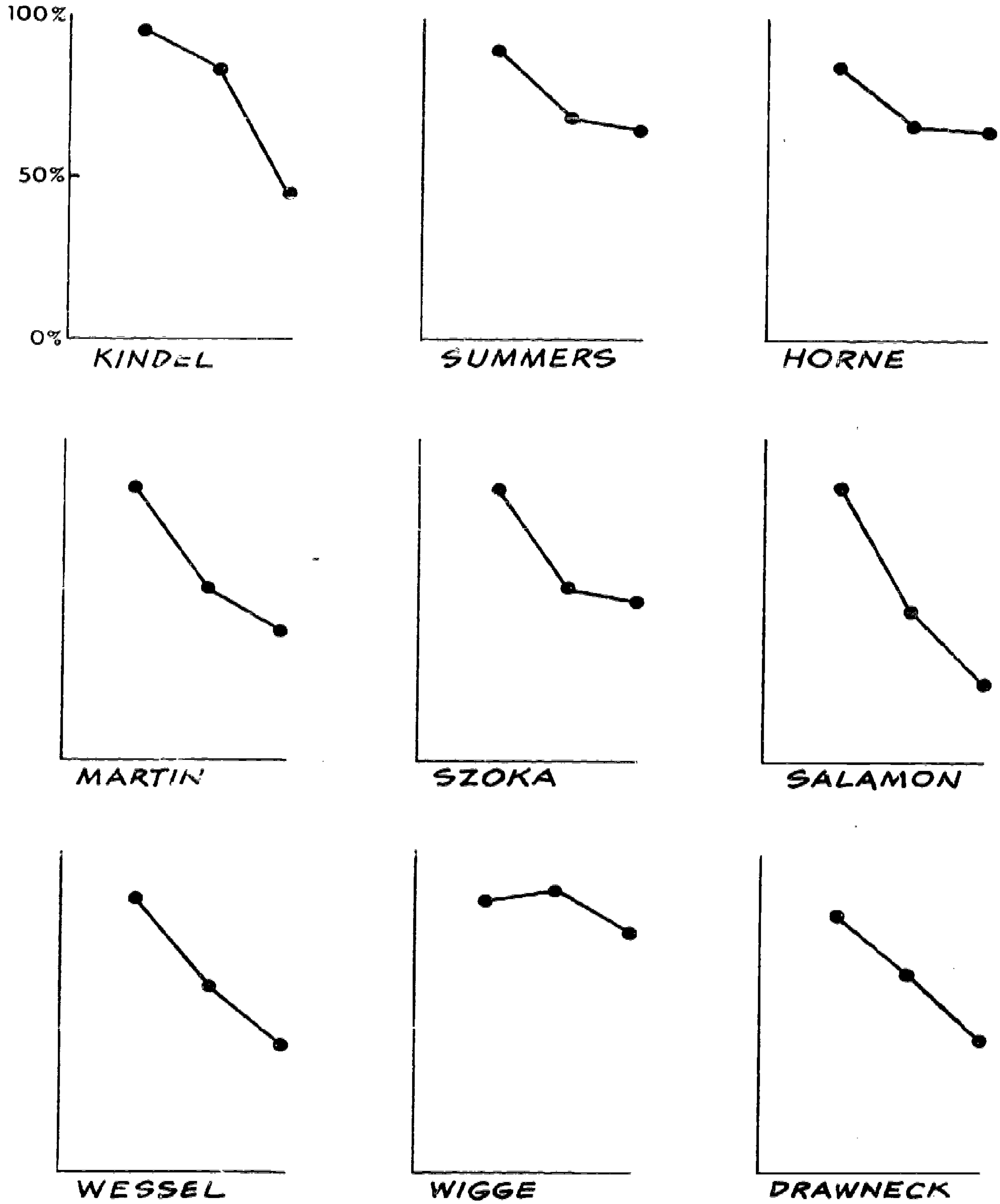
19. A closed conducting loop of width ℓ = 20 cm is moved to the right at a constant speed v = 5 m/sec in a region where a magnetic field B = 0.1 T exists. If the resistance of the loop is R = 2 ohms, what is the induced current through the loop at the moment a length x = 1 m of the loop is in the field?

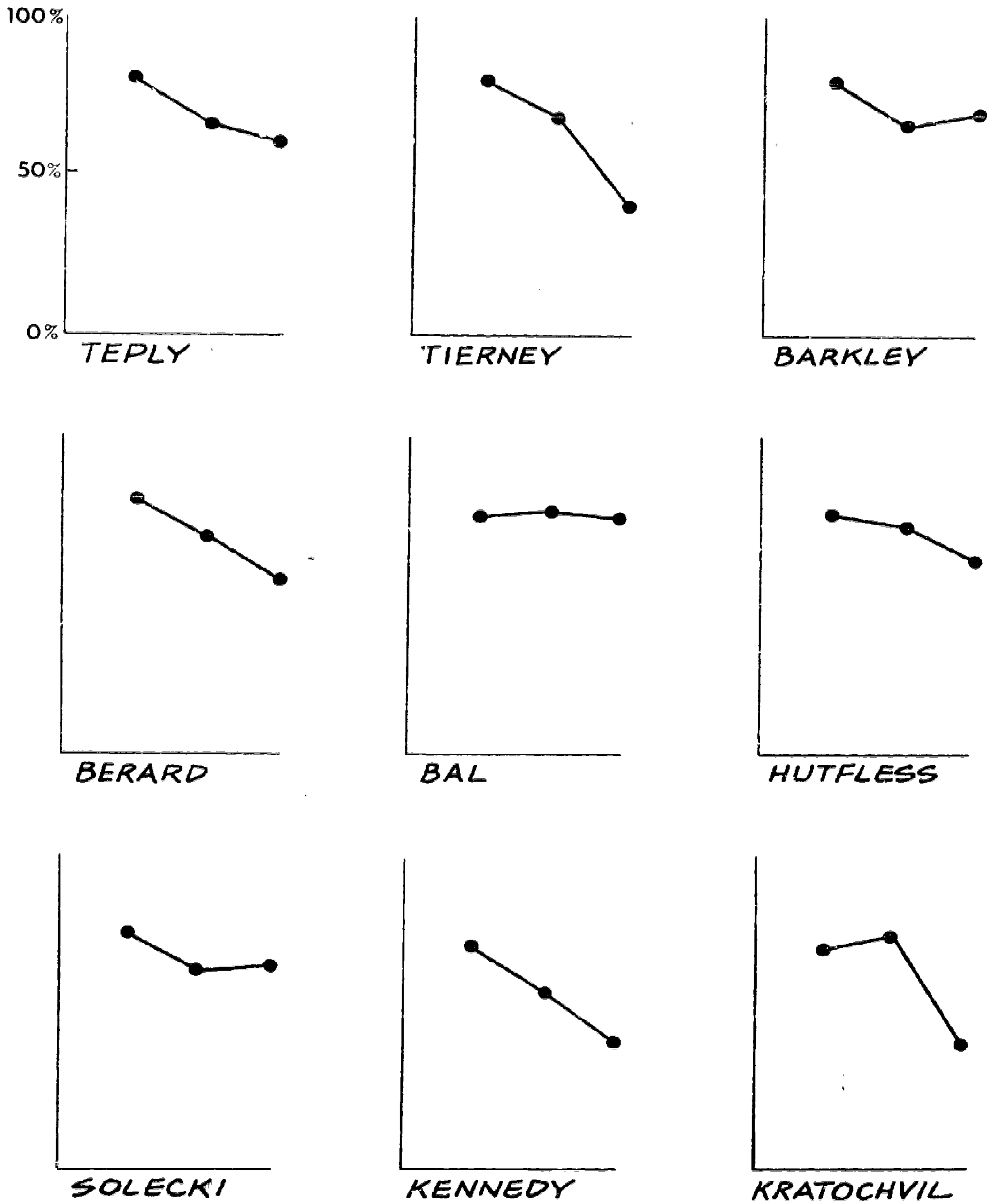


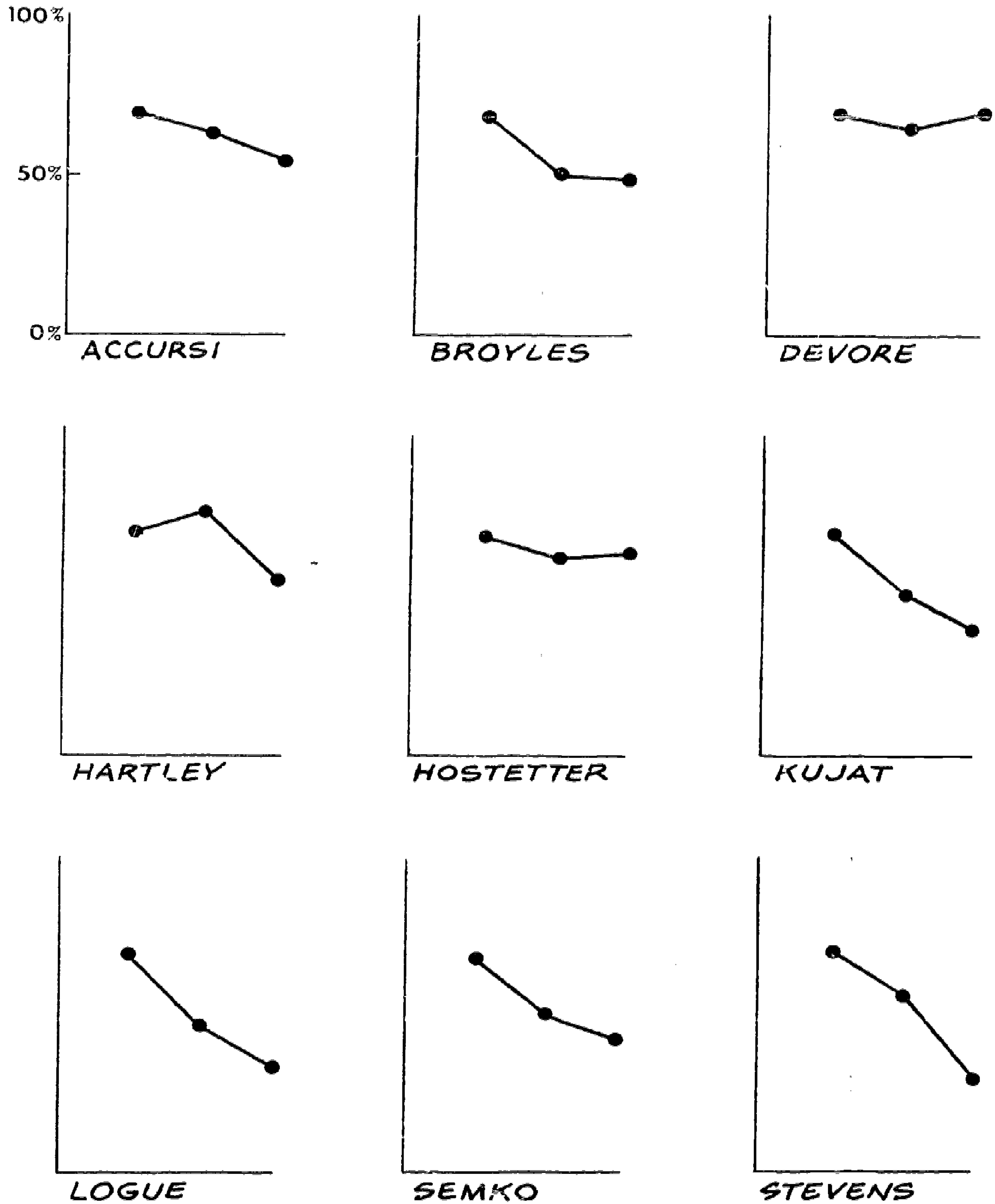
20. A 3-henry inductance having a resistance of 5 ohms is connected to an emf of 20 volts. What is the energy stored in the magnetic field when the current reaches its final steady state value?

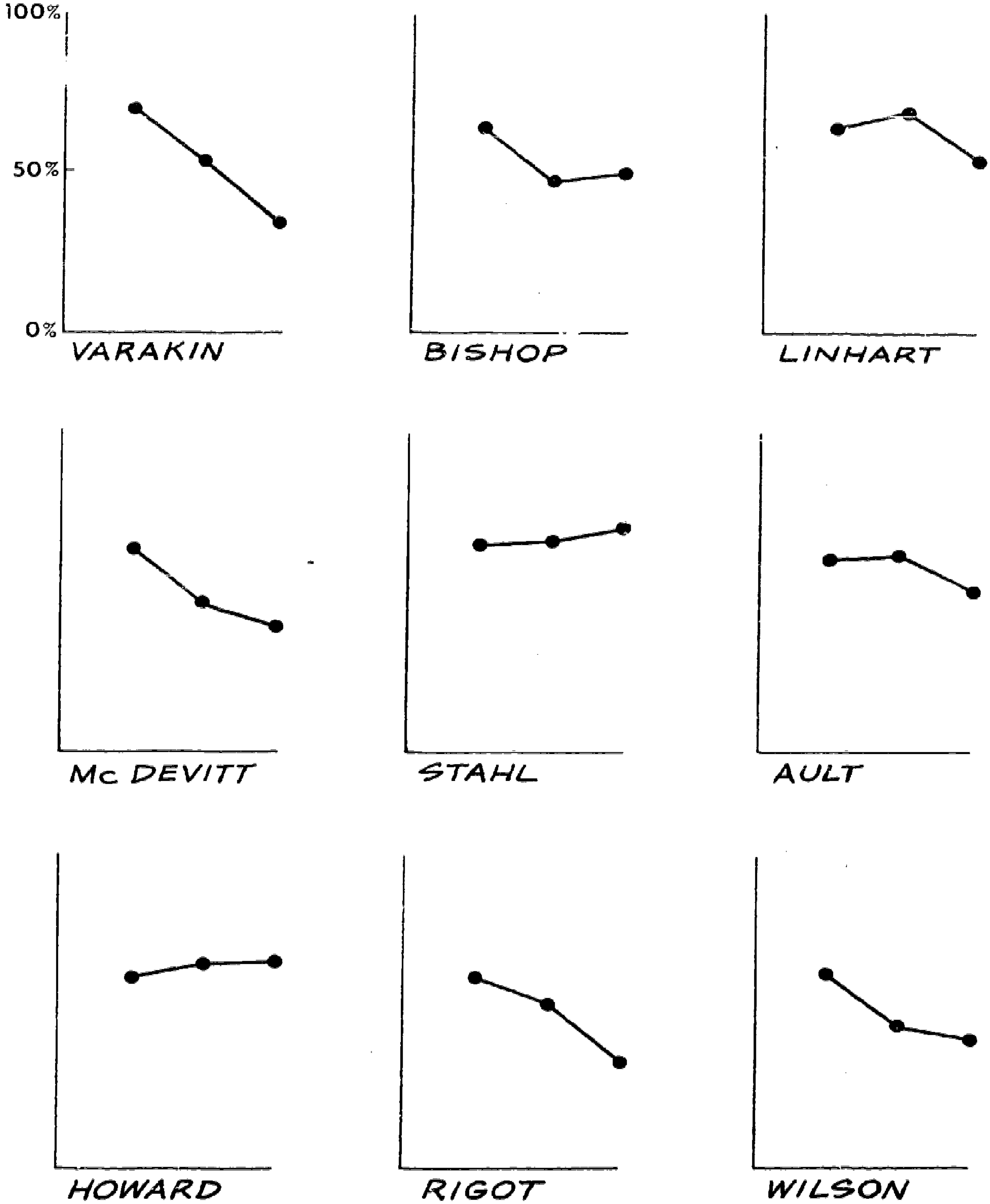
APPENDIX D

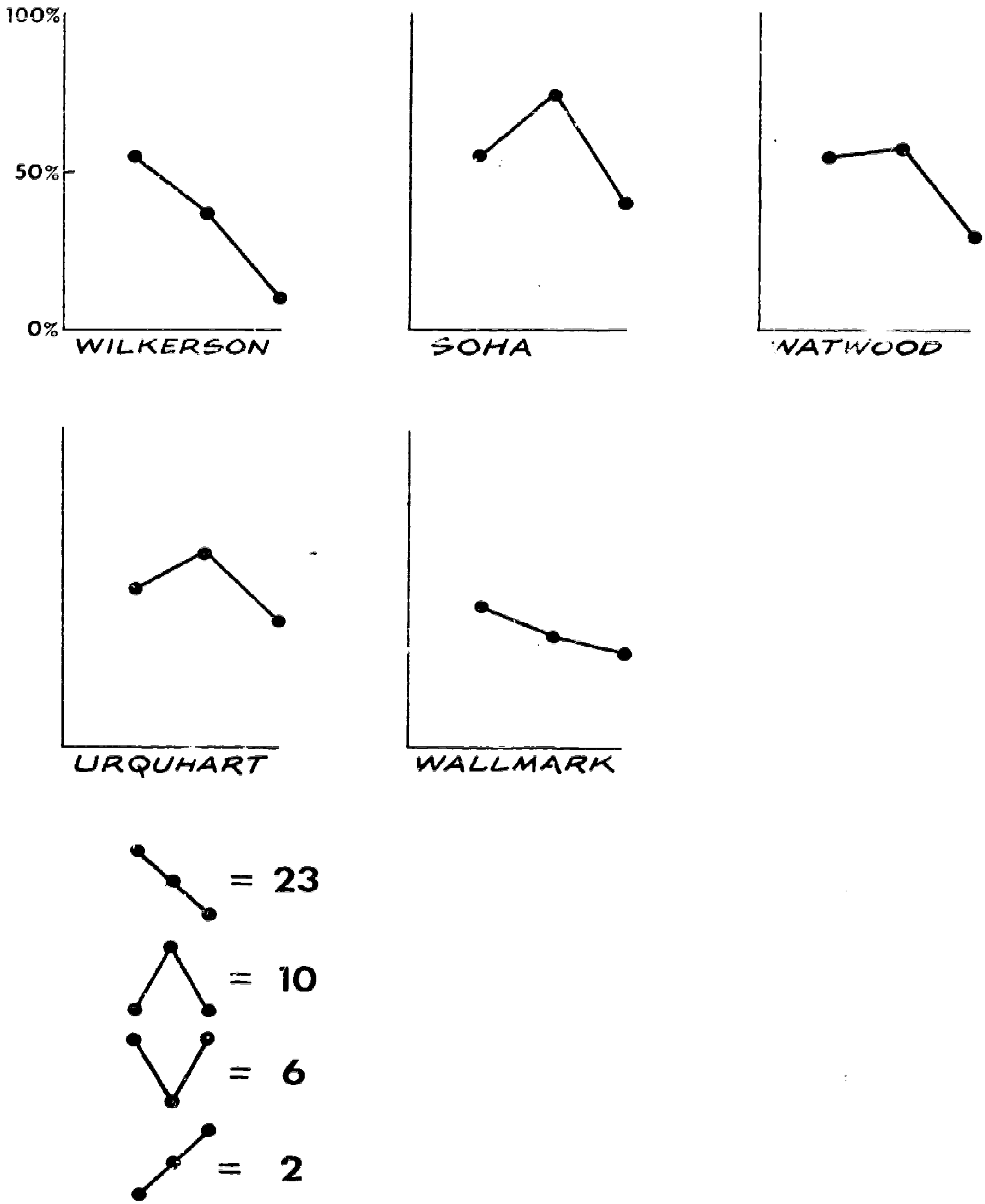
Individual Performance By Category


100%
50%
0%
KINDEL
SUMMERS
HORNE
MARTIN
SZOKA
SALAMON
WESSEL
WIGGE
DRAWNECK


100%
50%
0%
TEPLY
TIERNEY
BARKLEY
BERARD
BAL
HUTFLESS
SOLECKI
KENNEDY
KRATOCHVIL


100%
50%
0%
ACCURSI
BROYLES
DEVORE
HARTLEY
HOSTETTER
KUJAT
LOGUE
SEMKO
STEVENS


100%
50%
0%
VARAKIN
BISHOP
LINHART
Mc DEVITT
STAHL
AULT
HOWARD
RIGOT
WILSON


100%
50%
0%
WILKERSON
SOHA
WATWOOD
URQUHART
WALLMARK
= 23
= 10
= 6
= 2

APPENDIX E

Comupter Programs and Printouts

```
LOAD ZERO STEP PROBLEMS
READY


LIST


ZERO STEP PROBLEMS          17:14    ADVANCED SYSTEMS LABS.

1 DATA 'BAL',15,'BISHOP',13,'DRAWNECK',16,'HORNE',17,'KENNEDY',14
2 DATA 'KRATOCHVIL',14,'LINHART',13,'MARTIN',17,'MCDEVITT',13
3 DATA 'SUMMERS',18,'SZOKA',17,'TEPLY',16,'TIERNEY',16,'WILKERSON',11
4 DATA 'ACCURSI',14,'AULT',12,'BARKLEY',16,'BERARD',16,'BROYLES',14,
'DEVORE',14
5 DATA 'HARTLEY',14,'HOSTETTER',14,'HOWARD',12,'HUTFLESS',15,'KINDEL',19
6 DATA 'KUJAT',14,'LOGUE',14,'RIGOT',12,'SALAMON',17,'SEMKO',14,'SOHA',11
7 DATA 'SOLECKI',15,'STAHL',13,'STEVENS',14,'UROUHART',10,'VARAKIN',14
8 DATA 'WALLMARK',9,'WATWOOD',11,'WESSEL',17,'WIGGE',17,'WILSON',12
11 DIM A$(41),B(41)
12 FOR I = 1 TO 41
14 READ A$(I),B(I)
20 NEXT I
25 FOR I = 1 TO 39
30 FOR J = 1 TO 41
40 IF B(J) = 40-I GOTO 70
50 GOTO 80
70 PRINT A$(J),B(J)
80 NEXT J
90 NEXT I
100 FOR M = 1 TO 41
105 S = S + B(M)
110 NEXT M
120 A = S/41
125 P = (A/20)*100
130 FOR N = 1 TO 41
135 G = G + (B(N)-A)**2
140 NEXT N
145 V = G/41
150 D = V**0.5
155 PRINT 'AVERAGE =',A
156 PRINT S
157 PRINT 'VARIANCE =',V
158 PRINT 'STANDARD DEVIATION =',D
159 PRINT 'AVERAGE PERCENT CORRECT =',P
160 PRINT 'ZERO STEP PROBLEMS'
170 END
```

READY

RUN

ZERO STEP PROBLEMS 17:38 ADVANCED SYSTEMS LAB

KINDEL	19
SUMMERS	18
HORNE	17
MARTIN	17
SZOKA	17
SALAMON	17
WESSEL	17
WIGGE	17
DRAWNECK	16
TEPLY	16
TIERNEY	16
BARKLEY	16
BERARD	16
BAL	15
HUTFLESS	15
SOLECKI	15
KENNEDY	14
KRATOCHVIL	14
ACCURSI	14
BROYLES	14
DEVORE	14
HARTLEY	14
HOSTETTER	14
KUJAT	14
LOGUE	14
SEMKO	14
STEVENS	14
VARAKIN	14
BISHOP	13
LINHART	13
MCDEVITT	13
STAHL	13
AULT	12
HOWARD	12
RIGOT	12
WILSON	12
WILKERSON	11
SOHA	11
WATWOOD	11
URQUHART	10
WALLMARK	9

AVERAGE = 14.2439
584
VARIANCE = 4.9649
STANDARD DEVIATION = 2.2282
AVERAGE PERCENT CORRECT = 71.2195
ZERO STEP PROBLEMS

```
LOAD ONE STEP PROBLEMS
READY

LIST

ONE STEP PROBLEMS          17:32   ADVANCED SYSTEMS LAB

1 DATA 'BAL',30,'BISHOP',19,'DRAWNECK',24,'HORNE',26
2 DATA 'KENNEDY',22,'KRATOCHVIL',29,'LINHART',28,'MARTIN',21
3 DATA 'MCDEVITT',19,'SUMMERS',27,'SZOKA',21,'TEPLY',26
4 DATA 'TIERNEY',27,'WILKERSON',15,'ACCURSI',25,'AULT',24
5 DATA 'BARKLEY',26,'BERARD',27,'BROYLES',20,'DEVORE',26
6 DATA 'HARTLEY',30,'HOSTETTER',25,'HOWARD',25,'HUTFLESS',28
7 DATA 'KINDEL',33,'KUJAT',20,'LOGUE',19,'RIGOT',20
8 DATA 'SALAMON',19,'SEMKO',20,'SOHA',29,'SOLECKI',25
9 DATA 'STAHL',26,'STEVENS',22,'UROUHART',24,'VARAKIN',21
10 DATA 'WALLMARK',14,'WATWOOD',23,'WESSEL',23,'WIGGE',34,'WILSON',17
11 DIM A$(41),B(41)
12 FOR I = 1 TO 41
14 READ A$(I),B(I)
20 NEXT I
25 FOR I = 1 TO 39
30 FOR J = 1 TO 41
40 IF B(J) = 40-I GOTO 70
50 GOTO 80
70 PRINT A$(J),B(J)
80 NEXT J
90 NEXT I
100 FOR M = 1 TO 41
105 S = S + B(M)
110 NEXT M
120 A = S/41
125 P = (A/39)*100
130 FOR N = 1 TO 41
135 G=G+(B(N)-A)**2
140 NEXT N
145 V = G/41
150 D = V**0.5
155 PRINT 'AVERAGE =',A
156 PRINT S
157 PRINT 'VARIANCE =',V
158 PRINT 'STANDARD DEVIATION =',D
159 PRINT 'AVERAGE PERCENT =',P
160 PRINT 'ONE STEP PROBLEMS'
170 END
```

READY

RUN

```
ONE STEP PROBLEMS          17:40   ADVANCED SYSTEMS LAB

WIGGE                          34
KINDEL                         33
BAL                            30
HARTLEY                        30
KRATOCHVIL                     29
SOHA                           29
LINHART                        28
HUTFLESS                       28
SUMMERS                        27
TIERNEY                        27
[illegible]ERARD               27
HORNE                          26
TEPLY                          26
BARKELY                        26
DEVORE                         26
STAHL                          26
ACCURSI                        25
HOSTETTER                      25
HOWARD                         25
SOLECKI                        25
DRAWNECK                       24
AULT                           24
URQUHART                       24
WATWOOD                        23
WESSEL                         23
KENNEDY                        22
STEVENS                        22
MARTIN                         21
SZOKA                          21
VARAKIN                        21
BROYLES                        20
KUJAT                          20
RIGOT                          20
SEMKO                          20
BISHOP                         19
MCDEVITT                       19
LOGUE                          19
SALAMON                        19
WILSON                         17
WILKERSON                      15
WALLMARK                       14
AVERAGE =                      23.878
 979
VARIANCE =                     19.9119
STANDARD DEVIATION =                          4.46227
AVERAGE PERCENT =              61.2257
ONE STEP PROBLEMS
```

```
LOAD MULTIPLE STEP PROBLEMS
READY

LIST

MULTIPLE STEP PROBLEMS          17:36   ADVANCED SYSTEMS LAB

1 DATA 'BAL',15,'BISHOP',10,'DRAWNECK',8,'HORNE',13,'KENNEDY',8,'KRATOCH
VIL',8
2 DATA 'LINHART',11,'MARTIN',8,'MCDEVITT',8,'SUMMERS',13
3 DATA 'SZOKA',10,'TEPLY',12,'TIERNEY',8,'WILKERSON',2
4 DATA 'ACCURSI',11,'AULT',10,'BARKLEY',14,'BERARD',11,'BROYLES',10
5 DATA 'DEVORE',14,'HARTLEY',11,'HOSTETTER',13,'HOWARD',13,'HUTFLESS',12
6 DATA 'KINDEL',9,'KUJAT',8,'LOGUE',7,'RIGOT',7,'SALAMON',5,'SEMKO',10
7 DATA 'SOHA',8,'SOLECKI',13,'STAHL',14,'STEVENS',6,'UROUHART',8,'VARAKI
N',7,'WALLMARK',6
8 DATA 'WATWOOD',6,'WESSEL',8,'WIGGE',15,'WILSON',8
11 DIM A$(41),B(41)
12 FOR I = 1 TO 41
14 READ A$(I),B(I)
20 NEXT I
25 FOR I = 1 TO 39
30 FOR J = 1 TO 41
40 IF B(J) = 40-I GOTO 70
50 GOTO 80
70 PRINT A$(J),B(J)
80 NEXT J
90 NEXT I
100 FOR M = 1 TO 41
105 S=S+B(M)
110 NEXT M
120 A = S/41
125 P = (A/20)*100
130 FOR N = 1 TO 41
135 G = G + (B(N)-A)**2
140 NEXT N
145 V = G/41
150 D = V**0.5
155 PRINT 'AVERAGE =',A
156 PRINT S
157 PRINT 'VARIANCE =',V
158 PRINT 'STANDARD DEVIATION =',D
159 PRINT 'AVERAGE PERCENT CORRECT =',P
160 PRINT 'MULTIPLE STEP PROBLEMS'
170 END
```

READY

RUN

MULTIPLE STEP PROBLEMS	17:42	ADVANCED SYSTEMS LAB
BAL	15	
WIGGE	15	
BARKLEY	14	
DEVORE	14	
STAHL	14	
HORNE	13	
SUMMERS	13	
HOSTETTER	13	
HOWARD	13	
SOLECKI	13	
TEPLY	12	
HUTFLESS	12	
LINHART	11	
ACCURSI	11	
BERARD	11	
HARTLEY	11	
BISHOP	10	
SZOKA	10	
AULT	10	
BROYLES	10	
SEMKO	10	
KINDEL	9	
DRAWNECK	8	
KENNEDY	8	
KRATOCHVIL	8	
MARTIN	8	
MCDEVITT	8	
TIERNEY	8	
KUJAT	8	
SOHA	8	
UROUHART	8	
WESSEL	8	
WILSON	8	
LOGUE	7	
RIGOT	7	
VARAKIN	7	
STEVENS	6	
WALLMARK	6	
WATWOOD	6	
SALAMON	5	
WILKERSON	2	
AVERAGE =	9.70732	
398		
VARIANCE =	8.79235	
STANDARD DEVIATION =		2.96519
AVERAGE PERCENT CORRECT =		48.5366
MULTIPLE STEP PROBLEMS		

```
LOAD PMCORR1
READY

LIST

PMCORR1                 14:05    ADVANCED SYSTEMS LABS

10 REM PRODUCT MOMENT CORRELATION 1
20 DIM A$(50), B(50,3), C(50)
24 READ N
25 DATA 41
30 OPEN 1,'PHYSDATA',INPUT
40 FOR I = 1 TO N
45 GET 1:A$(I), B(I,1), B(I,2), B(I,3)
47 NEXT I
50 FOR I = 1 TO 2
60 FOR J = 2 TO 3
70 IF I = J GO TO 190
80 FOR K = 1 TO 41
90 LET S = S + B(K,I)*B(K,J)
100 LET X = X + B(K,I)
110 LET Y = Y + B(K,J)
120 LET X2 = X2 + B(K,I)**2
130 LET Y2 = Y2 + B(K,J)**2
140 NEXT K
150 LET L = S-X*Y/N
160 LET M = (X2-(X**2)/N)*(Y2-(Y**2)/N)
170 LET R = L/SQR(M)
180 PRINT 'CORRELATION COEFFICIENT FOR' ; I; J; '='; R
183 LET S = 0
184 LET X = 0
185 LET Y = 0
186 LET X2 = 0
187 LET Y2 = 0
190 NEXT J
200 NEXT I
210 END

RUN

PMCORR1                 14:04    ADVANCED SYSTEMS LABS

CORRELATION COEFFICIENT FOR 1       2        = .437185
CORRELATION COEFFICIENT FOR 1       3        = .34745
CORRELATION COEFFICIENT FOR 2       3        = .645591

TIME 0 SECS.
```

```
LOAD KENDW1
READY

LIST

KENDW1          19:08   ADVANCED SYSTEMS LABS.

10 PRINT 'KENDALL COEFFICIENT OF CONCORDANCE'
15 DIM A$(50) B(50,3),C(50,3),D(50),E(50),F(50,3),R(50),T(3)
20 OPEN 1, 'PHYSDATA',INPUT
25 FOR I = 1 TO 41
30 GET 1: A$(I),B(I,1),B(I,2),B(I,3)
40 NEXT I
47 PRINT
48 PRINT 'NUMBER OF TIES'
50 FOR K = 1 TO 3
55 LET R = 0
60 FOR I = 1 TO 39
65 LET L = 0
70 FOR J = 1 TO 41
80 IF B(J,K) = 40-I GOTO 103
90 GOTO 150
103 LET R = R + 1
104 LET F(J,K) = R
110 LET L = L + 1
150 NEXT J
160 IF L < 0.1 GOTO 200
170 LET M = M + 1
180 LET C(M,K) = L
181 PRINT 'C';M;K;C(M,K)
200 NEXT I
210 LET M = 0
220 NEXT K
240 FOR K = 1 TO 3
250 LET M = 0
260 LET I = 0
265 LET N = 0
270 LET N = N+1
280 FOR L = 1 TO C(N,K)
290 LET I = I + 1
295 LET J = 0
300 LET J = J+1
310 IF F(J,K) = I GOTO 330
315 GOTO 300
330 LET F(J,K) = M+(C(N,K)+1)/2
340 NEXT L
350 LET M=M+C(N,K)
360 IF M < 40.5 GOTO 270
```

```
370 NEXT K
380 FOR I = 1 TO 41
390 FOR K = 1 TO 3
400 LET R(I) + F(1,K)
410 NEXT K
420 NEXT I
430 FOR I = 1 TO 41
440 LET A1 = A1 + R(I)
450 NEXT I
460 LET A1 = A1/41
470 FOR I = 1 TO 41
480 LET D(I) = R(I)-A1
490 LET E(I) = D(I)**2
500 LET S = S + E(I)
501 NEXT I
510 FOR K = 1 TO 3
520 FOR J = 1 TO 20
530 LET T(K) = T(K)+C(J,K)**3-C(J,K)
540 NEXT J
560 LET T = T+T(K)/12
570 NEXT K
580 LET W = S/(0.75*(41**3-41)-3*T)
585 PRINT
590 PRINT 'OUTPUT RESULTS FROM KENDW1'
595 PRINT
600 PRINT 'STUDENT NAME','0 RANK','1 RANK','M RANK','R(I)','DELTA(I)'
605 PRINT
610 FOR I = 1 TO 41
620 PRINT A$(I),F(I,1),F(I,2),F(I,3),R(I),D(I)
630 NEXT I
640 PRINT
650 PRINT 'KENDALL W ='; W
660 CLOSE 1
670 END
```

RUN

OUTPUT RESULTS FROM KENDW1

STUDENT NAME	0 RANK	1 RANK	M RANK	R(I)	DELTA(I)
KINDEL	1	2	21.5	24.5	-38.5
SUMMERS	2	10	8	20	-43
HORNE	5.5	14	8	27.5	-35.5
MARTIN	5.5	29	28	62.5	-.5
SZOKA	5.5	29	18.5	53	-10
SALAMON	5.5	36.5	40	82	19
WESSEL	5.5	24.5	28	58	-5
WIGGE	5.5	1	1.5	8	-55
DRAWNECK	11	22	28	61	-2
TEPLY	11	14	11.5	36.5	-26.5
TIERNEY	11	10	28	49	-14
BARKLEY	11	14	4	29	-34
BERARD	11	10	14.5	35.5	-27.5
BAL	15	3.5	1.5	20	-43
HUTFLESS	15	7.5	11.5	34	-29
SOLECKI	15	18.5	8	41.5	-21.5
KENNEDY	22.5	26.5	28	77	14
KRATOCHVIL	22.5	5.5	28	56	-7
ACCURSI	22.5	18.5	14.5	55.5	-7.5
BROYLES	22.5	32.5	18.5	73.5	10.5
DEVORE	22.5	14	4	40.5	-22.5
HARTLEY	22.5	3.5	14.5	40.5	-22.5
HOSTETTER	22.5	18.5	8	49	-14
KUJAT	22.5	32.5	28	83	20
LOGUE	22.5	36.5	35	94	31
SEMKO	22.5	32.5	21.5	76.5	13.5
STEVENS	22.5	26.5	38	87	24

VARAKIN	22.5	29	35	86.5	23.5
BISHOP	30.5	36.5	18.5	85.5	22.5
LINHART	30.5	7.5	14.5	52.5	-10.5
MCDEVITT	30.5	36.5	28	95	32
STAHL	30.5	14	4	48.5	-14.5
AULT	34.5	22	18.5	75	12
HOWARD	34.5	18.5	8	61	-2
RIGOT	34.5	32.5	35	102	39
WILSON	34.5	39	28	101.5	38.5
WILKERSON	38	40	41	119	56
SOHA	38	5.5	28	71.5	8.5
WATWOOD	38	24.5	38	100.5	37.5
URQUHART	40	22	28	90	27
WALLMARK	41	41	38	120	57

KENDALL W = .631613

TIME 2 SECS.