Course Content in High School Physics

High School Physics – Views from AAPT

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CONTENTS

High School Physics—Views from AAPT includes several papers published by the American Association of Physics Teachers (AAPT), 5112 Berwyn Road, College Park, MD 20740. They concern resources and policies needed to match high school physics teaching to its responsibilities and opportunities. The present document was prepared by the AAPT Committee on Special Projects for High School Physics, whose members were Donald Barron, Robert Beck Clark, Carole Escobar, William C. Kelly, John W. Layman, Katherine Mays, Jim Nelson, Joe P. Meyer, and Jack M. Wilson, in cooperation with the AAPT Committees on High School Physics and Professional Concerns.

1. WHAT TO TEACH

Choosing the proper content for high school physics courses from the universe of possibilities is not an easy task for the teacher or the school. Depth or wide coverage, student interests and background, teacher strengths, and degree of rigor must be considered. For many students, a high school course may be their only formal experience with physics. For other students, the high school physics course lays the foundation for later work in physics in college. The adequacy of the preparation it provides is therefore of keen interest to those students and their families and to colleges and universities. Many states are concerned about course content and offer syllabuses to help guide the schools. But in the final analysis, the choice must be made by classroom teachers, who know their students and communities, their school resources, and, above all, the contributions different topics make to learning.

2. OVERVIEW

There is much knowledge under the heading of "an introduction to physics"—too much to be learned well in one school year. Beginning teachers especially should be wary of trying to teach too many topics. A few topics taught well are to be preferred to a bird's-eye view of physics. How then should teachers make their choices of "course content"—the topics to be taken up by their classes?

We begin (Section 3) by considering the universe of physics as a science and physics as an activity. The range of possible topics open to teachers and students is enormous. We discuss the opportunities and hazards in making these choices.

Although excessive narrowness and specialization are not desirable characteristics of a high school physics course, understanding should be favored over mere acquaintance in the selection of subject matter appropriate for the needs of the many kinds of students in high schools. A relatively few topics should be learned well (Section 4).

Pedagogical goals of many sorts need to be kept in mind. What skills do we want our students to acquire? Some examples are given in Section 5.

When assembling lists of candidate topics for the course, we have chosen to view the problem from several vantage points. Textbooks, often the central factor in choosing course content, are discussed in Section 6. Groups of teachers have reviewed leading textbooks in physics and described their characteristics, including the topics dealt with and the relative emphasis given to each topic; the results are summarized for the reader.

Nationally written and administered physics examinations are considered next in Section 7. By the choice of test questions, these examinations can indicate approximately the relative importance of different topics. Most states have recommended guidelines or syllabuses for high school physics courses, and some examples are given in Appendices B, C, and D.

Section 8 deals with the *process* by which physics teachers develop course content, often constructing "personalized" syllabuses. We believe the syllabus should be determined largely by the teacher using it. Beginning teachers may want to call on more experienced colleagues for advice, but the choice should be theirs. A syllabus is a plan, not a commitment, and should be adjusted as circumstances dictate.

Section 9 gives the results of a national survey of physics teachers to determine the relative emphasis placed on different topics in "real world" classroom situations.

Finally, Section 10 and Appendices F, G, and H contain descriptions of several interesting contemporary physics courses, including information about the school setting in which each course is given.

Not included here is a discussion of the physics laboratory which is an essential element of any excellent high school physics course.

3. A UNIVERSE OF POSSIBILITIES

The scope of physics is so large that a huge number of topics could be included in the high school course.[1] At the outset we wish to point out the following:

- Physics, the most basic of natural sciences, is both broad and deep. Its field of investigation ranges from the interior of stars to the tiny atomic nucleus and, in time, from today back to the time of the "big bang."
- Although broad, physics is tied together by basic ideas which run through all of it. These universal principles give unity, strength, and beauty to physics.
- Physics provides an occupation which is pursued with enthusiasm by men and women, our contemporaries. The frontiers of physics are expanding as these scientific pioneers push into the unknown. Physics is growing.
- Methods of inquiry are largely responsible for the successful development of the natural sciences. Physicists ask questions about nature and get answers in a variety of ways. These "ways of the physicist" are characteristic of the science. They deserve to be more widely known.
- Physics is not engineering, but it underlies engineering. Modern engineering developments can be traced to developments in the basic sciences. Applications of physics to engineering—and to medicine and many other fields—are interesting and can be understood by someone who understands the underlying principles of physics.
- Other applications of physics—fascinating ones indeed—deal with phenomena of the natural world: the redness of sunsets, the blueness of the sky, how birds navigate, and what causes ocean waves to break into surf.
- Still other applications of physics in technology underlie many public policy concerns: nuclear power plants, nuclear waste disposal, the space program, energy sources, protection of the environment, and national defense.

Each of these seven points contains something that could—and, we believe, should—be a part of any high school physics course, whatever its objectives. The course should include topics drawn from a variety of subfields of physics (e.g., mechanics, wave motion, molecular physics and heat, electricity and magnetism, light, and atomic and nuclear physics). These topics should be sufficient in number to illustrate the breadth of the science, yet not so numerous that the teaching of each is slighted. Throughout the course, the basic principles should be stressed, the ideas that tie one subdivision of physics to the other. Physics should be experienced by high school students as a developing science and as one of the most exciting of contemporary frontiers. Furthermore, from this encounter with physics, the student should learn how the physicist asks questions about nature and works the answers into a picture of our universe and how to ask similar questions. Finally, applications of basic principles of physics to technology and everyday life, if used in moderation, add interest to the course for most students and teachers.

All of this is easily said, but not easily done. The physics teacher needs experience, sound judgment, a considerable knowledge of physics, a firm grasp of the art of teaching, and time to think, in order to cope successfully with these requirements. Pitfalls are numerous. An attempt to cover too many topics leads to superficiality, a besetting sin of introductory courses in the basic sciences. On the other hand, concentration on too few topics may turn students into junior-grade specialists when they should be generalists and may turn off students who would be attracted by a wider range of topics. Applications of physics in everyday life, in technology, and in related sciences enliven the course. A good teacher will use them skillfully to lead into discussions of basic principles. Used in excess, however, technological examples can cause the class to forget that applications are the apples on the tree of science, but not the tree itself. The alert teacher will want to present physics to his or her class as a growing science with contemporary developments, without neglecting the classical foundations upon which these developments rest.

Solving problems in the selection of content is not difficult for well-prepared physics teachers who have considerable teaching experience. Given an opportunity to keep up-to-date in physics and provided with the support and encouragement that they need, they will develop physics courses that meet high standards of quality and that hold the interest of students with many different backgrounds and career goals. It is the less well prepared teacher who most needs assistance in selecting content. This paper is intended to assist teachers whose college background may be weak in physics or who may not have had opportunities to keep up-to-date.

4. A RELATIVELY FEW TOPICS LEARNED WELL

First, a few words about the "coverage" of the physics course. A common mistake of inexperienced teachers is to try to cover too much material. Textbooks, by their comprehensiveness, sometimes mislead novice teachers. In order to satisfy the special interests of different teachers and different kinds of students, textbooks contain more topics than the authors expect to be discussed by any one class. Rather than cover many topics superficially, the physics teacher should deal with fewer topics well. This point was stated several decades ago at a conference called by the American Association of Physics Teachers (AAPT):

> Physics, as a body of knowledge, is now far too extensive to receive adequate general coverage in an introductory course. The instructor must not sacrifice depth and understanding by attempting to cover too many topics in encyclopedic fashion. As one of our colleagues has well said: "Let us uncover physics, not cover it."
>
> It was the opinion of the conference that a satisfactory introductory physics course could be constructed around the following seven basic principles and concepts and the material leading up to them:
>
> 1. Conservation of momentum
> 2. Conservation of mass and energy
> 3. Conservation of charge
> 4. Waves
> 5. Fields
> 6. The molecular structure of matter
> 7. The structure of the atom
>
> Furthermore, these seven principles and concepts outline the minimum content which any introductory course must encompass in order to provide a satisfactory treatment of present-day physics.
>
> Lest this list appear too brief, we point out that the discussion of such topics as Newton's laws of motion would ordinarily be included in the development of the principles of conservation of energy and of momentum at an introductory level.[2]

The point made in the conference report is still valid. However, physics has moved ahead since 1956, and an introduction to modern physics (simple applications of basic physics in elementary-particle physics, solid-state physics, relativity, and cosmology) is now also appropriate for high school courses.

5. SOME SKILLS TO BE IMPARTED

One extremely important component of high school physics is the acquisition by students of certain skills. There are many of these, and it is not possible to list them all here. Following are some examples of skills or abilities to be developed:

- Recognizing variables in an observed phenomenon (e.g., pressure, volume and temperature describe the state of an expanding gas in the cylinder of an automobile engine).
- Organizing observed information (e.g., observing and recording the potential difference across an electrical conductor as the current varies).
- Displaying information so that it may be examined for relationships (e.g., graphing potential difference versus current).
- Interpreting graphical information and relating a graph to its algebraic equation (e.g., determining the algebraic meaning of a straight-line graph of potential difference versus current).
- Learning problem-solving techniques and quantitatively solving simple physics problems (e.g., finding the velocity of a freely falling body at a given time).

- Making rough estimates based on simplifying assumptions (e.g., estimate of the volume and total floor space of a building).
- Transferring spatial information to other forms (e.g., understanding the relationship between a wired circuit and the wiring diagram for the circuit).

For students to acquire abilities or skills such as these requires much repetition and practice. Skills are not learned by teaching a single unit devoted to "skills" at the beginning of the year. Only by repeated attention to their application throughout the year do such skills become the property of the user. These skills should be utilized and learned as the students study mechanics, optics, heat, electricity and magnetism, waves, modern physics, etc. The steady development of skills is part of the underlying agenda in physics courses.

6. CONTENT OF TEXTBOOKS

In most U.S. high schools offering physics, the physics textbook has great importance as the chief teaching tool– even though textbook reading should be generously supplemented by reading other books and periodicals, working with apparatus and using computers and calculators, and viewing films and videotapes. However, the physics student may be expected to spend more time with the textbook than with laboratory apparatus or, indeed, with the physics teacher. The textbook therefore should be carefully chosen to meet the needs of the teacher and the students.

Some sections of textbooks are organized so that certain topics can be either omitted or discussed as the teacher wishes. Usually these topics deal with applications of physics. The physics teacher should exercise to the fullest the right to make a selection among such topics and to supplement the text discussion with other topics of the teacher's own choosing. He or she may also want to change the sequence of topics; sometimes it is not optimal for the physics course being offered.

What are some of the criteria that the teacher (or, sometimes, the textbook committee or the administrator) should consider in selecting a textbook? What kinds of content are included in textbooks? A panel of physics teachers working under the auspices of the AAPT identified seven major criteria for evaluating physics textbooks for high school courses:

1) *content* (accuracy and appropriateness of subject matter);
2) *level* (appropriateness of the presentation for high school students);
3) *readability* (ease with which the book can be studied);
4) *appearance* (attractiveness of the book to the eye);
5) *science* (presentation of physics as a growing body of knowledge);
6) *social problems* (awareness of the impact of physics on society); and
7) *assignments* (adequacy of materials for additional work by students).

On the basis of these criteria, the panel evaluated 14 of the more frequently used high school physics textbooks.

The same panel analyzed the contents of these textbooks and concluded that the major topic divisions were the following:

- *Measurement:* introductory statements, mathematical skills, uncertainty, making measurements, SI system of units.
- *Mechanics:* equilibrium states, kinematics, Newton's laws of motion, gravitation, momentum, energy and work.
- *Molecular physics:* calorimetry, kinetic molecular theory, gas laws, thermodynamics.
- *Waves:* mechanical waves in spring and ripple tank, sound.
- *Optics:* wave model of light, ray tracing, mirrors and lenses, diffraction and interference, polarization.
- *Electromagnetism:* electrostatics, simple circuits, magnetostatics, electric and magnetic fields, magnetic forces, induction.

- *Quantum physics:* photoelectric effect, energy levels in hydrogen atom, atomic spectra, nuclear structure, radioactivity, nuclear energy.

In addition, the panel found that a number of other topics were treated with widely varying degrees of emphasis: electromagnetic waves, relativity, energy resources, history of physics and/or astronomy, fluid mechanics, electronics, solid-state physics, astrophysics, and alternating-current circuits.[3]

As physics changes and as ways of teaching physics change, textbooks must change too. Most school districts and states have established procedures for reviewing physics textbooks and selecting ones that meet the needs of their educational programs. The physics teachers who will use the book should have ample opportunity to express their preferences when a new textbook is being considered. A list of physics textbooks currently in print can be obtained by writing to R. R. Bowker Co. for a copy of *Textbooks in Print*. Copies of this book are also often available in schools or public libraries.[4] Also useful are the "Physics Textbooks" issues of *Science Books and Films*, published regularly by the American Association for the Advancement of Science (AAAS).[5] Criteria for the reviews of textbooks by teachers under AAAS auspices include: content currency, content accuracy, content scope, structure and methods of science, organization and coherence, and comprehensibility.

7. CONTENT OF EXAMINATIONS

Certain widely used physics examinations reveal by their composition clues to the kind of course content that are considered important by many physics teachers. Thus, they can provide some guidance in the choice of course content in physics. They do not, however, serve as absolute standards and should be used with caution as instruments for the analysis or choice of course content.

Of the various national examinations offered in physics (e.g., the College Entrance Examination Board's Physics Achievement Test, the Advanced Placement Test in Physics, and the AAPT/NSTA Introductory Physics Examination) only the last will be considered here.[6] Originally called the High School Physics Examination, it was developed under the auspices of the AAPT and the National Science Teachers Association (NSTA) in 1981-82 with the purpose of providing high school teachers with an examination at low per-copy cost that would allow them to compare the achievement of their physics students with that of students in the rest of the country. The emphasis was to be on the understanding of physics; the mathematics required by the test items was restricted to introductory high school algebra and geometry. Some forty teachers from all over the United States took part in either determining the distribution of topics to be included or in writing test items. Throughout this work, the examination committee wanted to provide flexibility and to prevent the examination from becoming a *de facto* national syllabus.

The AAPT/NSTA Introductory Physics Examination is of interest in its own right as a test instrument, but here we are concerned with what it reveals about the typical content of high school physics courses. In the form published January 1, 1985, the major topic divisions of the Examination and percentages of the total number of test items devoted to them are:

Mechanics	30%
Heat and Kinetic Theory	10%
Electricity and Magnetism	25%
Waves, Optics, and Sound	20%
Modern Physics	15%

Further details about the topic distribution will be found in Appendix A. For information about the Examination, which is revised regularly, write to the AAPT at the address on page one.

8. SYLLABUSES

A syllabus lists in outline form topics to be discussed and indicates their relation to one another and to the objectives of the course. Experienced physics teachers usually develop–formally or informally–their own "personalized" syllabuses. Physics syllabuses prepared by state departments of education or by local school systems also furnish guidance to teachers in selecting content. In many of the states, curriculum committees are currently at work preparing or revising syllabuses for physics courses with various objectives. Information about the syllabus or syllabuses

in physics recommended by any state department of education can usually be obtained by writing to that department in the state capital. Larger school districts may have copies on hand.

A syllabus in physics has both advantages and disadvantages. Among the advantages are that it can define objectives for an educational program in physics which reflects the thinking of both physicists and educators and that it can guide new teachers of physics in the critical early years of their teaching.

Among the disadvantages is the tendency of a syllabus to "freeze" the pattern of teaching and to restrict the choice of topics. Teachers often feel obliged to follow literally the suggestions contained in a syllabus and are unable to experiment with new and fresh approaches to teaching. Any syllabus should provide considerable leeway for the experienced teacher to develop his or her own physics course.

The *"personalized" syllabus.* When the beginning teacher plans and develops a syllabus, in consultation with a more experienced colleague, he or she must remember that it is only an initial organization of topics and time. The teacher should retain the initiative to adjust the order and pace, the development of skills, and the mathematical level as the course progresses and the ability and interests of the students become apparent. Although it is desirable to cover some part of each of the major areas of physics during the year, many experienced teachers find they cannot. They believe that it is far more important to develop student confidence and skill. Some important questions must be asked and answered:

- What are the most important ideas and skills to be covered each semester? Starting the year with mechanics–as most textbooks do–the teacher may decide that Newton's Laws, their historical development, and their applications are the central ideas for the first semester. Or, it may be that the conservation laws–conservation of energy, linear momentum, and angular momentum–should be emphasized. When it has been decided what cannot be eliminated from the semester's work, the weekly and daily schedule should be planned accordingly.
- Which topics in the syllabus can be omitted, leaving more time for the primary topics and their development? The teacher should take a hard look at the list of topics and decide–*in advance*–which topics are the less essential ones and are candidates for omission. Thereafter, progress in the course should be continuously compared with the plans (the syllabus) as the semester goes on and omissions made steadily, not just in the last few weeks of the course. To inexperienced teachers, such adjustments may seem to be an impossible task because they fear inadvertently to omit "essential" topics. They should call on more experienced colleagues for assistance: another high school physics teacher, Physics Teaching Resource Agents (PTRAs) of the AAPT, or representatives of the American Physical Society (APS)/AAPT College High School Interaction Committee (CHIC), or other physicists in nearby colleges and universities. For information about PTRAs or CHIC, write to AAPT at the address on page one.
- What can the students be expected to retain in the months and years following the final examination? Has the syllabus stressed the primary topics sufficiently? Has it inculcated and reinforced the desired skills? Has it made students more confident that they can learn physics and strengthened (or created) an interest in physics?

Some examples of syllabuses that seem to have answered these questions satisfactorily for their teacher authors follow.

State syllabuses. Physics syllabuses prepared under the auspices of the states can be approached in a similar way. For example, reading the state syllabus, the physics teacher might mark each topic listed with one of three symbols:

*** Fundamental, must be included, allow time for careful development and for exercises, demonstrations, and laboratory work;

** Interesting and important, but less than fundamental, to be included in classroom discussion if time permits, or covered by film showings or supplementary reading;

* Optional topics for gifted students, students with special vocational interests, or students working on projects.

In most instances, experienced teachers will find themselves assigning the same weights as the syllabus–not a surprising result, since such teachers are usually strongly represented on state syllabus committees. The point, once

again, is that the physics teacher should have some latitude to choose. As examples of state guidance, copies of guidelines or syllabuses in California (Appendix B), Texas (Appendix C), and New York (Appendix D) are appended.

9. WHAT CONTENT IS *ACTUALLY* USED?

Guided by syllabuses, influenced by examinations, and dependent on textbooks in varying degrees, physics teachers choose course content. What is the result?

In 1983, Will Pfeiffenberger and Gerald Wheeler helped to guide a survey of schools by the Educational Testing Service and prepared an article[7] describing the results. The purpose of the survey was to determine the "common core of material that is normally a part of most high school physics courses" as a basis for writing test questions for the Physics Achievement Test of the College Board. The survey yielded returns from 110 schools, about a third of a sample of 317 schools selected from a national total of about 24,000 high schools.

Among the results of the survey were determinations of the percentage of course time devoted to each major topic of physics and percentages of teachers indicating coverage of subtopics in each of these major areas. For example, the following mean percentages of course time were obtained: Mechanics, 36%; Electricity and Magnetism, 20%; Optics and Waves, 20%; Heat and Kinetic Theory, 13%; Modern Physics, 9%; and Other, 2%. The detailed graphs of percentages of teachers indicating coverage of subtopics in each of the major fields will be found in Appendix E.

10. NEW COURSES

Underlying the validity of the choice of course content is always the creativity, knowledge, experience, and enthusiasm of the physics teacher. Each generation of physics teachers–even in a single school–solves this problem anew.

Physics is a living subject. Newly observed phenomena are continually being added to its subject matter, and models for dealing with old and new phenomena are continually changing. Moreover, new applications of physics spring up at every turn. Content of physics courses should not be frozen.

There are encouraging signs that the present generation of high school physics teachers is, in fact, aware of the need for continual review and reconsideration of course content. A sizable number of teachers are devising new courses, based on their own ideas of how to organize the changing content of physics to meet the goals described at the beginning of this document and to provide a better match to the needs of their students, whether college-bound or headed for technical school or immediate employment.

We give brief descriptions of examples of such courses in two school districts (with detailed lists of course topics in the Appendices.) We also include information about a course in Applied Physics, developed by the Ontario Ministry of Education in Canada and used in a number of schools in Ontario. Each of the three examples pursues a somewhat different set of course objectives.

Lower Merion (PA) High School. (Carl C. Duzen, physics teacher reporting.) Lower Merion High School in Ardmore, Pennsylvania, is located in the western suburbs of Philadelphia. The community is generally well-to-do, but not universally so. The curriculum caters to college-bound students, who make up over 85% of the school population. There is a significant minority-group representation. In the standard-level course, for which the syllabus is provided in Appendix F, the classes are split fairly evenly between 11th and 12th graders and between males and females. About 100 students are enrolled. The total enrollment in physics at all levels is near 200, and over 60% of the 1986 graduating class had taken a course in physics. Each physics class has six 47-minute meetings a week, including a double period once a week.

Standard-level physics assumes prior instruction in elementary algebra and in plane geometry. It is a general education course which will be the only physics exposure for many of those enrolled. Happily, numbers of students find their curiosity stimulated and do go on to further study, although they had not intended to.

Mr. Duzen reports that the syllabus given below has been developed and used by four physics teachers at Lower Merion with a success that is indicated by a doubling of the number of students completing a physics elective. The syllabus presents a plan of student-centered activities. These activities provide a mechanism whereby students can grow from a state of apprehension about their abilities to do physics and mathematics to a condition of being novice, but qualified, practitioners of science. The basic philosophy of the teachers is to "finish the story," rather than to "finish the syllabus."

The syllabus consciously proceeds from the concrete to the abstract, from direct experiences to generalizations based on sets of experiences. It then takes up the extension of the generalizations. It seeks always to engage students in the issues of quality and sources of knowledge. It contains (say the authors) an expectation of growth.

The textbook issued to the students is *Project Physics*, but the structure of the course is strongly influenced by the original plan of the Physical Science Study Committee physics course. The first part of the syllabus is executed without the textbook to emphasize the fact that the ultimate authority for science is experience rather than books. The point in the course where the textbook is introduced is indicated in the syllabus. Thereafter, one may use the textbook index as a guide to the companion reading.

The goals or objectives of the course are:

1. To help students increase their knowledge of the physical world by concentrating on ideas that characterize physics as a human enterprise rather than concentrating on isolated facts or bits of information.
2. To present physics as a many-sided human activity, showing the subject in historical and cultural perspective as its traditional content is developed.
3. To provide opportunities for students to express technical material in written form, thereby reinforcing their expository writing skills.
4. To provide a setting where mathematics is reinforced by use in problem-solving in the laboratory.
5. To provide concrete experiences as the foundation for physics concepts through the extensive use of investigation and personal interaction with nature in a laboratory setting.
6. To develop a general appreciation for the methods and content of science by exploring the material of physics with students who may not select careers in science or applied science.
7. To explore the limitations of scientific knowledge by participation in the collection of data and the formulation of supportable generalizations derived from the data.

Des Moines (Iowa) High Schools. (Herman H. Kirkpatrick, physics teacher reporting.) The five public high schools of Des Moines serve students having a wide range of backgrounds and needs. The Des Moines syllabus given in Appendix G grew out of a project organized locally by the science supervisor to write a single set of objectives for the physics courses in all of the public high schools of Des Moines. Six physics teachers took part. Preparation of the objectives was followed by the construction of an objectives-based final examination in physics, which was tested and is now administered annually in the schools. The objectives listed are also useful in a review of the course by the students at the end of the year. Two textbooks are included in the current adoption by the Des Moines schools: *Physics: Principles and Problems* by Murphy and *Conceptual Physics* by Hewitt. The level of difficulty of the courses differs greatly from one school to another. Two of the teachers offer two levels of physics in their schools.

To illustrate the setting in which the physics courses are given, the Theodore Roosevelt High School has provided the following data about itself: Total enrollment (grades 9-12) in September 1986 was 1,565. There were 84 teachers on the faculty and 6 teacher associates. The median G.P.A. of the 1987 class (at the end of six semesters) was 2.50; there were four National Merit Finalists in 1986. The mean score for the class of 1986 in the Scholastic Aptitude Test (Verbal) was 472 and for SAT (Mathematical) was 500. Of those graduating in 1986, 66% planned to enter a college or university. Among the requirements for graduation were one year of mathematics and one year of science. Other mathematics and science courses are elective. Science enrollments in September 1986 were: Earth Science 99, Biology 285, Physical Science 118, Cosmos 46, Physics 114, Chemistry 148, Advanced Biology 44, and Anthropology 41.

The physics course (four classes) at Theodore Roosevelt High School uses *Conceptual Physics* as the textbook and for the Physical Science Study Committee laboratory activities. Mr. Kirkpatrick also offers a course "Special Topics in Physics" to high school achievers in physics, who meet once a week (at 7:00 a.m.) to discuss topics in contemporary physics based on their reading of *The Second Creation* by Crease and Mann.

Ontario Ministry of Education, Canada. (Alan Hirsch, physics teacher reporting.) The course described here is entitled *Applied Physics*, formerly *General Level Physics*. It is a grade 12 course aimed toward the needs of a different part of the student population than is catered for by the traditional physics course. It is the only full course in physics offered at the general level–that is, in the non-academic stream. The course guidelines emphasize the rela-

tion among science, technology, and society. Core units require 86 hours of instruction; optional units require an additional 24 hours, chosen from a possible 60 hours covering various optional topics.

Draft guidelines, presently under review by the Ministry, describe the purpose of the course as follows:

> The principles of physics are involved in many daily activities and provide a foundation for an ever-expanding technology.
>
> This course is the first full course in physics offered at the general level. It has two aims. First, it is designed to provide students with an understanding of some of the principles of physics and also an appreciation of technology as an application of these principles. Second, students will study concepts such as energy and develop skills in measurement and graphing needed to continue into the technological science course. This course may be an admission requirement for technical and technological programs at Colleges of Applied Arts and Technology. Achievement of the first aim will increase the scientific literacy of students as they learn how to explain physical phenomena; the second aim is directed toward preparing students for possible careers in science and technology.
>
> The course offers some optionality in unit selection. Approximately 80 percent of the time will be taken up by core units while 20 percent will involve optional material. This is intended to allow for variations in student interest, teacher expertise, local community resources and student background.

Appendix H contains a list of the units included in the course, including the optional units, and the topics dealt with in each unit. Other sections of each unit, not included because of lack of space, are: objectives, attitudes and skills to be developed in the student, specific knowledge to be attained, student activities, applications, societal implications, evaluation of student achievement, safety considerations, possible extensions and teaching suggestions.

AN ACKNOWLEDGMENT

AAPT wishes to acknowledge the important role played by an earlier publication in inspiring this report and providing portions of the text for its first draft. *Physics in Your High School*, a handbook prepared by Thomas D. Miner and William C. Kelly under the auspices of the American Institute of Physics, was published by the McGraw-Hill Book Company in 1960. Although now long out of print, it served to stimulate local discussion about improving physics courses in many communities of the United States for a decade or so. Chapter IV – "The Courses - Their Content" – provided many helpful suggestions and felicitous phrasings for the present document. In place of detailed citations of the borrowed text, which was subsequently edited for this report, we acknowledge here with thanks the many contributions of this predecessor.

11. REFERENCES

(1) *Physics in your High School,* American Institute of Physics, (1960) *loc. cit.*

(2) Frank Verbrugge, "Carleton Conference on Improving the Quality and Effectiveness of Introductory Physics Courses," *American Journal of Physics* **25,** 127 (1957).

(3) Robert Lehrman et al., "Physics Texts: An Evaluative Review," *The Physics Teacher*, November 1982, page 509.

(4) *Textbooks in Print*, R. R. Bowker and Co., 245 West 17th Street, New York, New York, 10011. Published annually.

(5) Andrew Ahlgren, ed., "Physics Textbooks Special," *Science Books and Films*, Sept./Oct. 1986, American Association for the Advancement of Science, 1333 H Street, NW, Washington, D.C. 20005.

(6) James Nelson, "AAPT/NSTA High School Physics Examination," *The Physics Teacher*, February 1983, page 100.

(7) Will Pfeiffenberger and Gerald F. Wheeler, "A Curriculum Survey of High School Physics Courses," *The Physics Teacher*, December 1984, page 569.

APPENDIX A.

TOPIC DISTRIBUTION FOR AAPT/NSTA INTRODUCTORY PHYSICS EXAMINATION (JANUARY 1, 1985)

MECHANICS [30 %]

1. Analysis of data [1%]
   a) graphing data
   b) scientific notation and significant figures
   c) interpreting graphical information
   d) units of measurement
   e) proportional thinking
   f) order of magnitude estimations
2. Motion in one dimension [5%]
   a) kinematics (speed, velocity, and acceleration)
   b) motion with constant acceleration (e.g. free fall)
3. Motion in two dimensions [5%]
   a) uniform circular motion
   b) projectile motion
   c) vectors (addition, subtraction, and scaling)
4. Dynamics of a single body [5%]
   a) static equilibrium (forces as vectors)
   b) dynamic equilibrium
   c) Newton's three laws of motion
   d) friction (solid - solid coefficient of friction)
   e) centripetal acceleration and force
   f) inertial mass
5. Conservation of energy [5%]
   a) work
   b) kinetic and gravitational potential energy
   c) power
6. Conservation of linear momentum [5%]
   a) elastic and inelastic collisions
   b) "explosions"
   c) impulse
7. Torque and rotational equilibrium [1%]
8. Newton's law of gravitation [2%]
   a) circular orbits and satellites
   b) Kepler's laws of planetary motion
   c) gravitational field
9. Oscillations [1%]
   a) simple harmonic motion
   b) motion of mass vibration on spring
   c) motion of a simple pendulum
   d) Hooke's law

HEAT AND KINETIC THEORY [10%]

10. Temperature and heat [4%]
    a) specific heat
    b) heat as form of energy (i.e. mechanical equivalence)
    c) calorimetry
    d) heat transfer by conduction, convection, and radiation
11. Kinetic theory of matter [4%]
    a) ideal gas law
    b) phase change and energy
    c) density
    d) absolute temperature and molecular kinetic energy
12. Thermodynamics [2%]
    a) first law as statement of conservation of energy
    b) second law

ELECTRICITY AND MAGNETISM [25%]

13. Electrostatics [7%]
    a) electrical charge and Coulomb's electric force law
    b) electrostatic induction
    c) electric fields
    d) electric potential of point charges
    e) parallel plate capacitors
14. Direct - current circuits (steady state) [6%]
    a) current
    b) resistance (series and parallel resistor networks)
    c) voltage and d-c sources
    d) Ohm's and Kirchhoff's laws
    e) electrical power and energy
    f) use of ammeters and voltmeters
    g) internal resistance
15. Alternating-current circuits (steady state) [1%]
    a) effective values
    b) inductance
    c) capacitance
16. Magnetism and magnetic fields [15%]
    a) permanent magnets
    b) magnetic field produced by moving charge
    c) magnetic force on a moving charge
    d) magnetic force on long current-carrying wire
17. Electromagnetic induction [6%]
    a) Lenz's law
    b) Faraday's law

WAVES, OPTICS, AND SOUND [20%]

18. Waves [6%]
    a) properties of waves (transverse and longitudinal waves)

b) traveling and standing waves (beats)
c) principle of superposition
d) waves moving from one medium to another
e) relationship between wavelength, frequency, and propagation speed

19. Geometric optics [7%]
    a) rectilinear propagation
    b) reflection and mirrors (concave, convex, plane)
    c) refraction and lenses (diverging and converging)
    d) total internal refraction
    e) dispersion
    f) inverse square law
    g) particle versus wave model of light
20. Physical optics [5%]
    a) interference
    b) diffraction
    c) polarization
    d) electromagnetic spectrum
    e) color
21. Sound [2%]
    a) properties of sound waves (intensity and pitch)
    b) Doppler effect
    c) harmonics
    d) resonance

MODERN PHYSICS [15%]

22. Atomic physics [7%]
    a) properties of photons
    b) photoelectric effect
    c) wave - particle duality
    d) atomic energy levels (Bohr model of atom)
    e) Planck's constant
23. Nuclear physics [7%]
    a) Rutherford scattering experiment and nuclear model of atom
    b) radioactivity (half-life)
    c) nuclear reaction (fission and fusion)
    d) isotopes
24. Special relativity [1%]
    a) Einstein's postulates
    b) mass, length, and time dependence on speed
    c) equivalence of energy and mass
    d) speed of light as limit

APPENDIX B.

STATEMENT ON PHYSICS PREPARATION EXPECTED OF ENTERING FRESHMAN IN THE STATE OF CALIFORNIA* COURSE CONTENT - PHYSICS

Introduction

The study of physics provides a systematic understanding of the fundamental laws that govern physical, chemical, biological, terrestrial, and astronomical processes. Physics is the root science. The basic principles of physics are the foundation of most other sciences and of technological applications of science. Physics is also part of our culture and has had enormous impact on technological developments. Many issues of public concern, such as energy, nuclear power, national defense, pollution, and space exploration involve physical principles that require some understanding for informed discussion of the issues. Thus comprehending physics is important for a rational, enlightened citizenry to participate responsibly in decisions on public policy regarding complex technological issues.

Physics is not just for physicists. In fact, few people who study the fundamentals of physics actually become physicists. Many enter related fields, such as engineering or other sciences, and many pursue nonscientific careers. For this reason, pre-college physics should be taught at a general level and should demonstrate the general principles of the science.

Physics is an experimental science in that every statement of physical law is subject to verification and should be taught with this in mind. The relevance of physics to present and future technology should be made apparent.

The course content list that follows is offered as a best estimate of what should be included in the high school physics course for college-bound students. It is hoped the list will serve as a starting point for continuous discussion regarding the nature and scope of the course.

Mathematics: The physics course can be taught well with various levels of mathematical preparation. In fact, physics lends itself well to introducing students to the mathematical aspects of science. Physics is easy to describe mathematically, but it should not be inferred that physics can be easily learned mathematically. An overemphasis on mathematical analysis will disenfrancise many capable students from studying physics at the high school level. Ideally, a balance must be struck between the conceptual and mathematical aspects of physics - with neither predominating. Physics teachers should make reasonable adjustments in their presentations to ensure this balance and to keep the scientific level compatible with the mathematical preparation of their students. Prerequisites consistent with the *Statement on Competencies in Mathematics Expected of Entering Freshmen* are Algebra I and geometry with a *corequisite* of Algebra II. A closer idea of the mathematical depth of high school physics can be gained from the sample exercise given in Appendix III.

Topics for a One-Year Course in Physics

The topics are grouped under five main classifications: Mechanics, Heat and Thermodynamics, Electricity and Magnetism, Light and Optics, and Modern Physics. Specific concepts are grouped in relation to the topics within which they may best be covered. It is assumed that basic concepts of the nature of science have been covered at an earlier stage either in other science courses or, preferably, at a pre-secondary level. Basic to an understanding of science would be an appreciation of:

- the nature of scientific evidence
- strengths and limitations of science as a way of "knowing"
- the objective process of scientific inquiry
- accuracy and predictability of scientific knowledge

There are other topics that should be covered in introductory science courses, such as climate, weather, and weather predictions; plate tectonics; descriptive astronomy. Additional coverage of weather behavior (not just prediction) and plate tectonics (and the consequences of plate motion), while based in physics, is the domain of Earth science.

The topics marked with a single asterisk (*) are also listed under chemistry curriculum. The topics marked with a double asterisk (**) are considered to be special or advanced topics.

From "Statement on Preparation in Natural Science Expected of Entering Freshmen," issued by the Academic Senates of the California Community Colleges, The California State University, and The University of California. California State Department of Education, July 1986.

A. Mechanics

1. The Metric System of Units for Length, Time, and Mass*
   - estimates and approximations
   - Metric units: their relation to units commonly used in everyday life
   - dimensions
   - measurement and error
   - scientific notation
2. Concepts of Velocity and Acceleration
   - falling bodies:
   - in vacuum (constant acceleration)
   - in air
   - in viscous fluids (terminal velocity)
3. Projectile Motion in a Vertical Plane
   - trajectories
4. Newton's Three Laws of Motion
   - law of inertia
   - Newton's second law:
   - gravity of Earth
   - springs
   - viscosity
   - friction
5. Gravity (Newtonian)
   - universal gravitation:
   - on Earth (law of falling bodies)
   - beyond (orbits)
6. Concepts of Torque, Center of Mass, Equilibrium
   - levers
   - tension
   - center of mass and torque
   - machines (mechanical advantage)

Comment: The fundamentals of simple machines (lever, wheel, pulley, etc.) and mechanical advantage should be addressed in this segment as these discussions have been largely displaced from the college curriculum.

Give me somewhere to stand, and I will
move the Earth.
Archimedes, in reference to the lever.

7. Concepts of Work, Energy, and Power; Conditions for the Conservation of Energy
   - work
   - kinetic energy
   - gravitational potential energy
   - other potential energy
8. Linear Momentum; Conditions for Conservation of Linear Momentum
   - conservation of momentum
   - collisions and other applications
9. Circular Motion
   - centripetal force
   - centrifugal force
   - speed, acceleration
10. Rotational Motion and Angular Momentum
    - conservation of angular momentum
    - gyroscopes
    - Kepler's second law **
11. Fluids; Statics and Dynamics
    - fluid statics (Archimedes' principle) **
    - energy in fluid flow (Bernoulli's principle) **
12. Harmonic Motion
    - springs
    - pendulums (time-keeping)
13. Waves in Linear Media; Principle of Superposition; Sound
    - waves (water waves, sound waves)
    - wave properties (speed, frequency, wavelength, standing waves, propagating waves)
    - resonance **

B. Heat and Thermodynamics

1. Temperature and Heat
   - heat
   - heat and temperature
   - thermometers; F, C, K scales
   - heat as a kinetic phenomenon
2. Thermal Equilibrium and Heat Transfer
   - spread of heat
   - conduction
   - convection
   - radiation
3. Mechanical Equivalent of Heat
4. Change of State *
   - state of matter
   - phase transitions
5. Thermal Expansion of Matter
   - thermal coefficient of expansion
6. The Ideal Gas Law *
7. Kinetic Theory of Matter
   - ideal gas law as a kinetic phenomenon *
8. First and Second Laws of Thermodynamics
   - Carnot engine **
   - absolute temperature *
   - cryogenics **

C. Electricity, Magnetism, and Electromagnetism

1. Coulomb's Law
   - charge
   - charge conservation
   - Coulomb's law
2. Electric Field and Electric Potential
   - potential energy and voltage
   - electric field

3. Ohm's Law
   - electricity in matter
   - conductors and insulators
   - current
   - batteries
   - Ohm's law
   - simple circuits
   - power and heat
4. Capacitance
   - capacitors
   - typical values of voltage, charge, and energy
   - electrostatics machines and devices
5. The Magnetic Field; Magnetic Forces
   - force on a moving charge
   - atomic magnetism (magnetic materials) **
   - permanent magnets
   - planetary magnetism **
6. Electromagnetic Induction
   - principle of electromagnetic induction
   - transformers
7. Energy of Electric and Magnetic Fields
8. Alternating Current
   - AC generators; motors
   - AC transmission lines (reason for)
9. Electromagnetic Waves

D. Light and Optics

1. Light and Color
2. Reflection and Refraction
   - prism spectrometer (observation and discussion of)
   - refraction; Snell's law
   - colors
3. Mirrors and Lenses
   - lenses and images
   - telescopes and microscopes
   - fiber optics **
4. Diffraction and Polarization
   - grating spectrometer (observation and discussion of)
   - wave nature of light; diffraction
   - the electromagnetic spectrum
   - polarization
5. Coherent Light
   - lasers (holograms) **

E. Modern Physics

1. Special Relativity **
   - the Michelson-Morley experiment
   - time dilation and space contraction
   - relativistic mass
   - $E = mc^2$
   - gravitational and inertial mass
   - principle of equivalence
   - curved space and black holes
2. The Heisenberg (Indeterminacy) Principle **
   - quantum physics
   - the photoelectric effect; waves are particles
   - electron diffraction; particles are waves
   - Heisenberg principle of uncertainty (indeterminacy)
3. Atomic Theory and Structure (introductory)
   - electricity: nature of atoms, solids and liquids
   - x-ray diffraction **
   - transistors **
   - integrated circuits and computers **
4. Nuclear Structure (introductory) **
   - elementary particles, quarks, etc.
5. Radioactivity; Fission; Fusion **
   - stability of nuclei
   - fission, fusion
   - nuclear decay, lifetimes
   - nuclear reactors; health-physics concerns

F. Science and Human Affairs

- public participation in scientific undertaking
- using knowledge to reach informed decisions
- careers and avocations in science

APPENDIX C.

PHYSICS SYLLABUS OF THE STATE OF TEXAS **

PHYSICS I

Physics is the study of matter and energy and their interactions. Students are introduced to fundamental concepts in the areas of mechanics, light, sound, heat, electricity, magnetism, and nuclear phenomena. Students acquire information using the senses and instrumentation. Observations of the laws of force and motion, the nature of light, wave phenomena, and properties of electricity and magnetism are integral components of the course. Student investigations emphasize accurate observations, collection of data, analysis of data, and the safe manipulation of laboratory apparatus and materials.

Physics I (1 unit)

Essential elements	Subelement
Physics I shall be a laboratory-oriented course and shall include the following essential elements:	The student shall be provided opportunities to:
(1) Manipulative laboratory skills	demonstrate the safe use of physics laboratory equipment and supplies
(2) The use of skills in acquiring data through the senses	observe physics phenomena
(3) The use of classification skills in ordering and sequencing data	(A) classify physical interactions according to similarities (B) sequence a physics investigation
(4) Experience in oral and written communication of data in appropriate form	describe physical processes
(5) Experience in concepts and skills of measurement using relationships of standards	(A) measure physical quantities (B) plot data on graphs and other displays
(6) The use of skills in drawing logical inferences, predicting outcomes, and forming generalized statements	(A) predict the outcome of a physics investigation from trends in data using inference, extrapolation, or interpolation (B) deduce a physics hypothesis from cause-and-effect relationships
(7) Experience in skills in relating objects and events to other objects and events	(A) evaluate scale models of vector problems (B) compare the functions of electronic circuits (C) compare the electrical efficiency of appliances
(8) Experience in applying defined terms based on observations	clarify operational definitions used in explaining physics processes
(9) Experience in identifying and manipulating the conditions of investigations	(A) identify the variables remaining constant, the variables being manipulated, and the variables responding in an investigation in physics (B) choose an experimental design to test a hypothesis in physics
(10) Application of science in daily life	(A) apply principles of physics to an investigation (B) evaluate the applications and career implications of physics principles and the findings of research

** Source: Division of Curriculum Development, Texas Education Agency, Austin, Texas.

Suggested Topics for Physics I

Fundamental Physical Quantities
- characteristics of fundamental physical quantities: mass, time

Vectors and Scalars
- characteristics
- prepresentations
- mathematical operations

Kinematics
- characteristics of motion
- speed
- rectilinear velocity
- rectilinear acceleration
- circular motion

Dynamics
- characteristics of dynamics
- friction
- gravity
- impulse and momentum

Mechanical Energy
- characteristics of energy
- work
- kinetic energy
- potential energy
- conservation of energy

Machines
- characteristics of machines
- simple machines
- mechanical advantage

Properties of Matter
- characteristic properties of matter
- solids, liquids, and gases
- elasticity
- hydrostatics
- hydrodynamics

Heat and Thermodynamics
- characteristics of heat and thermodynamics
- temperature
- thermal expansion and contraction
- quantity of thermal energy
- change of state
- transfer of heat
- thermodynamics

Waves
- characteristics of waves
- reflection
- refraction
- diffraction
- interference of waves

Sound
- characteristics of sound
- transmission of sound
- reflection and absorption of sound
- intensity of sound
- frequency of sound

Light (electromagnetic radiation)
- characteristics of light
- photometry
- color
- photoelectric effect

Electricity
- characteristics of electricity
- electrostatics
- electrical forces
- potential differences
- electric current
- electric circuits
- electric energy

Magnetism
- characteristics of magnetism
- magnetic forces
- electromagnetism
- electromagnetic induction
- generators and motors
- alternating current circuits

Atomic Physics
- characteristics of atomic physics
- subatomic particles
- spectra of elements

Nuclear Physics
- characteristics of nuclear physics
- nature of radioactivity
- nuclear reactions
- nuclear energy

APPENDIX D.

PHYSICS SYLLABUS OF THE STATE OF NEW YORK ***

(The excerpts given below contain the outline of topics and the development of Topic I: Kinematics as an example.)

TOPICAL OUTLINE

MECHANICS

I. Kinematics
- A. Linear motion
  - 1. Distance and displacement
    - a. The meter
  - 2. Velocity and speed
    - a. The second
  - 3. Acceleration
  - 4. Distance traveled by a uniformly accelerating object
  - 5. Freely-falling objects

II. Force
- A. Composition of forces
- B. Resolution of force

III. Dynamics
- A. Mass, force, and acceleration—the inertial and gravitational properties of objects
  - 1. First law of motion
  - 2. Second law of motion, inertial mass
    - a. The kilogram
    - b. The newton
  - 3. Newton's law of gravitation
  - 4. Weight
- B. Uniform circular motion
  - 1. Centripetal acceleration
  - 2. Centripetal force
- C. Momentum
  - 1. Impulse
  - 2. Change of momentum
  - 3. Law of conservation of momentum

IV. Work and Energy
- A. Work
  - 1. The Joule
- B. Energy
  - 1. Potential energy
  - 2. Gravitational potential energy
  - 3. Kinetic energy
- C. Power
  - 1. The watt

V. Conservation of Energy
- A. Friction

VI. Internal Energy and Heat
- A. Mechanical equivalent of heat
- B. Temperature
  - 1. Absolute temperature
    - a. Absolute zero
- C. MKS temperature scales
  - 1. Celsius
  - 2. Kelvin
- D. Exchanges of internal energy
  - 1. Kilocalorie
  - 2. Specific heat
  - 3. Change of phase
    - a. Heat of fusion
    - b. Heat of vaporization

VII. Kinetic Theory of Gases
- A. Pressure
- B. Gas Laws

*** From *Physics: A Syllabus for Secondary Schools*, The University of the State of New York, The State Education Department, Bureau of Curriculum Development, Albany, New York, 1984.

TOPICAL OUTLINE (continued)

WAVE PHENOMENA

I. Introduction to Waves
- A. Transfer of energy
- B. Pulses and periodic waves
  - 1. Pulses in a material medium
    - a. Speed
    - b. Reflection and transmission
  - 2. Periodic waves
- C. Types of wave motion
  - 1. Longitudinal waves
  - 2. Transverse waves
    - a. Polarization
  - 3. Other types of waves

II. Common Characteristics of Periodic Waves
- A. Frequency
- B. Period
- C. Amplitude
- D. Phase
- E. Wavelength
- F. Speed
  - 1. Effect of medium
  - 2. Dispersive medium
  - 3. Nondispersive medium
- G. Doppler effect
  - 1. Sound
- H. Wave propagation
  - 1. Wave fronts
  - 2. Huygens' principle

III. Periodic Wave Phenomena
- A. Reflection
- B. Refraction
  - 1. Snell's Law
  - 2. Speed and refraction
- C. Diffraction
- D. Interference
  - 1. Superposition
    - a. Constructive interference
    - b. Destructive interference
  - 2. Two sources in phase
  - 3. Standing waves
    - a. Reflection

IV. Light
- A. Speed
  - 1. In space
  - 2. In a material medium
- B. Reflection
  - 1. Law of reflection
  - 2. Regular reflection
  - 3. Diffuse reflection
- C. Refraction
  - 1. Index of refraction
  - 2. Critical angle
  - 3. Total internal reflection
  - 4. Dispersion
- D. Lenses
  - 1. Converging lens
    - a. Images
    - b. Size and distance of images
  - 2. Diverging lenses
- E. Wave nature of light
  - 1. Interference of light
    - a. Coherent sources
    - b. Double slit
    - c. Single slit
    - d. Resolution
    - e. Thin films
  - 2. Transverse nature of light
- F. Electromagnetic radiation
  - 1. Electromagnetic spectrum
  - 2. Sources of electromagnetic radiation
    - a. Continuous spectra
    - b. Line spectra
  - 3. Doppler Effect

TOPICAL OUTLINE (continued)

ELECTRICITY

I. Static Electricity
- A. Microstructure of matter
- B. Charged objects
- C. Transfer of charges
  - 1. Conservation of charge
  - 2. Separation of charge by contact
  - 3. Conduction
  - 4. Induction
- D. Elementary charges
- E. Quantity of charge
- F. Coulomb's law
- G. Electric fields
  - 1. Field around a point charge
  - 2. Field around a uniformly charged rod
  - 3. Field between two parallel charged plates
  - 4. Electric potential
- H. Potential difference
  - 1. The volt
  - 2. The electron volt
  - 3. Electric field in terms of electric potential
- I. Granular nature of charge. The Millikan experiment.

II. Electric Current
- A. Conductivity in solids
- B. Conductivity in liquids
- C. Conductivity in gases
- D. Conditions necessary for a current
- E. Unit of current
- F. Resistance
  - 1. Unit of resistance
  - 2. Resistance in conductors
  - 3. Ohm's law
  - 4. Temperature
- G. Conservation of charge and energy in electric circuits
  - 1. Conservation of charge
  - 2. Conservation of energy
  - 3. Series circuits
  - 4. Parallel circuits
  - 5. Electric power
  - 6. Electric energy and heat

III. Magnetism
- A. Magnetic force
- B. Magnetic field
  - 1. Direction
  - 2. Magnetic flux lines
  - 3. Flux density
    - a. Permeability
  - 4. Magnetic field around a straight conductor
  - 5. Magnetic field around a loop
  - 6. Magnetic field around a solenoid
- C. Force on a current-carrying conductor in a magnetic field
- D. Force between two straight parallel conductors
- E. Magnetic effects of moving charges
  - 1. Force on a moving charge
  - 2. Force on a loop or solenoid
    - a. The galvanometer
- F. Magnetic nature of matter
  - 1. Field around a permanent magnet

IV. Electromagnetic Induction
- A. Magnitude of an induced electromotive force
- B. Generator principle

V. Electromagnetic Radiation

VI. Electron Beams
- A. Thermionic emission
- B. Electron beams in an electric field
- C. Control of electron beams
- D. Charge to mass ratio
- E. Mass of the electron

TOPICAL OUTLINE (continued)

ATOMIC AND NUCLEAR PHYSICS

I. Dual Nature of Light
- A. Wave phenomena
- B. Particle phenomena
  - 1. Photoelectric effect

II. The Quantum Theory
- A. The quantum
  - 1. Planck's constant
- B. Explanation of the photoelectric effect
  - 1. Photon
  - 2. Photoelectric equation
    - a. Threshold frequency
- C. Photon-particle collisions
  - 1. Photon momentum
- D. Matter waves

III. Models of the Atom
- A. The Rutherford model of the atom
  - 1. The alpha particle
  - 2. Alpha particle scattering
  - 3. Trajectories of alpha particles
  - 4. Scattering and atomic number
  - 5. Dimensions of atomic nuclei
- B. The Bohr model of the hydrogen atom
  - 1. Bohr's assumptions
  - 2. Energy levels
    - a. Ground state
    - b. Ionization Potential
  - 3. Standing waves

IV. Atomic spectra
- A. Excitation and emission
- B. Absorption spectra
- C. The hydrogen spectrum
  - 1. Balmer series

V. The Nucleus
- A. Observational tools
- B. Accelerators
- C. Nucleons
- D. Atomic number
- E. Mass number
- F. Nuclear force
- G. Nuclear mass and binding energy
- H. Isotopes

VI. Nuclear Reactions
- A. Natural radioactivity
  - 1. Alpha decay
  - 2. Beta decay
  - 3. Gamma radiation
- B. Half life
- C. The atomic mass unit
- D. Mass-energy relationship
  - 1. Conservation of mass-energy
  - 2. Einstein's mass-energy equation
- E. Induced (artificial) transmutation
  - 1. Beta decay
  - 2. The neutron
- F. Nuclear fission
  - 1. Thermal neutrons
  - 2. Moderators
- G. Fusion

TOPICAL OUTLINE (continued)

KINEMATICS (AN EXAMPLE)

Topics	*Understandings and Fundamental Concepts*
I. Kinematics	Kinematics deals with the mathematical methods of describing motion without regard to the forces which produce it.
A. Linear motion	The motion of a body may be described in terms of its velocity and acceleration.
1. Distance and displacement	Distance is a scalar quantity that represents the length of a path from one point to another.
a. The meter	The meter is the MKS unit of length. It is a fundamental unit.
2. Velocity and speed	Velocity is a vector quantity which represents the time-rate of change of displacement. Speed is a scalar quantity that represents the magnitude of the velocity.
a. The second	The second is the MKS unit of time. It is a fundamental unit.
3. Acceleration	Acceleration is a vector quantity that represents the time-rate of change in velocity.
4. Distance traveled by a uniformly accelerating object	The distance traveled by a uniformly accelerating object is equal to the product of the average speed and the elapsed time. The distance traveled by an object accelerating uniformly from rest is proportional to the square of the time.
5. Freely-falling objects	Freely-falling objects may be considered as examples of objects with constant acceleration.

APPENDIX E.

PERCENTAGES OF TEACHERS INDICATING COVERAGE OF SUBTOPICS
(From Pfeiffenberger and Wheeler, *loc. cit.*)

Fig. 1. Percentages of teachers indicating coverage of subtopics in mechanics

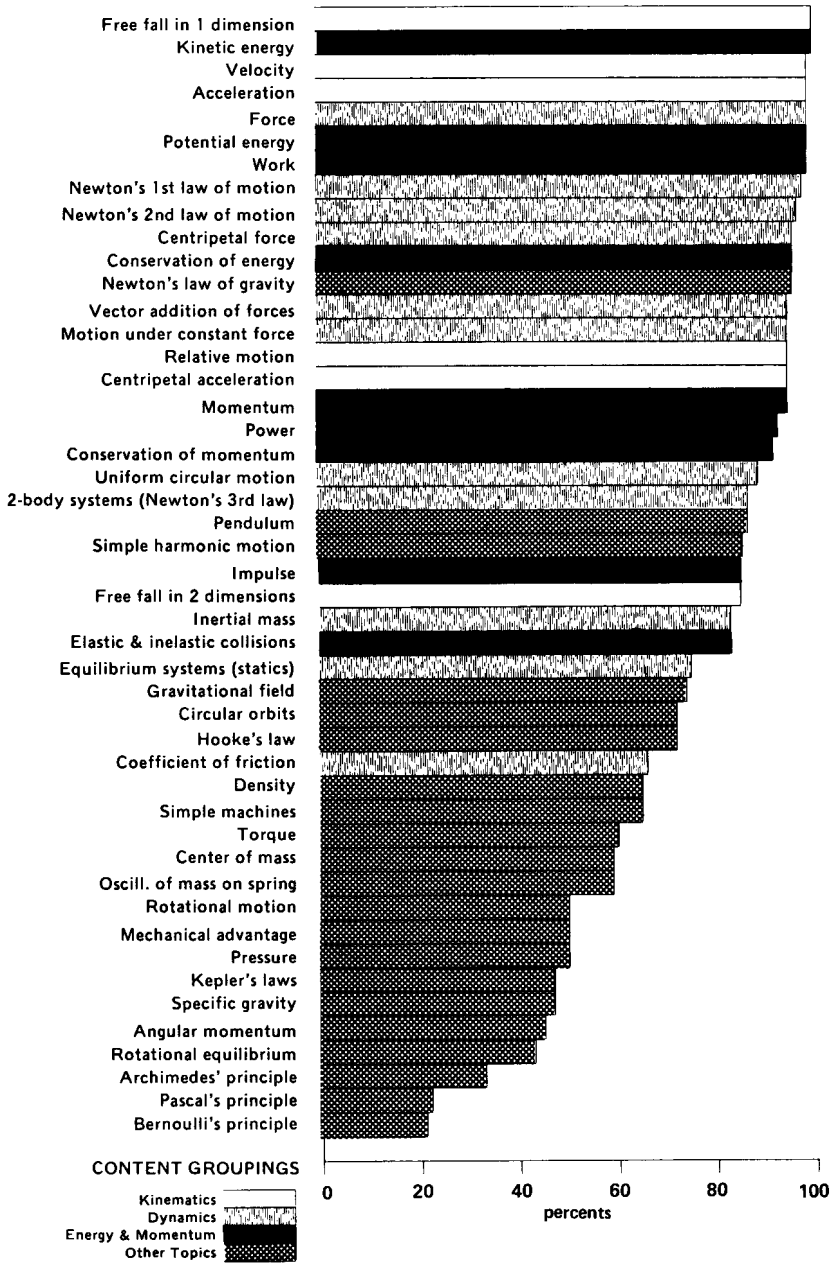


Fig. 2. Percentage of teachers indicating coverage of subtopics in electricity and magnetism

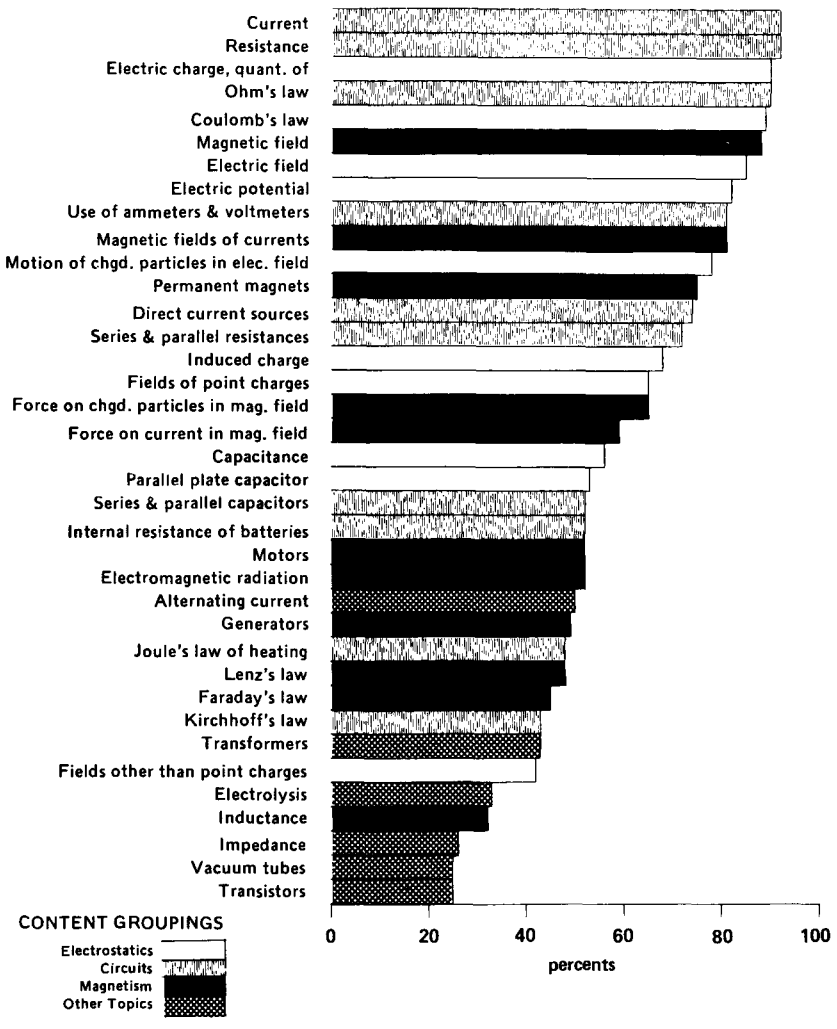


Fig. 3. Percentage of teachers indicating coverage of subtopics in optics and waves

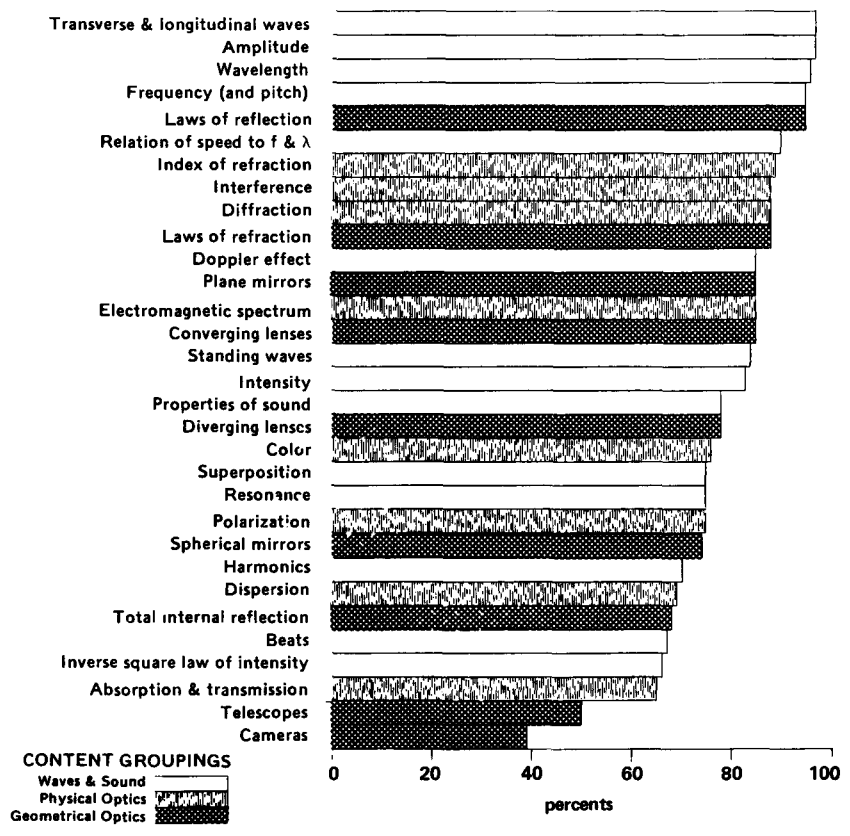


Fig. 4.

Percentage of teachers indicating coverage of topics in heat and kinetic theory

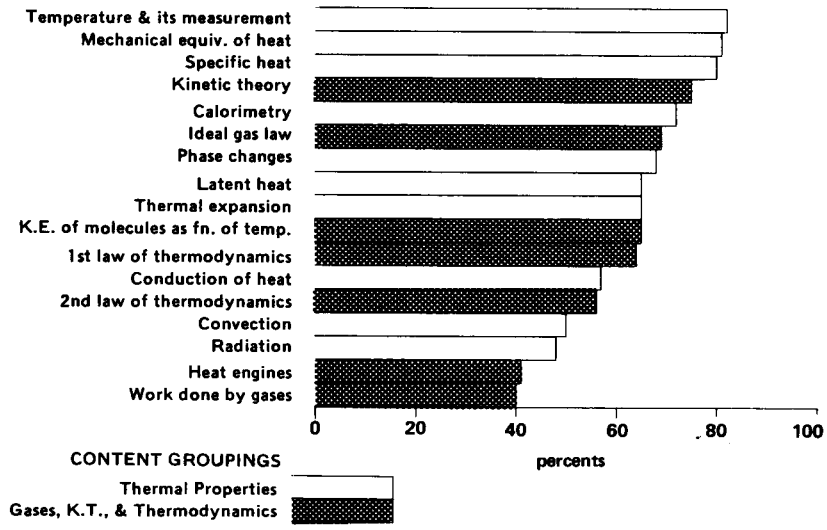
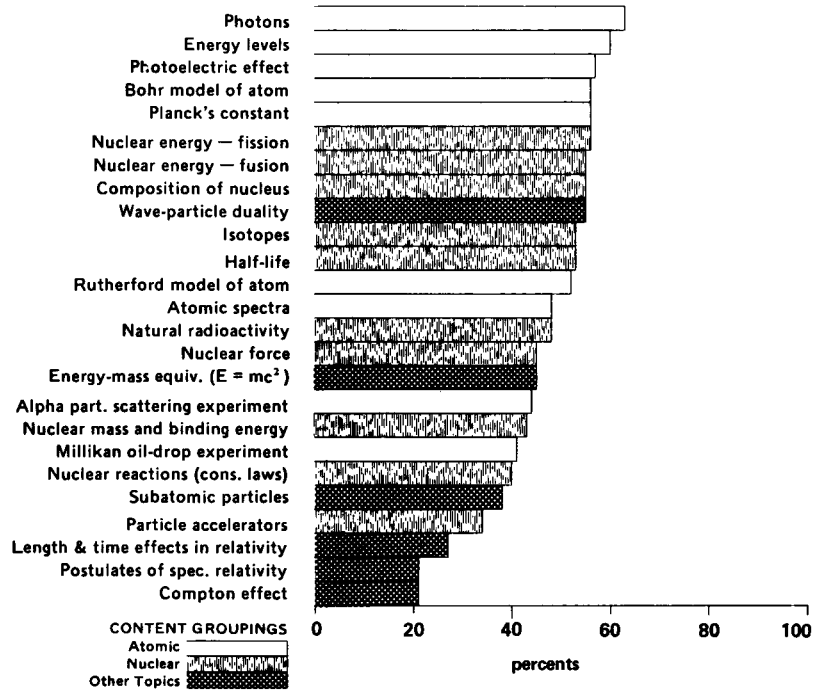


Fig. 5.

Percentage of teachers indicating coverage of topics in modern physics



APPENDIX F.

PHYSICS SYLLABUS OF LOWER MERION HIGH SCHOOL

(No textbook is issued at the outset of this course. Lectures, discussions, worksheets, and laboratory investigations are the sources. The *Project Physics* textbook is issued at a later point in the syllabus, as indicated below.)

A. OBTAINING, COMBINING, AND COMPARING MEASUREMENTS

1. Qualitative judgments and trichotomy schemes (can, can't, can't tell; >, <, =)
2. Measurements on continuous scales
   a. Quantifying classroom performance (grading system)
   b. Reading analog and digital instruments
      1. Limitations of instrument scales
      2. Least count of a scale
      3. Resolution limit of a scale
      4. Identifying and counting significant digits
      5. Numbers in which zeros confuse the issue (eg 300)
      6. Using scientific notation with measured quantities
   c. Performing calculations with measured quantities
      1. Tracing the influence of uncertain digits in the product of two measurements and reporting the result so that only one uncertain digit is included
      2. Tracing the influence of uncertain digits in constructing the product of two measurements and reporting the product with only one uncertain digit
      3. A set of rules that mostly accomplish the same thing as tracing uncertainties
   d. Sets of independent measurements of the same event
      1. Computing the mean, $\overline{x}$, of a set of values
      2. Computing the average absolute deviation from the mean (This quantity, $|\overline{d}|$ is used as the measure of the uncertainty in the average in this course.)
      3. A criterion for significant differences
      4. Applying the difference criterion (e.g. to determine whether the amplitude of a simple pendulum affects its period)

B. COMMUNICATING DATA AND RESULTS OBTAINED FROM MEASUREMENTS

1. Written descriptions
2. Graphical representations

C. AN EXAMPLE OF THE DEVELOPMENT OF LAWS IN SCIENCE

1. An empirical relationship between angles in specular reflection
   a. Establishing and locating light paths by "line of sight"
   b. Following a light path modified by a plane mirror
   c. Erecting a normal and measuring angles
   d. Angle I = angle R by applying the significant difference criterion to a class set of data (from c)
   e. Locating images by the coincidence of independent lines of sight (uniqueness of image of a point)
   f. Locating images by parallax (images of various shapes indicated by locating images of selected points)
   g. Plotting angle R vs. angle I for many lines of sight to the same image

h. Using the law of parsimony to extract angle I = angle R (from g)
i. Predicting and measuring other angle R and angle I pairs
j. Testing the path reversibility implied by the symmetric form of the equation

2. Completing a Law of Specular Reflection
   a. Why an empirical relationship cannot constitute proof (cannot test an infinite set of possibilities and cannot perform any measurement without uncertainty)
   b. The requirement for testable consequences
   c. Establishing Do/Di = 1 as a logical consequence of angle I = angle R (use of formal proof and the distinction between Do/Di = 1 as a logical consequence and as a proved proposition)
   d. Exploring what various outcomes of measuring Di and Do would mean for the states of angle I = angle R. (Includes a discussion of the equivalence of an implication and its contrapositive showing that if Do/Di = 1 fails, then angle I = angle R fails. Also includes the proposition that if Do/Di = 1 does not fail, than angle I = angle R does not fail, but is still not proved.)
   e. Measuring Di and Do from image-locating activities (1e and 1f) and testing Do/Di = 1
   f. Angle I = angle R is established as law; the law cannot be proved, and the test of every logical extension provides the possibility of its destruction
3. Extending the law to spherical mirrors
   a. Applying angle I = angle R to paraxial rays to predict the existence of focal properties for spherical mirrors
   b. Testing the prediction
   c. Rays far from the axis and spherical aberration
   d. Using parabolic reflectors to produce a focal Point
   e. Deriving equations for image-object relationships from the existence of a focal point for rays parallel to the axis
   f. Testing the equations (using change of variable methods to establish a linear plot of the data if the equations are valid)
   g. Status of specular reflection law (still intact and made more credible by another successful application)
4. Diffuse reflectors and the generality of angle I = angle R

D. AN EMPIRICAL STUDY OF REFRACTION

1. Following light paths and establishing a data base for air to water
   a. Finding refracted rays for rays incident along the normal and at 10-degree increments from the normal to the boundary. (The more individuals performing the task the better)
   b. Determining the angle of refraction and the uncertainty in that angle from the data of part a. (We use the average absolute deviation as the uncertainty. A set of 20 or more values is desirable for each angle.)
   c. Plotting angle of refraction vs. angle of incidence for air to water and drawing a smooth curve to pick up the trend of the results within error bars determined by the uncertainties
2. Following paths of light passing from water to air
   a. Gathering data (same format as 1a and 1b) and observing the critical angle phenomenon
   b. Plotting angle in water vs angle in air (on same graph as 1c)
   c. Establishing reversibility of paths in refraction (from the graph)
   d. Finding the critical angle (from the graph)
3. Gathering data for an air-glass boundary and plotting angle in glass vs. angle in air (on the same graph as c)
4. Amount of refraction for a given angle in air depends on the other material at the boundary (from the graph)
5. Demonstration that a parabola will not fit the data (with equation determined by presuming the vertex to be

at 90, critical angle) and (0,0) to be contained, note that the plotted parabola will be far from the limits of acceptable fit defined by the error bars

6. Prisms and lenses: applications of refraction that do not require a knowledge of the refraction law
7. Dispersion
8. When easy equations (power laws) do not work, a conceptual model may give insight as to what else to try: thinking about light as objects in motion
   a. Material objects can travel from one place to another
   b. Material objects can reflect (qualitative demonstration only)
   c. Material objects can refract (qualitative demonstration only)
   d. Not likely to be a fruitful contemplation unless a more complete understanding of the motion of objects is obtained

(At this juncture, the *Project Physics* textbook is issued. Since the details content can be determined from the text, a more cursory description will be employed from this point. The text chapters are not followed in order, so one must use the table of contents of the text as a guide. Material not explicitly covered in the text is marked with *.)

E. DESCRIBING MOTION

*1. Assumptions of measurability and continuity of position and time
*2. Requirements for workable definitions of physical quantities
3. Average speed
4. Uniform (constant) speed
5. Instantaneous speed
6. Average, uniform, and instantaneous acceleration (analogous geometry yields analogous expressions)
*7. Primitive quantities, operational definitions, and derived quantities

F. THE NATURAL STATE OF MOTION (Appearances and arguments)

1. Aristotle picks rest (a position consistent with objects seeking their natural place in a system of four elements)
2. Galileo picks constant speed, linear motion (based on speculation about an extension of the behavior of swinging chandeliers)
3. Aristotle's source of authority
   a. Plato's cosmology (* and teleology)
   *b. Aristotle's perfection of systematic logic (refinements in the arts of disputation achieved in Greek philosophy)
   c. The appearances, including the Mars retrograde problem
   d. Ptolemy's geocentric system
   *e. Greece, The Roman Empire, and the Middle Ages in Europe
   f. Thomas Aquinas and the accommodation of Aristotle's teachings (Aristotle becomes "official")
4. The heliocentric system of Copernicus
5. Additional data from Tycho
6. Kepler's contributions
7. Galileo's information via the telescope
8. The authorities hold the line
9. Galileo's intimidation and frustration

G. THE MOTION OF FREELY FALLING BODIES

1. Two New Sciences
   a. Attacking Aristotle with his own logic: Galileo works from a safe position
   b. Idealizations and approximations (* Galileo, the Neo-Platonist)
2. A lesson in how available technology shapes knowledge (the problems with performing a direct test of the hypothesis)
3. The use of mathematical reasoning to find an alternate test (a critical link between mathematics and physics is forged)
4. Galileo chooses a definition of acceleration (in two tries)
5. The kinematics of uniformly accelerated motion

H. DYNAMICS

*1. Laboratory investigation to determine factors affecting acceleration using combinations of matched pullers (P) and matched carts (C) to vary aspects of the system
   a. 1P 1C system (reference set up)
   b. 2P 1C
   c. 1P 2C (carts tandem)
   d. 1P 2C (carts piggyback)
   e. 2P 2C (carts piggyback)
   f. 1P and Mystery cart (later used to bring in measurement of mass)
   g. Extraction of empirical relation using difference criterion to select simple connections permitted by the data, $a = kP/C$
   h. Identifying the physical quantities associated with P and C: force and mass
2. Newton's laws of motion
3. Forces in equilibrium
4. Mass, weight and free-fall acceleration
5. Systems of units
6. Projectile motion and separability of components
7. Uniform circular motion as accelerated motion
8. Newton's universal gravitation
9. Cavendish experiment
10. The unity of Earth and Sky: one system of dynamics - the mechanical universe

I. APPLICATION OF DYNAMICS TO THE PROBLEM OF LIGHT REFRACTION

1. Suppositions about light particles consistent with observations
2. A model for light refraction and a gravitational analog
3. Derivation of Snell's law from the imagined dynamics of refraction
4. Test of Snell's law against refraction data
5. Index of refraction - a figure of merit for refraction
6. Derivation of critical angle values
7. A model for color as a light property - dispersion
8. The prediction of relative speeds of light in refraction

J. ADDITIONAL DYNAMICS

1. Momentum and its conservation as a consequence of the third law
2. Work and mechanical energy defined
3. Kinetic energy and potential energy
4. Conservation of mechanical energy
5. Analysis of collisions
6. The dynamics of ideal gases - Boyle's law derived
7. Heat and heat transfer
8. The scope of application of Newtonian mechanics
9. A problem left over from light refraction—the speed of light

K. WAVES AND AN ALTERNATIVE LIGHT MODEL

1. Energy transfer without matter transfer
2. Properties of waves and wave propagation
3. Periodic waves
4. Reflection of waves and pulses, superposition, and standing waves
5. Refraction of waves
6. Snell's law from wave refraction and relative speeds
7. Interference of waves and a prediction of interference in light
8. A test of interference predictions for light—Young's experiment
9. A wave-model interpretation of color and dispersion
10. Scattering
11. Sound waves
12. The Ether problem

L. ELECTRIC AND MAGNETIC FIELDS (just enough background to understand the photoelectric effect)

1. Static charges and electric forces
2. Action-at-a-distance and fields
3. The quantization and conservation of charge
4. Electric potential difference and electric currents
5. Electrical power
6. Additional forces due to the motion of charges (the relative motion of charge and observer)
7. Generating, transporting, and using electricity
8. Electromagnetic waves

M. THE PHOTOELECTRIC EFFECT

1. Producing photoelectrons
*2. A wave prediction of photoejection promptness
*3. A particle prediction of photoejection promptness
4. Einstein's photoelectric equation
5. Not all questions are meaningful: Is light a particle or a wave?

APPENDIX G.

OBJECTIVES AND TOPICS OF PHYSICS COURSES IN DES MOINES PUBLIC SCHOOLS

I. Description of Motion
   A. Measure position or distance traveled as a function of time
   B. Plot and interpret graphs of position, velocity, and acceleration as a function of time
   C. Solve problems that deal with distance, velocity and acceleration
   D. Represent motion in vector form
   E. Collect and interpret projectile motion data
   F. Collect and interpret circular motion data

II. Dynamics
   A. Determine acceleration as a function of force and mass
   B. Plot and interpret graphs of acceleration as a function of force and mass
   C. Experience force as the cause of change in motion of an object
   D. Define inertial mass as a measure of how difficult it is to accelerate an object
   E. Relate units of force to units of mass, distance, and time
   F. Solve problems dealing with force, mass, and acceleration
   G. Solve problems dealing with weight, mass, and acceleration due to gravity.
   H. Relate period of horizontal elastic oscillation to inertial mass
   I. Experimentally determine the relationship between mass, spring constant and period of oscillation
   J. Measure momentum before and after an interaction
   K. Understand conservation of momentum and solve problems dealing with specific applications of conservation of momentum
   L. Solve problems relating impulse to change of momentum
   M. Solve problems dealing with gravitational forces anywhere
   N. Solve problems dealing with Newton's universal law of gravitation
   O. Solve problems dealing with gravitational force fields
   P. Understand the vector nature of force, impulse, momentum, and gravitational fields
   Q. Understand the difference between inertial and accelerating frames of reference

III. Work, Energy, and the Kinetic Theory of Matter
   A. Express and relate the concepts of work, power, kinetic energy, gravitational potential energy, and elastic potential energy in words and mathematically
   B. Solve problems dealing with work and energy changes
   C. Solve problems dealing with elastic and inelastic collisions
   D. Understand conservation of energy and solve problems dealing with specific applications of conservation of energy
   E. Know the basic assumptions of kinetic theory of matter
   F. Know the various behaviors and properties of gases, liquids, solids, and plasmas as they relate to the kinetic theory of matter. (Special emphasis on gas laws)

G. Relate temperature, heat and molecular motion

IV. Electromagnetic Waves and the Electromagnetic Spectrum

A. Observe the properties of light (i.e., transmission, reflection, refraction, diffraction, polarization, interference and dispersion) through laboratory experimentation, problem solving and ray diagrams

B. Examine the properties of particles (i.e., transmission, reflection and refraction) through laboratory experimentation

C. Examine the properties of waves (i.e., transmission, reflection, refraction, diffraction, interference and dispersion) through laboratory experimentation, and problem solving

D. Compare the observed properties of light to the properties of waves and particles

E. Know the common properties of the electromagnetic spectrum

F. Solve problems that relate velocity, frequency, and wavelength of electromagnetic waves

V. Electricity and Magnetism

A. Know the basic observational facts about attraction or repulsion of the charged and uncharged objects and apply these facts to explain the operation of electroscopes and charging by contact and by induction

B. Express Coulomb's law verbally, mathematically, and graphically

C. Solve problems applying Coulomb's law

D. Define resistance as the ratio of voltage to current (i.e. $R = V/I$)

E. Draw parallel, series, and combination circuits showing proper location of voltmeters and ammeters

F. Solve resistance problems for parallel, series, and combination circuits

G. Measure the magnetic field of a solenoid

H. Solve problems and interpret relationships dealing with the following: time, charge, force, distance, electric potential, field strength, work, power, current, and electrical resistance

I. Know the SI units and be able to derive the equivalent fundamental units of length, mass, time, and current for the following: electric potential, electric field strength, magnetic field strength, work, current, resistance, and power

VI. Atomic and Nuclear Physics

A. Describe Rutherford's alpha scattering experiment and how data from this experiment led to the concept of nuclear atoms

B. Understand how classical physics failed to explain the multiple identical copies of nuclear atoms of each chemical element

C. Observe and measure wavelengths of atomic spectrum

D. Calculate photon energy from measured wavelength

E. Describe the processes used by Niels Bohr to incorporate the findings of classical physics, Rutherford scattering, and Einstein's explanation of Hertz's photoelectric effect into a model of the hydrogen atom utilizing stationary states and specific energy transitions

F. Describe how the de Broglie wavelength provided an explanation for the specific energy transitions of the Bohr model of the atom

APPENDIX H.

TOPICAL OUTLINE OF APPLIED PHYSICS COURSE, ONTARIO MINISTRY OF EDUCATION

Unit	Suggested Number of Hours	Unit Title
	CORE UNITS (86 h)	
CU1	16 h	Properties of Solids
CU2	18 h	Motion
CU3	18 h	Electrical Energy
CU4	18 h	Thermodynamics
CU5	16 h	Nuclear Energy
	OPTIONAL UNITS : Select any two (24 h)	
OU1	12 h	Time and its Measurement
OU2	12 h	Distance: Measurement and Application
OU3	12 h	Fluids
OU4	12 h	Sound
OU5	12 h	Light and Color

Note: The order of units is suggested. Units may be rearranged or integrated at the discretion of the teacher.

CU1 Properties of Solids

- Hooke's Law
- Non-destructive testing
- Equilibrium and stability: center of mass
- Objects in equilibrium: stress, strain
- Increasing the strength of materials
- Weakening materials
- Physical properties of solids

CU2 Motion

- Speed
- Distance and speed graphs
- Acceleration (Scalar)
- Factors affecting motion: friction, air resistance
- Resultant displacements, velocities and forces

CU3 Electrical Energy

- Electrical DC motors and magnetic fields
- Electrical generators
- Transformers
- Electrical circuits
- Current, voltage, resistance, energy and power

Note: The topics in this unit start with applications and finish with theory. This sequence is proposed in order to motivate students to learn the theory. There are other possible sequences of topics, based on different motivational concepts. For example:

a) The production of electrical energy and distribution to consumers could produce the following sequence of topics.
- electrical generators and magnetic fields
- transformers
- current, voltage, resistance, energy, and power

- cost of electrical energy
- electrical circuits - series and parallel
- DC motors

CU4 Thermodynamics

It is recommended that this unit begin with an investigation of methods of heat transfer from a variety of sources. Emphasis should be placed on an understanding of home heating systems and related concepts.

Heat and its transfer: applications in the home
Heating and cooling curves
Changes of state: applications to weather
Temperature vs. heat
Refrigerators, heat pumps
Heat engines
Law of conservation of energy
CO^2 and the Greenhouse Effect: other pollutants of heat engines
Remote sensing

or

Carbon dioxide and the Greenhouse Effect
Remote sensing
Heat engines
Law of conservation of energy

CU5 Nuclear Energy

It is recommended that this unit begin with an investigation of the problem of nuclear waste management and why it is an important concern. The nature of radioactivity and its applications would follow. The energy released through nuclear reactions has provided a useful but controversial energy source. This process and its future should then be discussed. The topics list below suggests two possible orderings of the topics.

Order 1:
Nuclear waste management
Biological effects of radiation
Radioactivity
Models of the atom - the nucleus
Radioisotopes and their applications
Nuclear reactions
Nuclear reactors: CANDU
Nuclear energy in the future

Order 2:
Nuclear waste management
Nuclear reactors: CANDU
Biological effects of radiation
Nuclear energy in the future
Radioisotopes and their applications
Models of the atom—the nucleus
Radioactivity
Nuclear reactions

OU1 Time and Its Measurement (optional)

Biological Clocks: The Pulse
Mechanical clocks: pendulum, spring, strobe
Astronomical clocks: the motion of sun, moon, stars

OU2 Distance: Measurement and Application (optional)

It is recommended that this unit begin with situations where indirect measurement of distance is necessary. Solving these problems will involve activities requiring direct measurements. The precision of direct measurements is then increased through the use of calipers and micrometers. Data taken in some cases then can be used to calculate areas and volumes. Introducing the concept of displacement and determining resultant displacements by scale diagram illustrates an application of distance measurement.

Indirect measurement: triangulation and scale diagrams
Precision: calipers and micrometer
Applications: area and volume
Resultant displacements: vector addition

OU3 Fluids (optional)

Since examples of air pressure are quite common it is recommended that this unit begin with this topic. Generalizing to pressure in liquids can then readily follow.

Air pressure
Pressure in liquids
Surface tension
Fluids in motion
Principle of continuity

OU4 Sound (optional)

Since music plays a significant role in the life of many young people, it is recommended that this unit begin with a study of musical instruments and the production of sound. The physiological effects of loud music and noise is a growing concern. Because of the desire to prevent hearing loss the characteristics of sound and the operation of the ear could then be discussed. An examination of the transmission of sound and related phenomena then fills out the unit.

Musical instruments - variations
Production of sound
Frequency and intensity of sound
The ear
Sound waves and their transmission
Speed of sound
Sound phenomena - reflection, interference, resonance and the Doppler effect.

OU5 Light and Color (optional)

Color is all around us. It plays a significant role in the psychological world. Conscious decisions regarding color are made when decorating buildings. The advertising industry makes effective use of color. Thus color is used as the introductory, motivating topic in this unit.

Color
Filters, including polaroids
Refraction
Convex lenses and the eye
Spectra
Total internal reflection

American Association of Physics Teachers