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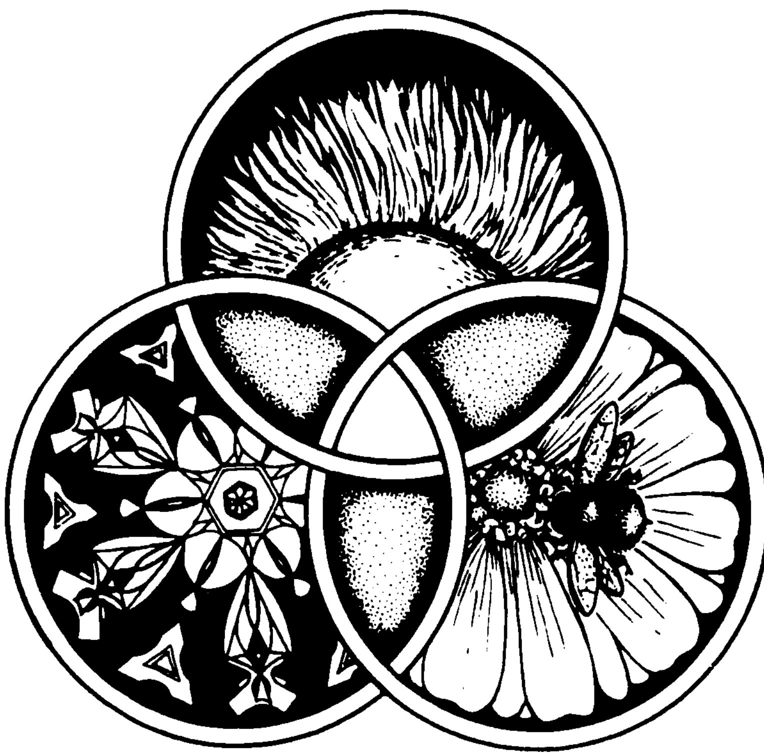
ABSTRACT

This teacher's guide includes parts one and two of the four-part third year Portland Project, a three-year integrated secondary science curriculum sequence. The Harvard Project Physics textbook is used for reading assignments for part one. Assignments relate to waves, light, electricity, magnetic fields, Faraday and the electrical age, electromagnetic radiation, the chemical basis of atomic theory, electrons and quanta, the Rutherford-Bohr model of the atom, and modern physical theories. The Chemical Education Materials Study (CHEMS) textbook is used for reading assignments for part two with assignments relating to many-electron atoms, ionization energy and the Periodic Table, molecules in the gas phase, and bonding in solids and liquids. The guide also contains entries on optics dealing with reflection, refraction, and images; and an extensive discussion of the electron structure and related quantum properties of the orbital model of the atom. A review of the development of the three-year program, a discussion of its rationale and the content of each of the three courses, and a three-year course subject outline are included in this volume, as well as notes to the teacher, examples of data, and problem calculations. (Author/SL)

YEAR THREE

WAVES AND PARTICLES
THE ORBITAL ATOM

PARTS ONE AND TWO
OF
AN INTEGRATED SCIENCE SEQUENCE



TEACHER GUIDE

1973 EDITION

prepared by
THE PORTLAND PROJECT COMMITTEE

under a grant from
THE NATIONAL SCIENCE FOUNDATION

WAVES AND PARTICLES
THE ORBITAL ATOM

AN INTEGRATED SCIENCE SEQUENCE

1973 EDITION

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Dedication

This volume is dedicated to the memory of Vernon Cheldelin under whose guidance and leadership integration of the sciences for Oregon secondary school youth was begun in 1963.

The Portland Project was initiated in the fall of 1962 when two secondary school teachers, one with background in CBA chemistry, the other having responsibility for PSSC physics, began to note and discuss the redundancy in their respective courses. Why should students be subjected to this repetitious and fragmented representation of the physical sciences? they asked. A Steering Committee met to pursue the problem further and perhaps enlist the support of a funding organization to permit its exploration in depth. Under the able and devoted leadership of Vernon Cheldelin, Dean of the School of Science at Oregon State University (deceased), two proposals prepared for support by the National Science Foundation were funded in the summers of 1963 and 1964.

Thirty-five scientists and teachers devoted various quantities of time as writers, consultants, pilot teachers, and evaluators, with the aim of ascertaining the feasibility and efficiency of the integration of chemistry and physics. Concurrently and subsequently, other groups in other parts of the country have carried on studies that are approximately parallel to this one.[1] Though the conceptual development and points of emphasis differ, the various groups are satisfied that integration of science courses is not only feasible but highly desirable.

Dr. Michael Fiasca of the Education and Science Staffs of Portland State University conducted an evaluation which revealed that subject matter achievement in chemistry and physics and critical thinking abilities are enhanced among students who studied the integrated courses over those who study the separate disciplines of

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[1] Federation for Unified Science (FUSE) was recently organized to act as a clearinghouse of information on integrated science courses. Victor Showalter at Ohio University is the chairman of this committee.

chemistry and physics. It should be emphasized that though these differences were apparent, it could not be demonstrated that they were statistically significant.[2] A concomitant result showed that enrollments in the two-year integrated courses were dramatically greater than in the separate courses.

A survey completed April 16, 1967 showed that there were forty-four schools in twenty states using the Portland Project integrated chemistry-physics course.[3]

Mounting evidence in the literature from prominent persons working in science education strongly supported this mode of organization. Dr. Jerrold R. Zacharias, the prime instigator of the PSSC physics program, exemplified the changing attitude of scientists and educators:

> The division of science at the secondary school level, into biology, chemistry and physics is both unreasonable and uneconomical.
>
> Ideally, a three-year course that covered all three disciplines would be far more suitable than a sequence of courses which pretends to treat them as distinct. Today such a three-year course would be difficult to fit into the educational system, but much of this difficulty might be overcome at once if such a course existed, and it might well be that present tendencies in education would soon overcome the rest.
>
> In any case, a greater coordination of the three subjects is possible even within the existing framework. It is understandable that the groups which developed the existing programs, each of which faced great problems of its own as it worked toward its goals, were reluctant to embark on the larger task of giving coherence to the sum of their efforts. With the programs now complete or approaching completion, it may be that the time has arrived for this necessary step.[4]

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[2] Detailed results of this study may be obtained by writing to Dr. Fiasca at Portland State University.

[3] Detailed enrollment figures and addresses of people who are using the Portland Project courses may also be obtained from Dr. Fiasca.

[4] From page 52 of Innovation and Experiment in Education, a Progress Report of the panel on Educational Research and Development to the U.S. Commissioner of Education, the Director of the National Science Foundation, and the Special Assistant to the President for Science and Technology, March, 1964.

Stimulated by the apparent success of their original work towards this kind of integrated course, persons close to the Portland Project began to discuss extension of their work to include biology with chemistry and physics in a three-year sequence. A third proposal was prepared in 1966 and granted support by the National Science Foundation. Dr. Arthur Scott, member of the Chemistry Department at Reed College who has had deep interest in the Portland Project since its inception, graciously offered his talents, energy and time to carry on the project after Dean Cheldelin's death.

A writing conference was conducted on the Portland State University campus during the summer of 1967 to develop materials such as teacher and student guides. Eight local pilot schools committed approximately five hundred students and twelve pilot teachers for testing and evaluation. Dr. Donald Stotler, Supervisor of Science for the Portland School District, has had an active part in this and other phases of this project.

Twenty-six persons whose functions were writing, consulting, analysis, and editing met on the Portland State campus beginning June 14, 1967 to begin preliminary work on the integrated course. Their first task was to formulate an outline that displayed logical content development utilizing concepts out of biology, chemistry and physics. Particular attention was paid to matching students' abilities, interest and maturity level with the sophistication of concepts as nearly as this was possible to do. Then the committee perused material developed by the national curriculum groups --PSSC, Project Physics, CBA, CHEMS, BSCS and IPS -- in search of material to implement the outline they constructed previously. In the absence of appropriate materials, major and minor writing projects were initiated.

The writing committee continued its work in the summers of 1968 and 1969 with Dr. Karl Dittmer, Dean of the Division of Science, as director. Four major projects were tackled and completed: (1) extensive revisions were effected in the three-year outline, (2) the first- and second-year courses were revised based upon student and teacher feedback, (3) the third-year course was developed incorporating Harvard Project Physics materials as a main vehicle, and (4) an evaluation program for the three-year course was developed.

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Portland, Oregon

Pilot Schools

The following schools have served as pilot schools for the pilot course during one or more of the past three academic years.

Adams High School
Portland, Oregon
- Glen Hampshire
- Lloyd Meskimen
- Thomas Miles

Aloha High School
Aloha, Oregon
- Mary Lou Combs
- Elvis Dellinger
- Nelson Doeleman
- Ted Parker

Beaverton High School
- Roger Berg
- Jean Halling
- Lois Helton
- H. Dean Smith

Benson Polytechnic School
- Howard Browning
- W. B. Chase
- Robert Franz
- W. L. Hoffman

Central Catholic High School
Portland, Oregon
- Jacob A. Mosbrucker
- Peter Roerig

Cleveland High School
Portland, Oregon
- John Brown
- Edmund McCollough

Franklin High School
Portland, Oregon
- John Neeley
- Joseph Sklenicka

Grant High School
Portland, Oregon
- Myra N. Rose

Jefferson High School
Portland, Oregon
- Ronald Kawamoto
- Leslie Morehead
- Kenneth Starbuck

Parkrose High School
Parkrose, Oregon
- Donald Pearson

Rex Putnam High School
Milwaukie, Oregon
- Dennis Axness
- David Cox
- Jerry Fenton
- Henry Kilmer
- Jack McGoldrick

Roosevelt High School
Portland, Oregon
Renee Bergman
Kenneth Fuller
Sue Storms

Sunset High School
Beaverton, Oregon
Leonard M. Dooley

Wilson High School
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Curtis D. Guthrie
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Alice Eyman - Secretary

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Jean Sims - Secretary

Linda Tham - Laboratory Assistant

Jill Timmons - Secretary

Kathryn Ann Torvik - Artist

Shirley Tsang - Laboratory Assistant

Barbara Wiegele - Secretary

STUDENT PARTICIPANTS

Patrick Moore - Jefferson High School (sow bug experiment)

The decision to try to develop a three-year integrated science course which would replace the traditional three courses in biology, chemistry and physics is based on several considerations. Among them are:

(1) a conviction that modern developments have made the division of science under these three headings obsolete;

(2) a recognition that the traditional courses overlap in many areas, resulting in a great deal of duplication and repetition as in the gas laws, atomic and nuclear structure, calorimetry and the kinetic molecular theory;

(3) a feeling that terminal students, who take no more than one year of science, deserve to get a taste of all of science rather than just one aspect, as they do in the conventional programs; and

(4) a desire to emphasize the unity in the approach to natural phenomena and the similarity in the methods, techniques and apparatus used by scientists in all fields.

A natural question arises as to what distinguishes this course from a general science course expanded to three years. The answer is that this course does not consist of a number of unrelated topics that might be taken up in any order; rather, it treats science as a structure that proceeds from observation to the development of general principles and then to the application of those principles to more involved problems. The emphasis in a general science course is on the results of science; the emphasis here is on the methods and reasoning by which scientists have arrived at these results.

The three-year course outline shows that a number of topics such as properties of matter, energy, heat, and certain biological concepts are discussed at the first-year level and again later in the course. This re-cycling is deliberate. It is intended to introduce students in a semi-quantitative way to some of the significant generalizations of science and to show how these generalizations arose. These topics are treated again in the second and third years when greater facility with mathematics on the part of students makes it possible for them to understand and appreciate discussions of these topics in the succinct and precise language of mathematics.

An excessively formal and quantitative approach is avoided in the first year for several reasons. Students at this level do not extract essential meaning from such a presentation of information; furthermore, first encounters with new ideas should proceed from an intuitive, non-quantitative confrontation to one that is more quantitative. Teachers have spoken out against teaching and learning methods which substitute equations, formulas and other quantitative representations for first-hand experience, word descriptions, examples and illustrations. These criticisms are just as valid for students who are very capable and very interested in science as they are for other students. Moreover, the mathematical sophistication of students at this level is such that they are unable to follow most mathematical arguments as explanations for natural phenomena.

The typical science experiences of most secondary school students consists of one or two years devoted to general science and biology. Few study physics and chemistry. A significant advantage to the course of study described here is that students are given a chance to study physics and chemistry at a level of rigor that is consistent with their ability and their mathematical maturity. Students who terminate their study of science at the end of one year get a significant exposure to the structure of biology, chemistry and physics as they are presented in the latest curricular developments. Students who might not elect science beyond the first year because of lack of interest in biology may be attracted by the chemistry or physics portions of the course and elect to take an additional year or two of science. Students who are "turned on" by biology may wish to pursue further study of biochemical topics in Years II and III.

After considering these problems and goals, the general course outline for the first year of the course was derived. It consists of four main parts:

(1) Perception and Quantification

(2) Heat, Energy and Order

(3) Mice and Men

(4) Environmental Balance?

The year begins with a study of the perceiver, moves on to the perceived, and ends with the interaction of the perceiver with the perceived. The first-year student starts out by gaining a better awareness of the nature of his perception and senses -- the faculties that make him aware of the world around him. With an increased understanding of these perceptual abilities, he can turn to the environment and then relate himself to it. He finds that his perception is limited and that he often needs to call on technological and conceptual extensions and that even these have their limitations.

The importance of organization and classification as parts of perception is emphasized. The physical properties of matter are introduced and studied as aids in organization and classification of chemicals. The identification of unknowns by study of their physical properties and use of organized data on punch cards is the culminating experiment of the Perception unit.

Apart from the great diversity exhibited in nature, which the scientist must organize in order to comprehend, certain unifying principles are essential for deeper understanding. The most powerful of these is the energy concept, which is explored in the "Heat, Energy and Order" unit in several of its ramifications - physical, chemical and biological. The discussion begins by developing an experientially important energy form, viz., heat. The macroscopic aspects of heat as embodied in calorimetry are related to the microscopic in terms of random molecular motion. This builds confidence in the idea of the atomic nature of matter, which is essential to much of the unit. Various energy conversions form the vehicle for extending and generalizing the energy concept. Nuclear energy is developed in sufficient detail to underscore its environmental and social significance. Finally, the thermodynamic limitations and implications of energy conversion are explored, ending with a view of life as a supremely artful organizer in nature, a mechanism powered by energy which creates wondrous "local order", but always at the expense of influencing its environment.

The growth of a mouse colony carries the thread of the unit "Mice and Men." As the colony develops, students learn many things about the concept of population. The food and water consumed and products eliminated tie the mouse colony back to the unit "Heat, Energy and Order", and point ahead to the chapter on communities and to the unit "Environmental Balance?".

The cell concept is given prime position in this unit. It is used to enter topics on reproduction, embryology and maturation which are observed in the mice and other organisms. The mice selected for the original colony are such that an experiment in Mendelian genetics comes out of the observations students make as the colony develops. In most of the chapters man is an important organism and receives as much attention as the mouse, although the data are often secondhand.

A rather unpleasant fact that must be faced is that as our population increases, and human activities are directed towards increasing the standard of living for this population, strains are placed upon the environment. As students discover in "Mice and Men," the size of the community has a relation to both the quantity of the food, water and energy required and the quantity of waste products produced. To develop the concept of a closed system and point out the necessity for environmental management, an analogy between the earth and a spaceship is made. Students are then introduced by a multi-media approach to the nature of some of our common pollutants (with emphasis upon air, water, heat, noise and radiation) as well as their effects. Following this students are encouraged to undertake a rather detailed study of a particular type or aspect of pollution. Emphasis here is placed upon student activity, which may take any number of forms. The culminating activity centers around discussion of these special studies together with the complex relations involved within the environment. It is hoped that out of these studies students will become aware of threats which exist to man's future on this planet.

THE SECOND YEAR COURSE

The second year of the course is considerably more quantitative in its approach than the first. This is the case because (1) the students are one more year along in their mathematical preparation, (2) the students who elect to take a second year of science are more likely to exert the effort to master more difficult topics, and (3) many of the quantitative aspects of physics and chemistry are basic to an understanding of molecular biology, which is an important part of the following year's work.

The second year consists of two parts:

(1) Motion and Energy

(2) Chemical Reactions

Year II begins with the study of motion, going from the quantitative description of motion to a consideration of what causes motion and a discussion of Newton's laws. There follows the development of the laws of conservation of momentum and energy, including a discussion of energy in biological systems. This section, which is primarily mechanics, culminates with a discussion of kinetic molecular theory.

Due to recent advances in both molecular biology and biochemistry, the descriptive approach to biology has gradually given way to one that is primarily analytical. It is now necessary, even on the high school level, for the serious biology student to have a more thorough understanding of those concepts normally embodied in the "modern" high school physics and chemistry courses. The major objective of "Chemical Reactions" is to build some of those basic chemical concepts that are necessary for an analytical study of "The Chemistry Of Living Matter" and "Energy Capture and Growth."

The following subtopics of this section help in the realization of the major objective: Some of the topics discussed are the mole concept, equation writing, energetics associated with chemical reactions, the dynamic nature of particles and their interactions and the application of energy and equilibrium to chemical systems.

THE THIRD YEAR COURSE

Year III consists of four parts:

(1) Waves and Particles

(2) The Orbital Atom

(3) Chemistry of Living Matter

(4) Energy Capture and Growth

The underlying rationale of the third year is a study of energy and its importance to life. The first thrust is to build the orbital model of the atom using, as background, waves, electromagnetism and historical models of the atom. Once the orbital model is established as a representation of the localization and directionalization of electronic energy, structural models are built to show how biopolymers are spatially arranged and experiments are done to give evidence of energy relationships. With shape, size and energy relationships of molecules established, the DNA molecule is introduced. The culmination of this work comes in the final section when photosynthesis is considered. With this topic, much that has gone before is brought to a logical focus.

These topics are most appropriately placed in the third year of the integrated sequence after students have developed some facility with basic ideas from chemistry and physics - e.g., quantitative knowledge about energy, mechanism of chemical reaction, equilibrium, rate of reaction, the photon and wave nature of light, electrical phenomena, and kinetic molecular theory. They should not now simply parrot biochemical processes such as photosynthesis and cell respiration but should understand the many chemical and physical principles which underlie these processes.

Time is allotted at the conclusion of Year III for individual investigation and studies.

Three-Year Course Outline

		TOPIC	REFERENCE
		First Year	
Part One:		Perception and Quantification	
	I.	Sensing and Perceiving	PP*
	II.	Measurement, Distribution, Organization and Communication	PP
Part Two:		Heat, Energy and Order	
	I.	Heat	PP
	II.	Temperature and Chaos	PP
	III.	Energy	PP
	IV.	Nuclear Energy and Radioactivity	PP
	V.	Trends in Nature	PP
Part Three:		Mice and Men	
	I.	Reproduction and Development	PP
	II.	Genetics	PP
	III.	Genetics and Change	PP
	IV.	Populations	PP
	V.	Ecology	PP
Part Four:		Environmental Balance?	PP

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* PP designation signifies materials produced by the Portland Project.

	TOPIC	REFERENCE
	Second Year	
Part One:	Motion and Energy	
I.	Motion	HP*
II.	Newton Explains	HP
III.	Multi-Dimensional Motion	HP
IV.	Conservation	HP
V.	Energy - Work	HP
VI.	Kinetic Theory of Gases	HP
Part Two:	Chemical Reactions	
I.	The Mole as a Counting Unit	PP
II.	Combinations of Gases	PP
III.	A Useful Form of P=kDT	PP
IV.	Chemical Equations	PP
V.	Electrical Nature of Matter	CHEMS+
VI.	Basic Particles	CHEMS
VII.	Energy Effects in Chemical Reactions	CHEMS
VIII.	Rates of Reactions	CHEMS
IX.	Equilibrium	CHEMS
X.	Solubility	CHEMS
XI.	Acid-Base	CHEMS
XII.	Oxidation-Reduction	CHEMS

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* HP designates Harvard Project Physics material.
\+ CHEMS designates material derived from the Chemical Educational Materials Study.

TOPIC		REFERENCES
	XIII. Stoichiometry	CHEMS

<u>Year Three</u>

Part One:	Waves and Particles	
	I. Waves	HP
	II. Light	HP
	III. Electricity and Magnetic Fields	HP
	IV. Faraday and the Electrical Age	HP
	V. Electromagnetic Radiation	HP
	VI. The Chemical Basis of Atomic Theory	HP
	VII. Electrons and Quanta	HP
	VIII. The Rutherford-Bohr Model of the Atom	HP
	IX. Some Ideas from Modern Physical Theories	HP
Part Two:	The Orbital Atom	
	I. Atoms in Three Dimensions	PP
	II. Many-Electron Atoms	CHEMS
	III. Ionization Energy and the Periodic Table	CHEMS
	IV. Molecules in the Gas Phase	CHEMS
	V. The Bonding in Solids and Liquids	CHEMS
Part Three:	The Chemistry of Living Matter	
	I. Monomers and How They Are Built	PP
	II. Polymers or Stringing Monomers Together	PP
	III. Polymers in 3-D or The Shape of Things to Come	PP
	IV. Where the Action Is--The Active Site	PP

WAVES AND PARTICLES

Outline: WAVES AND PARTICLES

Outline: THE ORBITAL ATOM

Programmed Materials Found Useful with Year Three Materials

Alexander, Joseph and Daniel Leahy, Programmed Physics, 4 volumes, John Wiley and Sons, 1965.

Eichinger, J. W., Jr., Chemical Bonds, Introduction and Fundamentals, Lyons and Carnahan, 1968.

Harris, Frank E., Principles of Chemistry, Addison-Wesley Publishing Co., 1965.

Sackheim, George, Naming Simple Hydrocarbons, Harper and Row, 1964.

Traynham, James G., Organic Nomenclature, A Programmed Introduction, Prentice-Hall, 1966.

Suggestions for Laboratory Procedures

A laboratory is a place where scientists look at phenomena under controlled conditions. It is a place for serious work. Always prepare for an experiment by reading the directions in the manual before you come to the lab. Make a special effort to know all precautions.

Do only the experiments approved by your teacher. If you wish to do an extension (this is encouraged), check with your teacher. This general rule is for your safety and that of your fellow students. Laboratory safety is as much an attitude as a set of rules. The lab will become a safe place for investigation if the student continually uses common sense about his safety and the safety of others. If any accident does occur, report to your teacher. What seems a minor injury may have severe consequences.

You will be asked to write laboratory reports. Opinions concerning the content of these reports vary greatly. It follows that teacher judgment will determine the type of laboratory reports you are asked to write. The following ways to improve laboratory reports are to be taken as suggestions only.

(1) Mistakes should not be erased. If there is room for the correction, the mistake should be crossed out without obliterating it and the correction made. If there is insufficient room, an extra piece of paper should be added.

(2) Spelling and punctuation are important. Sentence fragments should be avoided.

(3) The report should be carefully planned. It is best to know what type of observations should be sensed and, if possible, what regularities can be found. Planning will lead to the placement of items in a logical sequence in the report.

(4) The name of the experiment should be included.

(5) The date on which the experiment was done should be included.

(6) The names of all participants should be included and the name of the person who actually prepared the report should be designated.

(7) Some reports should include a simple statement or schematic diagram of the apparatus used in the investigation.

(8) Some reports will require a brief explanation of purpose and procedure. If these are given in the laboratory manual, they should not be included in the report. Copying items is "busy work."

(9) Nearly all experiments require taking measurements and subsequent collection of data. This must be carefully tabulated. If it is possible for you to make data tables before coming to the laboratory, you will have more time for observation, which is a major part of any laboratory experience.

(10) If computations are required to interpret results, they should be included in the report. However, if several computations of a similar nature are needed, they should be illustrated with a typical example. Mathematical equations, not arithmetical operations, should be shown.

(11) If the investigation could be altered to get better results, a statement to this effect should be included.

(12) If the investigation suggests extensions, these should be described.

(13) Reading professional reports from magazines such as The Journal of Chemical Education and Scientific American should result in better reports.

(14) Many times the most significant information about the experiment is to be found by graphing results. Whenever appropriate, graphs should be included in the report; they give a picture from which regularities can be sought. You will find the following suggestions very helpful.

a. Always use a full sheet of graph paper.

b. Position the ordinate and abscissa far enough from the edge of the paper to allow proper labeling.

c. Assuming a relationship exists, the abscissa should represent the independent variable; the ordinate, the dependent variable. As an example: The distance of the gas pedal from the floorboard in an automobile would be the independent variable, plotted on the x axis, while the speed of the car would be the dependent variable, plotted on the y axis.

d. Each axis must show units, e.g., cm/sec.

e. Labeling of each axis should run parallel to the axis.

f. The scale of each axis should be chosen such that the functional plot covers most of the graph paper.

g. The name of the graph, the name of the experiment and the date of the experiment should be suitably placed on the graph.

h. When plotting data, draw a circle around each point to indicate the uncertainty associated with the measurements.

i. Draw the smoothest possible curve suggested by your data.

7

KEY

Transparency..................T

Film Loop.....................L
Reference to L33, L34, etc. refer to sections in the Handbook, not to actual film loops.

Films.........................F

Reader........................R

Programmed Instruction........P

Demonstration.................D

Experiment....................Ex

Activity......................A

*.....Top Priority

x.....Recommended

+.....Optional

R.....Reading Only

Chapter I: WAVES

A NATURE OF WAVES
Read 12.1, 12.2, 12.3, 12.4 HP

B INTRODUCTION TO WAVES
Read 12.5 HP

B.1 Experiment: INTRODUCTION TO WAVES
Ex 30 HP

C WAVE PHENOMENA
Read 12.6, 12.7, 12.8, 12.9, 12.10 HP

TEXT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS QUAN E H	PROBLEMS QUAL E H	OUTSIDE READING
Introduction R					"Least time" or least energy situations			R13 Introduction to waves
Properties ...aves *	2 Days	Ex 30 Introduction to waves (First part best done by a couple of students as a demonstration) *		P10 Waves F PSSC Simple Waves	Mechanical wave machines			R14 What is a Wave? R16 Musical instruments and scales
Wave ...agation *			D37 Wave propagation * D38 Energy transport *	F26 Progressive waves, transverse and longitudinal (McGraw-Hill)				
Periodic ...s *	2 Days							
When waves ...: the super-...tion principle *			D39 Superposition D46 Beats and harmonic synthesis	T25 superposition + T26 square + wave analysis L38 superposition of waves +	Graphical addition of waves	10	1 2* 8*	
A two-source ...rference ...ern *	2 Days		D43 Interference patterns x	T28 two-slit interference+	Moire patterns	11		

TEXT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS		OUTSIDE READING
						Quant E → H	Qual E → H	
Standing waves	↑ 1 Day ↓		D 45 Standing waves *	T27 Standing waves + T29 Interference pattern analysis * L39 Standing waves on a spring + L42 Vibrations of a rubber hose + L43 Vibrations of a wire + F27 Stationary longitudinal waves F28 Stationary transverse waves	Standing waves on a drum and violin		13x	
Wave fronts iffractions	↑		D44 Diffraction				15 14	
Reflection	3 Days		D40 Reflection *	L44 Vibrations of a drum * L45 Vibrations of a metal plate		4 17* 24* 19+ 25* 16*	22x 23x 26* 27x	
Refraction	↓		D41 Wave trains D42 refraction			3* 7+ 29* 31*	28x 30x 32x 20 21	

A.1 OPTICS EXPERIMENT

Experiments in waves (HP Ch. 12) have demonstrated wave phenomena, including reflection and refraction. The behavior of light with regard to reflection and refraction has been a source of many technological developments such as plane mirrors, curved mirrors and lenses. In this experiment we shall observe some interesting outcomes of these uses of reflection and refraction properties of light.

A.1.a REFLECTIONS FROM A PLANE MIRROR

Hold a pencil vertically at arm's length. In your other hand, hold a second pencil about 15 cm closer than the first. Without moving the pencils, look at them while you move your head from side to side. Which way does the nearer pencil appear to move with respect to the one behind it when you move your head to the left? Now move the pencils closer together and observe the apparent relative motion between them as you move your head. Where must the pencils be if there is to be no apparent relative motion, that is, no <u>parallax</u>, between them?

Now we shall use parallax to locate the image of a nail seen in a plane mirror. Support a plane mirror vertically on the table by fast-

The students will discover that the incident and reflected rays make equal angles with the reflecting surface, that the image formed by a plane mirror is as far behind the mirror as the object is in front of it, and that the image and object are the same size.

Only nails and pins are used as objects in this experiment; unlike triangles and letters they are symmetrical, and finding their images in a plane mirror will not raise the matter of reversal.

Nails long enough to project above the mirror should be used in finding the image by parallax. Finding the image is then just a matter of putting the top on the image nail.

Because the angles between the rays and the reflecting surface are seen directly on the paper, these angles are the ones we compare.

The lines of sight drawn to locate an image should form a large angle with each other (30^{o} or more).

<u>Answers to Questions:</u> When the head is moved to the left, the nearer of the two pencils will appear to move to the right.

This exercise will introduce the student to the concept of parallax and make *clear to him at the outset that there is nothing mysterious about locating objects or images by parallax. In addition, noting that the nearer of two objects appears to move in the opposite direction to that of the eye will be useful to the student in locating images by helping him to decide which way to move his parallax indicator.*

Many of the students will think that the image of the nail is in the plane of the mirror. If they come to this conclusion before making measurements, let them have the fun of discovering where the image really is (behind the mirror).

The image and object are the same size, although the image appears smaller because it is farther away. When a nail identical to the object is used as a parallax indicator, the indicator and the image are clearly seen to be of the same size.

Materials and Equipment

- *1 plane mirror (about 1½"x 1½" front surface)*
- *2 nails - flat head (1½"-2½")*
- *3 pins (1")*
- *3 sheets of paper (8½" x 11")*
- *1 sheet of soft cardboard (8½" x 11")*
- *1 sharp, hard-lead pencil*
- *1 protractor*
- *1 wood block or piece of clay*
- *1 metric ruler*

ening it to a wood block with a rubber band. Stand a nail on its head about 10 cm in front of the mirror. Where do you think the image of the nail is? Move your head from side to side while looking at the nail and the image. Is the image in front of, at the same place as, or behind the real nail? Locate the position of the image of the nail by moving a second nail around until there is no parallax (i.e., no apparent relative motion) between it and the image of the first nail. In this way, locate the positions of the image for several positions of the object. Compare the perpendicular distances of the image and object from the reflecting surface.

We can also locate the position of an object by drawing rays which show the direction in which light travels from it to our eye. Stick a pin vertically into a piece of paper resting on a sheet of soft cardboard. This will be the object pin. Establish the direction in which light comes to your eye from the pin by sticking two additional pins into the paper along the line of sight. Your eye should be at arm's length from the pins as you stick them in place so that all three pins will be in clear focus simultaneously. Look at the object pin from several widely different directions and, with more pins, mark the new lines of sight to the object pin. Where do these lines intersect?

We can use the same me d to locate an image. On a fresh piece of paper, locate the position of the image of a pin seen in a plane mirror by tracing at least three rays from widely different directions. Mark the position of the mirror on the paper with a straight line before removing it. Where do the lines of sight converge?

Draw rays showing the path of the light from the object pin to the points on the mirror from which the light was reflected to your eye. What do you conclude about the angles formed between the mirror surface and the light paths?

Arrange two mirrors at right angles on the paper with a nail as an object somewhere between them. Locate all the images by parallax. From what you have learned about reflection in this experiment, show that these images are where you would expect to find them.

A.1.b IMAGES FORMED BY A CONCAVE MIRROR

Look at your image in a concave mirror. Is it right side up or upside down? Do the size and position of the image change when you move the mirror toward you or away from you?

To investigate systematically the images

In this experiment the student becomes familiar with the images formed by a concave mirror. The student will gain qualitatively an understanding of focus, image position and image inversion.

Students will need a work area about one meter long. A one-meter strip of *paper tape from the tape timer taped to the table can be used as an "optical bench." The mirror can be supported by a piece of modeling clay. The filament of the light and the center of the mirror should be the same height above the table. A convenient parallax indicator is a pin stuck into a cork stopper.*

formed by a concave mirror, arrange a mirror and a lighted flashlight bulb on a strip of paper as shown in Fig. A.1. Start with the bulb at one end of the paper tape and locate its image by prallax. Is the image right side up or upside down?

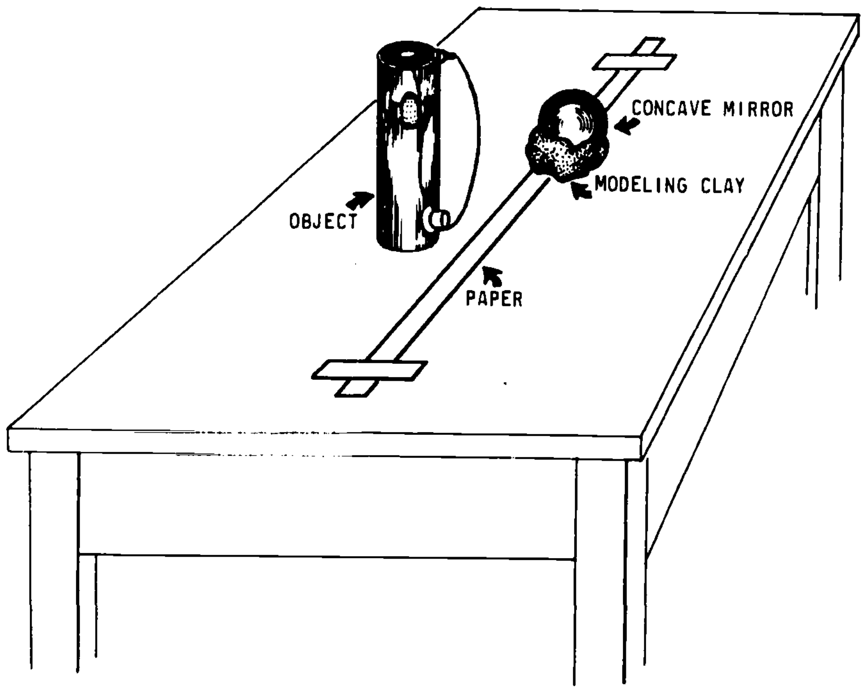


Figure A.1

Now move the object toward the mirror in small steps, marking and labeling the positions of both object and image as you go. Continue this until the image moves off the end of the tape and can no longer be recorded.

Answer to Questions: The image is inverted when the object is beyond the principal focus and right side up when the object

How does the change in the position of the image compare with that of the object? Where on your tape do you expect the image to be when the object is at least several meters away? Check it. With the object far away, you may find it easier to locate its image by finding where it focuses on a small (1 or 2 cm) piece of paper. The location of the image when the object is very far away is the principal focus of the mirror.

Now place the bulb as close to the mirror as possible and locate the image by parallax. Is it upside down or right side up? Again move the object away from the mirror in small steps, marking and labeling the positions of object and image until the image is no longer on the tape.

Where will the image be if the object is placed at the principal focus? Can you see it?

A.1.c REFRACTION

It is convenient to study the refraction of light in terms of the angle of incidence and the angle of refraction. When light passes from air into water, for example, the angle of refraction is the angle between a ray in the water and the normal to the water surface. In this experiment we shall try to find the relation between this angle and the angle of incidence.

Use a pin to scratch a vertical line down the middle of the straight side of a semicir-

is between the principal focus and the mirror. The image is smaller than the object when the object distance is larger than the focal length. The image is larger than the object when the object distance is less than the focal length. The image is the same size as the object when the object distance equals the focal length.

The image is sharply defined for all positions of the object except when the object is at the focus or close to it. When the object is at the focus, the image is at infinity and cannot be seen.

Materials and Equipment

- *1 good concave mirror (2" dia. 10 cm f.l.)*
- *1 long strip of paper (tape or adding machine tape)*
- *1 2.5-v. flashlight bulb, #41 and socket*
- *1 #6 dry cell, 1.5 volts*
- *2 connecting wires (1 foot long)*
- *1 lump of modeling clay*
- *1 sharp hard-lead pencil*
- *1 meter stick*
- *1 straight pin*
- *1 cork*
- *1 sheet of rectilinear graph paper*

The purpose of this experiment is to observe refraction and refraction in different liquids.

Some liquids that will not discolor or dissolve the plastic box are: glycerine, mineral oil, motor oil (nl.5), salt solution, sugar solution. Do not use carbon tetrachlo-

ride, carbon disulfide, acids or bases.

Materials and Equipment

- *1 semicircular clear plastic box (6cm rad., 3 cm deep)*
- *4 sheets of rectangular coordinate paper or 2 sheets rectangular, 2 sheets polar coordinate paper or 4 sheets of tracing paper*
- *1 sheet of soft cardboard (8-1/2 x 11)*
- *2 pins 1"*
- *75 cm^3 ea. glycerine, mineral oil, motor oil, salt solution, sugar solution, and water*
- *1 sharp hard-lead pencil*
- *1 protractor*
- *1 ruler*

cular, transparent plastic box. Fill the box half full of water and align it on a piece of graph paper resting on soft cardboard, as shown in Fig. A.2, making sure the bottom of the vertical line on the box falls on the intersection of two lines on the paper. Stick a pin on the line passing beneath the center of the box as shown in the figure. Be sure the pin is vertical.

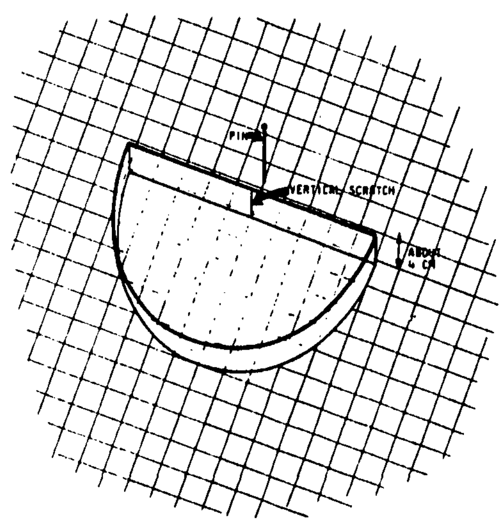


Figure A.2

You may want to use an optical disc to qualitatively demonstrate refraction by different shapes.

Now look at the pin through the water from the curved side and move your head until the pin and the vertical mark on the box are in line. Mark this line of sight with another pin. What do you conclude about the bending of light as it passes from air into water and from water into air at an angle of incidence of 0°?

Change the position of the first pin to obtain an angle of incidence of 20°. With the second pin, mark the path of light going from the first pin to the vertical line on the box and through the water. Repeat this every 20° for angles of incidence up to 80°. To ensure a sharp image of the first pin at large angles, it should never be placed more than 4 cm away from the vertical line on the box. (The pin-holes give a permanent record of the angles.)

On the paper draw lines denoting the front of the plastic box, the incident rays of light, and the refracted rays of light.

Is the path of the light through the water the same when its direction is reversed? Investigate this with your apparatus.

Repeat the experiment, using another liquid in the box, and again draw lines denoting the front of the box, incident rays, and refracted rays. Compare the direction of the refracted rays by superimposing the diagrams for different liquids over the diagram for water and holding them up to the light. Does each of the other liquids refract differently from water?

The index of refraction may be calculated by the ratio of the sine of the angle of incidence over the sine of the angle of refraction.

You may want to place the diagrams on a series of overhead transparencies. This will show the same incident rays and different refracted rays for angles 20°, 40°, 60°, and 80° in the different liquids.

A.1.d IMAGES FORMED BY A CONVERGING LENS

Look through a converging lens at an object. Is the image you see larger or smaller than the object? Is it right side up or upside down? Do the size and position of the image change when you move the lens with respect to

In this experiment, the student becomes familiar with the images formed by a converging lens.

Students will work in an area of about 2 meters. A 2-meter strip of paper fastened to the table with tape can be used as an "optical bench."

Answers to Questions: The image is smaller than the object when the object is beyond the principal focus and larger than the object when the object is between the lens and the principal focus. The image will not be visible when the object is at the principal focus or near it.

the object?

To investigate the images formed by a converging lens, arrange a lens and a lighted flashlight bulb on a long strip of paper as shown in Figure A.3.

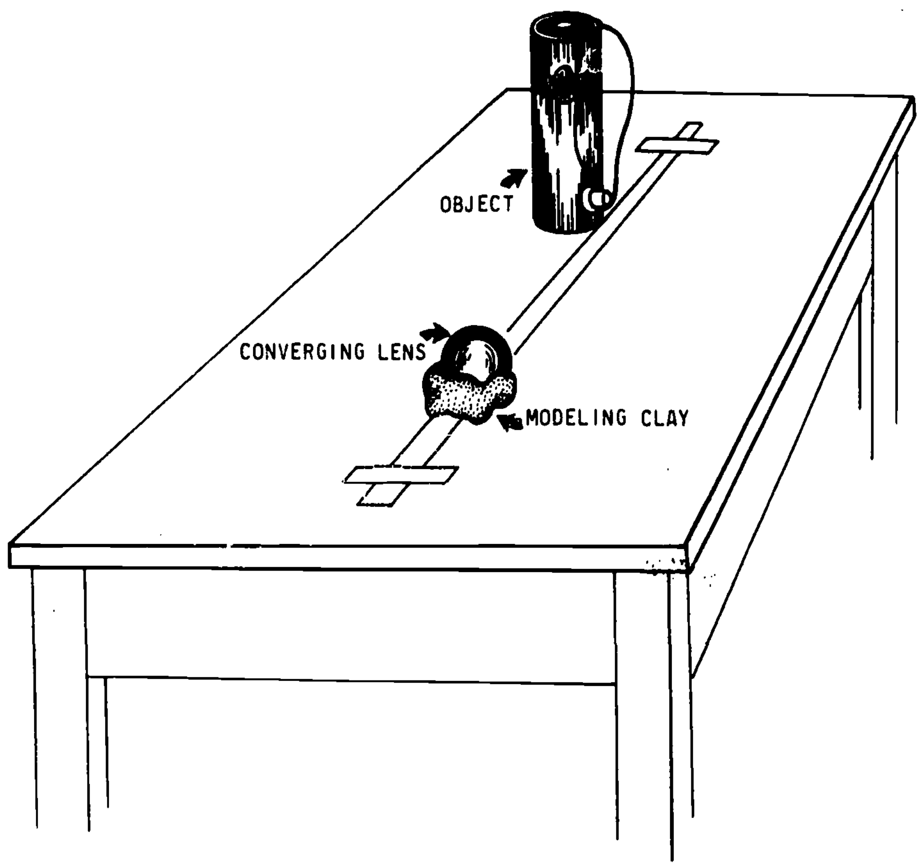


Figure A.3

The image is inverted when the object is beyond the focus and right side up when the object is between the lens and the focus.

Start with the bulb at one end of the paper tape and locate its image by parallax. Is the image right side up or upside down?

Now move the object toward the lens in small steps, marking and labeling the positions of both object and image as you go. Continue this until the image moves off the end of the tape and can no longer be recorded. How does the change in the position of the image compare with that of the object? Where (on your tape) do you expect the image to be when the object is at least several meters away? Check it. With the object far away, you may find it easier to locate its image on a piece of paper. The location of the image when the object is very far away is the principal focus of the lens. How can you convince yourself that the lens has two principal foci, one on each side and at the same distance from the center?

Materials and Equipment

- *1 converging lens (20cm f.l.)*
- *1 long strip of paper*
- *1 2.5-v. flashlight bulb (#41) and socket*
- *1 #6 dry cell, 1.5v.*
- *2 connecting wires, 1'*
- *1 lump modeling clay*
- *1 sharp hard-lead pencil*
- *1 meter stick*
- *1 straight pin*
- *1 cork*
- *1 sheet of graph paper*

Now place the bulb as close to the lens as possible and again locate the image by parallax. Is it upside down or right side up? Again move the object away from the lens in small steps, marking and labeling the positions of object and image until the image is no longer on the tape.

Where will the image be if the object is placed at the principal focus? Can you see it?

EXERCISES FOR HOME, DESK AND LAB (HDL)

HDL's 1-21 are made up of problems from Project Physics.

(22) Two students are positioned in the fun house as shown in Fig. 1. Because student A is fooled by the mirror, where does he think student

(22) Extend the line beyond the mirror from A the same distance as A is from the mirror.

B is?

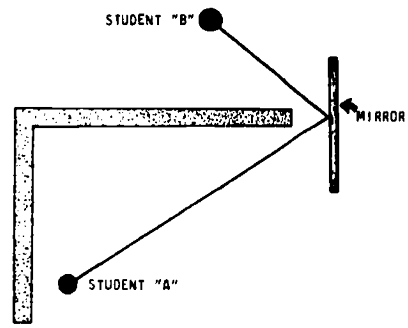


Figure 1

(23) What part of the driver can you see in the rear view mirror from the rear seat?

(23) His eyes.

(24) An arrow 6 cm long is placed 5 cm from principal focus between the focus and a concave mirror with a focal length of 10 cm. What is the position, orientation and size of the image?

(24) The image is virtual (behind the mirror) upright and 12 cm long. (Formula, if you're interested, is:

$$\frac{Hi}{Ho} = \frac{f}{So}$$

where Hi is image height, Ho is object height, f is focal length, and So is distance from object to focus.)

(25) If the arrow is placed 5 cm from the focal length away from the mirror, how will it affect the position, orientation and size of the image?

(25) The image is real (in front of the mirror), inverted and 12 cm long.

(26) What happens to the focal length on concave mirrors with larger and larger radii of curvature?

(26) They get longer and longer until at a plane mirror the focal length is infinite.

(27) How does the size, position and orientation of the image change as the object moves into the surface of a concave mirror from infinity?

(27) From infinity to twice the focal length the image is reduced, inverted and real, between f and 2f. At 2f the image is real, inverted and the same size. When the object is between f and 2f the image is enlarged, upright and virtual.

(28) If a ray passes from one media into another, as shown in Figure 2, which media has greater optical density, a or b?

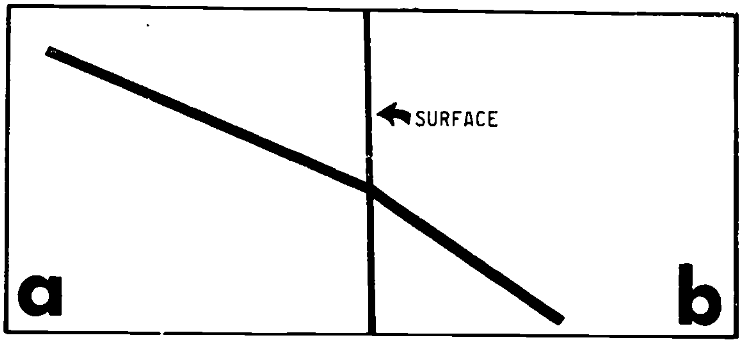


Figure 2

(29) A light ray enters a rectangular block of glass as shown in Figure 3 and is refracted.

a. What is the angle of refraction?

b. What is the angle of incidence?

c. When you replace the glass block with a block of another material, the angle of incidence must be 67^{o} to have the ray remain refracted to the same spot 3 cm from the edge on the bottom. What is the index of refraction on the new block?

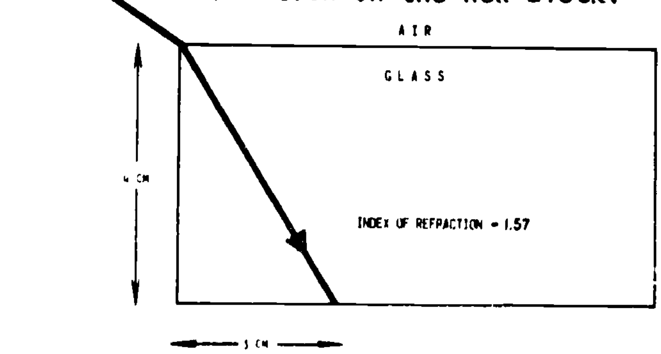


Figure 3

(30) In Figure 4 ray a passes from the point of the arrow through a principle focus to the lens. Ray b passes the point of the arrow parallel to the axis and goes to the lens.

At f the image is at infinity. When the object is at infinity the image is at the focus and very small.

(28) a.

(29) a. $3^2 + 4^2 = x^2$

$5 = x$

$\sin \angle r = 3/5 = .60$

$\angle r = 36.70$

b. $\sin \angle r$ = (index of refraction) $(\sin \angle r)$

$= (1.57)(.60)$

$= .94$

$\angle i = 70^{o}$

c. $\dfrac{\sin \angle i}{\sin \angle r}$ = index of refraction

$\dfrac{\sin 67^{o}}{\sin 36.7^{o}} = \dfrac{.92}{.60} = 1.52$

(30) a. Ray a goes out to the left, parallel to the axis.

b. Ray b goes through the other principal focus.

c. The tip of the image arrow is at the intersection of ray a and ray b. The rest of the arrow is from there down perpendicular to the axis.

a. Where does ray a go next?

b. Where does ray b go next?

c. Where is the image of the arrow?

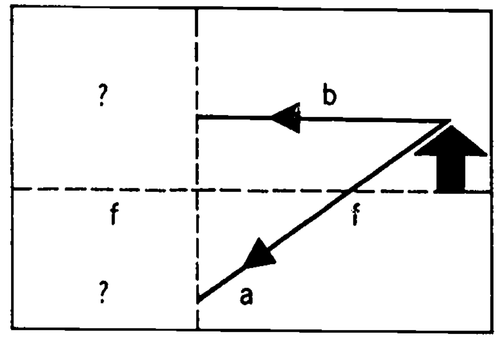
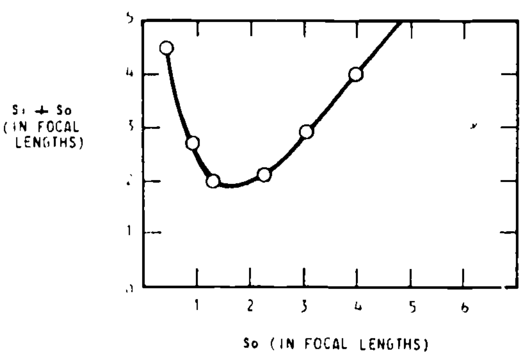


Figure 4

(31) The minimum distance is 4 focal lengths.



Above graph shows SiSo minimum at 2. Since SiSo are measured from principal foci which are 2 focal lengths apart, the total is four.

(31) What is the minimum distance between an object and the real image formed by a converging lens? Make a graph of the total distance versus the object distance. Use the focal length f of the lens as the unit of distance. ($S_iS_o = f^2$ where Si is the distance from the image to a principal focus and So is the distance of the object to a principal focus and f is the focal length.)

(32) In Figure 5, a parallel beam of monochromatic light enters each box from the left. Draw what could be in each box to produce the effects shown. The single and double arrows on the emerging beam show the corresponding edges of the entering beam.

(32)

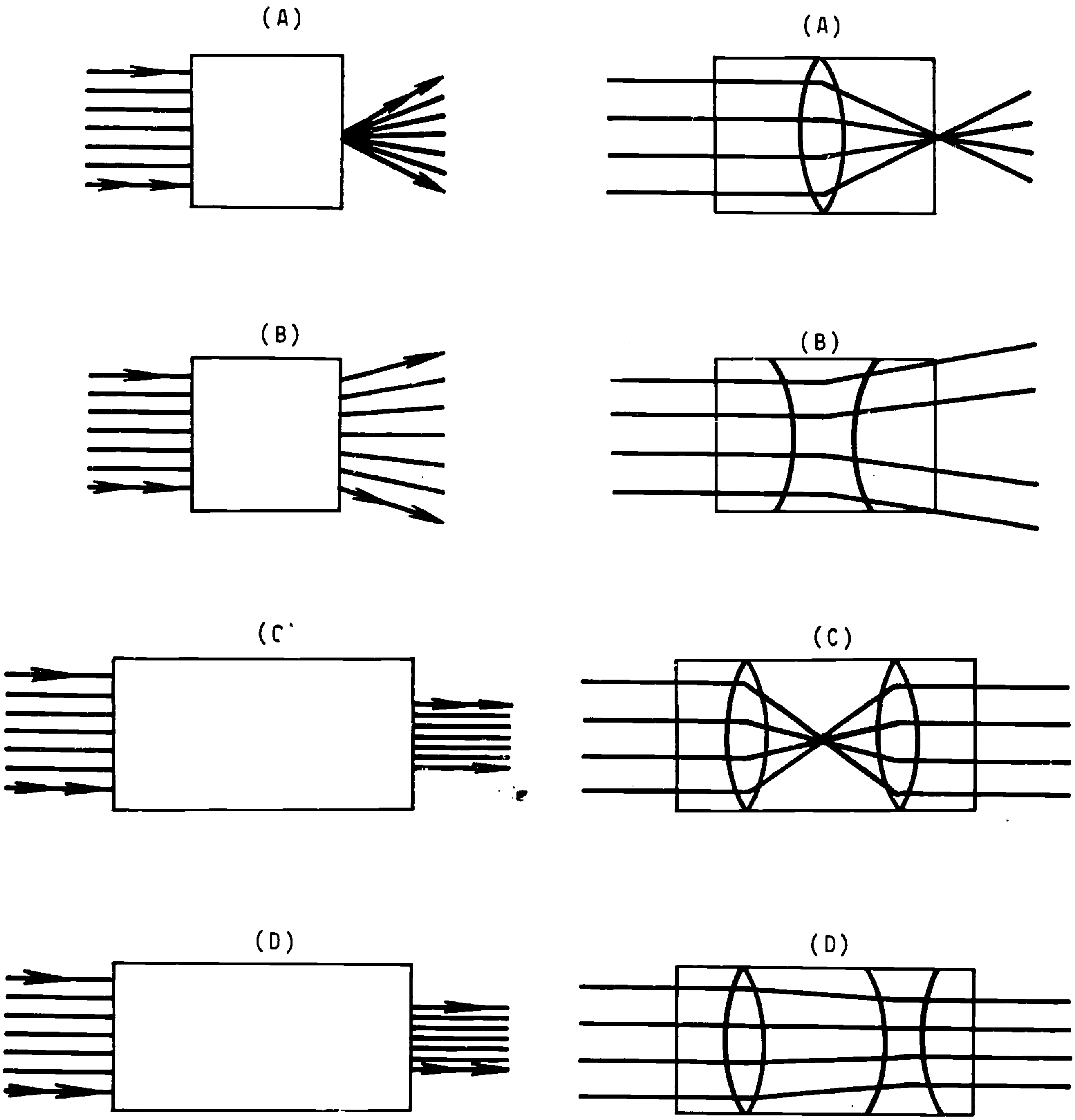


Figure 5

Chapter 11; LIGHT

A MODELS EXPLAIN LIGHT PHENOMENA
Read 13.1, 13.2, 13.3 HP

A.1 Experiment: OPTICS (PP)

B INTERFERENCE EFFECTS AND THE WAVE MODEL
Read 13.4 HP

C YOUNG'S EXPERIMENT
Read 13.5 HP

C.1 Experiment: YOUNG'S EXPERIMENT
HP Ex 32

D PROPAGATION OF LIGHT WAVES
Read 13.6, 13.7, 13.8 HP

T SECTION	ROUGH TIME ESTIMATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS				OUTSIDE READING
3 roduction R	↑			T30 The speed of light +	Looking into the eye	Quant E	H	Qual E	H	
pagation R	3 Days			F30 Speed of light +	Miscellaneous light activities	4+ 5+	1*	3*	2x	R4 Velocity of light
lection action *	↓	OPTICS (PP) x		F31 Introduction to optics x	Measuring index of refraction Matching index of refraction Making an ice lens	6+ 9*	7+ 11+	10+ 12+		
erference fraction *	↑ 1 Day ↓	Ex 32 Young's + Experiment or PSSC (#13) Young's experiment x			Handkerchief diffraction grating Seeing and photographing diffraction patterns	13*		14+15x		R3 Experiments and calculations relative to physical optics
or R	↑				Color vision by contrast (land effect) Properties of the human eye					
y is the ?	1 Day				Poisson's spot How to half silver a mirror					
arization +			Polaroid plastic sheets					18 19		
e Ether R	↓				Miscellaneous photography activities. The camera does lie	17				

Chapter III: ELECTRICITY AND MAGNETIC FIELDS

A RELATIONSHIP OF CHARGE TO FORCE
Read 14.1, 14.2, 14.3, 14.4 HP

A.1 Experiment: ELECTRIC FORCES - COULOMBS LAW
HP Ex 34

B A LOOK AT ELECTRIC CHARGES
Read 14.5, 14.6 HP

C MOVING CHARGES
Read 14.7, 14.8 HP

D CURRENTS AND CIRCUITS
Read 14.9, 14.10 HP

E RELATING ELECTRIC AND MAGNETIC FORCES
Read 14.11, 14.12 HP

F MAGNETIC FIELDS AND MOVING CHARGES
Read 14.13 HP

TEXT SECTION	ROUGH TIME ESTIMATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS Quant E → H	PROBLEMS Qual E → H	OUTSIDE READING
HP Ch 14 14.1 Introduction R		E33 Electric forces I +						R6 Action at a distance
14.2 The curious properties of lodestone and amber R				T31 E field inside a conducting sphere				
14.3 Electric charges and electric forces *	1 Day		D47 Electrostatic demonstrations * (Before students read 14.3)	F32 Coulomb's law	Demonstrating electric fields Demonstration of electric fields in three dimensions	1* 2*	4*	
14.4 Forces and fields *	2 Days	E34 Electric forces-Coulomb's law *		PSSC film Universal gravitation * (Before 14.4)		8* 5* 7*	6+ 9	
14.5 The smallest charge *				PSSC film * Millikan expt.		11* 12* 13*	10+	
14.6 Early research with electric charges R	1 Day		D48 The electrophorous *		Voltaic pile, an 11-cent battery			
14.7 Electric currents R								
14.8 Electric potential difference *						15* 18*	16 17*	
7 14.9 Electric potential difference and current x	5 Days				More perpetual motion machines	21x		
14.10 Electric potential difference and power x				T33 Forces between current carriers	Force law for bar magnets	22x 25x		

TEXT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS Quant (E H)	PROBLEMS Qual (E H)	OUTSIDE READING
14.11 Currents act on magnets *	↑	E35 currents and forces *	D49 Currents and forces +	PSSC film "magnet lab"	Who's who in TV			
Discuss in detail flow of electrons, flow of current, direction of magnet field.								
14.12 Currents act on currents *	5 Days ↓	E36 Currents, magnets and forces *	D50 Currents, magnets, and forces +	T32 Magnetic fields and + moving charges F33 Electrons in a uniform magnetic field	Measuring magnetic field intensity			R16 Radiation belts around the earth
14.13 Magnetic fields and moving charges *	1 Day					29* 30+ 32+ 31*		

THIS IS SO IMPORTANT THAT STUDENTS SHOULD NOT GO ON WITHOUT AN UNDERSTANDING OF THE MATERIAL IN CHAPTER 14.

Chapter IV: FARADAY AND THE ELECTRICAL AGE

A INVESTIGATING THE ELECTRIC FIELD
Read 15.1, 15.2, 15.3 HP

B MAGNETS AND CURRENTS
Read 15.4 HP

C ELECTROMAGNETISM PUT TO USE
Read 15.5 HP

TEXT SECTION	ROUGH TIME ESTI-MATE	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS		OUTSIDE READING
						Quant E → H	Qual E → H	
5 he problem: energy from ce to another	↑				Physics collage		10	
lue to the n: electro- sm	5 Days						2*	R2 On the method of theoretical physics
araday's ork on elec- and lines e	↓		D51 Electric fields (VTVM needed)		The lodestone; the magnet			
he discovery tromagnetic on	↑				R14 Relationship of electricity and magnetism		3* 4*	
enerating city from sm: the	3 Days ↓			T32 Magnetic fields and moving charges	Faraday disc-dynamo Bicycle generator Generator jump rope	20x	5*	

Chapter V: ELECTROMAGNETIC RADIATION

A DISCUSSION OF MAXWELL'S WAVES
Read 16.1, 16.2 HP

B ELECTROMAGNETIC WAVES AND LIGHT
Read 16.3, 16.4 HP

C MAXWELL - APPLICATIONS AND IMPLICATIONS
Read 16.5, 16.6, 16.7 HP

Chapter VI: THE CHEMICAL BASIS OF ATOMIC THEORY

A EARLY ATOMIC THEORIES
Read 17.1, 17.2 HP

B CHEMICAL PROPERTIES AND THE PERIODIC TABLE
Read 17.3, 17.4, 17.5 HP

C SYNTHESIS OF ELECTRICITY AND MATTER
Read 17.6, 17.7, 17.8 HP

SECTION	ROUGH TIME ESTI-MATE	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS	OUTSIDE READING
		THIS CHAPTER IS A REVIEW UNIT AT THE OPTION OF THE TEACHER; THEREFORE ALL ACTIVITIES OPTIONAL					
on's atomic d the laws al combina-				F35 Definite and multiple proportions F36 Elements, compounds and mixtures		1, 2, 3	R1 Failure and success
atomic the					Dalton's puzzle	4, 5, 6 7	
r proper- he elements:						8	
search for regularity elements							R21 Looking for a new law
eleev's table of nts							

SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER TEACHING ACTIVITIES	PROBLEMS	OUTSIDE READING
e modern table				T35 Periodic table	Periodic table	9, 10, 11	
ctricity er: quali- tudies				F37 Counting electrical charges in motion	The electroly-sis of water Single-elec-trode plating		
ctricity er: quanti- tudies				L46 Produc-tion of sod-ium by elec-trolysis		12-18	

Chapter VII: ELECTRONS AND QUANTA

A DISCOVERY OF THE ELECTRON
Read 18.1, 18.2 HP

B MEASUREMENT OF ELEMENTARY CHARGE
Read 18.3 HP

B.1 Experiment: MEASUREMENT OF ELEMENTARY CHARGE
HP Ex 40

C PHOTOELECTRIC EFFECT
Read 18.4, 18.5 HP

C.1 Experiment: PHOTOELECTRIC EFFECT
HP Ex 2

D X RAYS AND ATOMIC MODELS
Read 18.6, 18.7 HP

TEXT SECTION	ROUGH TIME ESTIMATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS		OUTSIDE READING
HP Ch 18 18.1 The problem of atomic structure: pieces of atoms R	↑					Quant E → H	Qual E → H	R18 The sentinel
18.2 Cathode rays *		#Ex 39 The charge-to-mass ratio for an electron +	D54 Charge-to-mass ratio for cathode rays +			1*		
18.3 The measurement of the charge of the electron: Millikan experiment *	10 Days	Ex 40 The measurement of elementary charge *		F38 Millikan experiment		2*		
18.4 The photoelectric effect *	↓	Ex 42 Photoelectric effect *	D55 Photoelectric effect x	T36 The photoelectric mechanism	Lighting a bulb with a match photoelectrically		3*	
18.5 Einstein's theory of the photoelectric effect: quanta *	↑ 3 Days	MENTION that $w = hf_o$		T37 Photoelectric equation F39 Photoelectric effect	Writings by and about Einstein	8* 7* 6+ 9* 10*	15	R5 Einstein R20 Space travel problems of physics and engineering
18.6 X rays R					X rays from Crooke's tube			
18.7 Electrons, quanta and the atom R	↓			L47 Thomson model of the atom			14	R4 The 'Thomson Atom'

E39, E40, E42 can be done by different teams of students, with a seminar to follow. Each takes a long time.

PSSC mass of electron option here

Chapter VIII: THE RUTHERFORD-BOHR MODEL OF THE ATOM

A SPECTRA OF GASES
Read 19.1 HP

A.1 Experiment: SPECTROSCOPY
HP Ex 43

B BALMER RELATION
Read 19.2 HP

C RUTHERFORD'S MODEL
Read 19.3, 19.4 HP

D BOHR THEORY
Read 19.5, .9.6 HP

E SHORTCOMINGS AND PRELUDE TO A NEW THEORY
Read 19.7, 19.8, 19.9 HP

TEXT SECTION	ROUGH TIME ESTIMATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS Quant	PROBLEMS Qual	OUTSIDE READING
HP Ch 19 19.1 Spectra of gases R	3 Days	Ex 43 Spectroscopy *	D56 Blackbody radiation +			E → H	E → H 1+	
19.2 Regularities in the hydrogen spectrum *			Work out example of Balmer's generalized formulas *		Modeling atoms with magnets Another simulation of the Rutherford atom	3* 4*	2+	R12 The Teacher and the Bohr theory of the atom
19.3 Rutherford's nuclear model of the atom *	3 Days		Nuclear scattering apparatus +	T38 Alpha scattering L48 Rutherford scattering F40 The structure of the atom F41 Rutherford atom		6 7	5* 6+ 7*	
19.4 Nuclear charge and size R						8+		
19.5 The Bohr theory: the postulates *						9*		
19.6 The Bohr theory: the spectral series of hydrogen *				T39 Energy levels-Bohr theory F42 A new reality			11x	
19.7 Stationary states of atoms: the Franck-Hertz experiment *	4 Days		D57 Absorption +	F43 Franck-Hertz experiment	Measuring a quantum effect: ionization		12+	
19.8 The periodic table of the elements R				T35 The periodic table			18+	
19.9 The failure of the Bohr theory and the state of the atomic theory in the early 1920's R					C[illegible] box atoms		10+ 16*	R19 The Sea-captain's box

Chapter IX; SOME IDEAS FROM MODERN PHYSICAL THEORIES

A MASS - ENERGY EQUIVALENCE
Read 20.1 HP

B PARTICLE BEHAVIOR OF WAVES
Read 20.2 HP

C WAVE BEHAVIOR OF PARTICLES
Read 20.3, 20.4 HP

D QUANTUM MECHANICS
Read 20.5, 20.6 HP

TEXT SECTION	ROUGH TIME ESTIMATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER TEACHING ACTIVITIES	PROBLEMS Quant E → H	PROBLEMS Qual E → H	OUTSIDE READING
HP CH 20 20.1 Some results of relativity theory * Don't Get In Too Deep In This Chapter	↑					1+ 2* 3* 4+ 5x 7*	6*	R6 Mr. Thompkins and simultaneity R7 Mathematics and relativity * R8 Relativity R9 Parable of the survivors * R10 Outside and inside the elevator
20.2 Particle-like behavior of radiation *				F44 Interference of photons		8*	9+ 10+	
20.3 Wave-like behavior of matter x	4 Days		Standing waves on a wire ring *	F45 Matter waves	Standing waves om a band-saw blade Turntable oscillator patterns	12+ 11*		
20.4 Quantum mechanics R			D58 Ionization potential	F46 Light: wave and quantum theories				R13 The new landscape of science * R15 Dirac and Born * R16 I am this whole world: Erwin Schrodinger *
20.5 Quantum mechanics-the uncertainty principle R							14+ 17x	R14 The evolution of the physicist picture of nature
20.6 Quantum mechanics-the probability interpretation *	↓			PSSC - Random events	Radioactive analog (dice)	18*	19 20x 21 22+	R11 Einstein and some civilized discontents R1 Failure and success *

39

THE ORBITAL ATOM

Chapter 1: ATOMS IN THREE DIMENSIONS

A STANDING WAVES

A.1 ATOMS AND MATTER WAVES

A.2 THE BASIC PROBLEM

A.3 DESCRIBING STANDING WAVES

A.4 THREE-DIMENSIONAL STANDING WAVES AND THE ATOM

B QUANTUM NUMBERS

B.1 PRINCIPLE QUANTUM NUMBER

B.2 ORBITAL QUANTUM NUMBER

B.3 MAGNETIC QUANTUM NUMBER

B.4 ELECTRON SPIN

B.5 ATOMS WITH SEVERAL ELECTRONS

C THE ORBITAL MODEL

D RELATIVE ENERGY LEVELS

The purpose of ATOMS IN THREE DIMENSIONS is to build the need for the four quantum numbers (n, l, m and s). After the need is recognized and the Pauli Exclusion Principle is accepted, it is possible to show the relation of the quantum numbers to the energy levels of atoms and hence the periodic table.

Because the "Auf Bau" is lightly treated in sections 1.5 to 2 of chapter 15, CHEMS, it is possible to move directly to 15-1.5 after completing chapter 20 of Project Physics.

A STANDING WAVES

A.1 ATOMS AND MATTER WAVES

We are now in a position to begin a realistic discussion of the structure of atoms. On one hand we have seen that the electrons that surround the nucleus can be described in terms of waves, so-called matter or de Broglie waves. On the other hand, we have learned a good deal about the general properties of waves which, we shall see, are applicable in discussing these matter waves. An inkling of the sort of ideas we will be concerned with is given in Section 20.3 of Project Physics. There we saw that consideration of the standing wave patterns in a circular path surrounding the nucleus of a hydrogen atom enables us to derive Bohr's quantization condition, viz., that the angular momentum of the electrons in such an atom is limited to certain discrete values.

The case of the hydrogen atom is the simplest possible case. Considering matter waves confined to a circular path around the nucleus leads to useful results, for the quantization condition is the basis for predicting the discrete energies of the hydrogen atom. A standing wave with just one wave length exactly occupying the circumference corresponds to the n=*1* level,

TEXT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS	OUTSIDE READING
I ATOMS IN THREE DIMENSIONS A Standing Waves	↑						
B Quantum numbers				Film--The Hydrogen atom as viewed by quantum mechanics		1	
C The orbital model	4 Days					2, 3	
D Relative energy levels	↓					4, 5, 6	

in which the electron has the lowest possible energy. This is called the ground state. (See HP section 19.5.) Standing waves involving larger numbers of wave lengths correspond to higher energy levels. A calculation of these possible energy states leads to exactly the right relationship to account for the observed hydrogen spectrum. The spectra are interpreted in terms of energy transitions between states each one of which is specified by an integer "quantum number" which tells how many loops there are in the standing wave.

It is not surprising to learn that the de Broglie wave length corresponding to an electron of moderate energy is about the same as the size of an atom. Now we suspect that this is just what determines how big an atom should be in the first place!

But this is clearly not the whole story. The approach given above predicts the correct energy values for hydrogen atoms, but it leaves many questions unanswered. For instance it does not say enough about the location of the electrons. According to the probability interpretation of matter waves (HP Chapter 20) the intensity of the wave at any particular place is proportional to the probability of the electron being found there. What then are the intensities of the waves in the various orbits? How shall we interpret the existence of nodes at certain points in the orbits? Are there thus no electrons in certain positions around the atom? If so, how are these positions oriented? After all, it is clear from our knowledge of the structure of molecules and crystals that atoms are joined together more readily along certain directions than along others, but the foregoing theory doesn't give any reasons for this. Not enough is revealed by these simple ideas regarding the shape of atoms.

Another difficulty is that not much is yet explained about the existence of sublevels or about atoms containing more than one electron in the outermost shell. The above model gives us valuable clues to explaining the structure of atoms but is highly oversimplified. In order to completely describe the state of the electrons in an atom, more than one quantum number is required. It is not enough to specify the main shell in which an electron is found. A complete description requires numbers which tell in which sublevels the electrons are found, what the orientation of the orbits are, etc.

A.2 THE BASIC PROBLEM

To further develop the theory, examine the assumption which has been made: Describing the path of an electron as a closed circle provides an essentially one-dimensional figure which can yield only a single quantum number. Of course a circle is really a two-dimensional figure, but if we consider nothing but the length of the path around its circumference we will have taken into account only one dimension for sound waves, the path length. A bugle provides an analogous case; this instrument makes use of standing-wave patterns to select only certain pitches. What counts is the length of the tube only, and no matter how it is bent around into a more convenient shape, it sounds the same as if it were straight. Musically speaking, it is a one-dimensional instrument.

Real atoms, however, are three dimensional; in addition to energy, they have characteristics like shape and orientation that affect the ways in which they react to form molecules or crystals. Perhaps we need to consider standing waves in more than one dimension in order to more fully explain the properties of atoms. We have already encountered a two-dimensional situation in Chapter 12 of Project Physics, when we studied vibrations in a drumhead and in a metal plate. Let us reexamine some of these ideas in order to see how they can yield a more complete description of atomic phenomena.

A.3 DESCRIBING STANDING WAVES

Recall the experiments and film loops of HP Chapter 12 in which you observed standing waves in a variety of one-dimensional objects: a string, a wire, a gas-filled pipe and a rubber hose. For a given situation many different vibrating situations (modes) were possible. For instance, in a string of a given length (Film loop 39, also Section 12.7) there can be various numbers of segments of vibration between the ends. A convenient way of designating these modes is by the number of segments: mode 1 would refer to the case of 1 segment between ends, mode 3 the case of 3 segments, etc. These numbers, each referring to a different "state" of the string, can be thought of as the "quantum number" for that state. The analogy with quantum numbers of the Bohr atomic model is appropriate in that it can be shown that each mode of vibration of a given string at a given amplitude involves its own unique amount of energy. Only one number is necessary to designate a particular state and hence a particular energy.

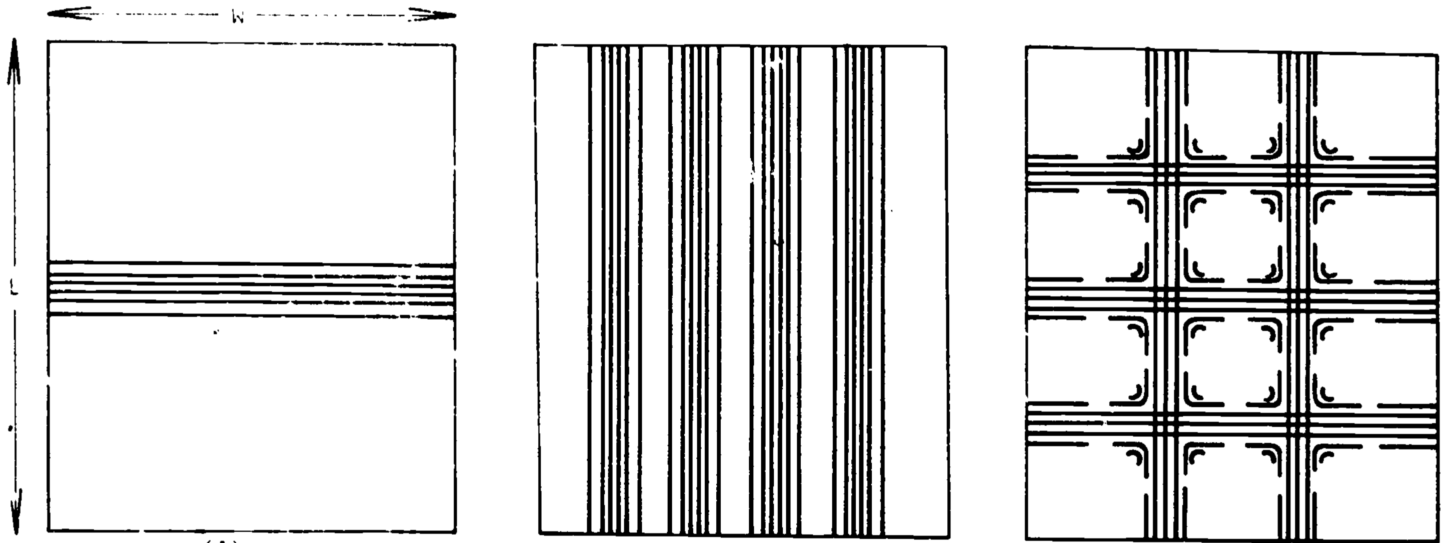
However, a two-dimensional medium like a drumhead or a metal tank can transmit waves along more than one direction and, as a result, more than one independent set of standing waves can exist in such a medium. Another two-dimensional example is a rectangular ripple tank in which standing-wave patterns can be made by straight waves that move from one end of the tank to the other. Upon reflection from that end, standing waves are set up whose modes and loops lie along lines parallel to the ends. Likewise, another set of standing waves is generated by straight waves moving back and forth between the sides of the tank. Two entirely independent sets of standing waves are possible, each one limited only by the condition that a whole number of loops must exactly fit into the space between the reflecting walls. In Figure A.1 (a) and (b) samples of standing-wave patterns in a rectangular ripple tank are reproduced. If the length of the ripple tank is L and its width is W, then one set of standing waves is specified by the equation

$$L = n(\lambda/2)$$

where n must be an integer and the other set by the equation

$$W = m(\lambda/2)$$

where m must be an integer. Thus two sets of integers are necessary in order to allow for all

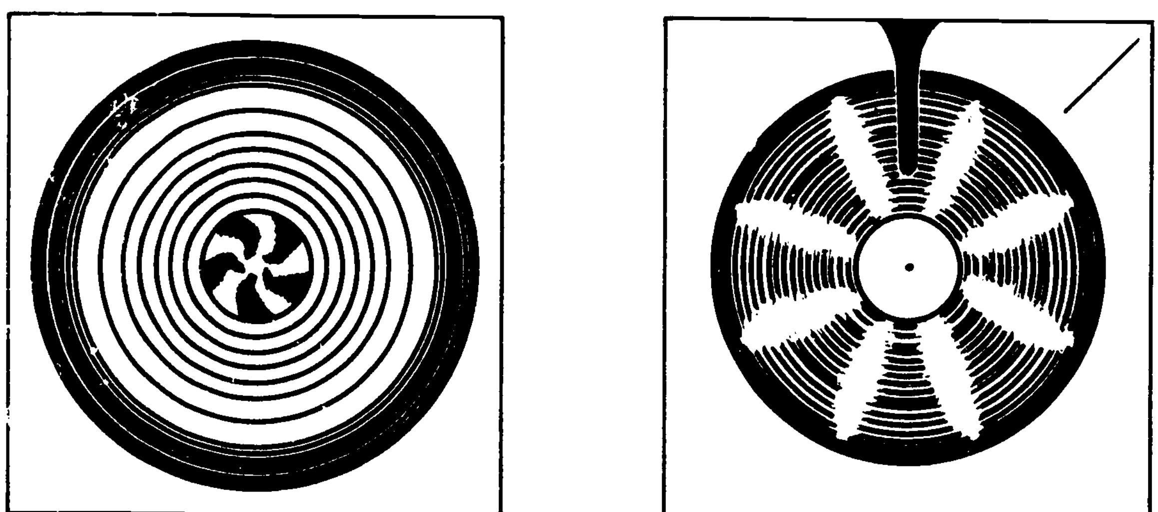


(A) (B) (C)

(a) Vibrations in a ripple tank such that end to end standing waves are produced; $n = 2$.

(b) Side to side standing waves; $m = 5$.

(c) Combination pattern; $n = 4$, $m = 3$.



(D) (E)

(d) Schematic diagram of waves moving radially. The waves can be made by vibrating the tank.

(e) Schematic diagram of waves moving circumferentially produced in a ring-shaped tank by a rippler aligned along a radius.

Figure A.1

possibilities. For a ripple tank having some particular ratio of length to width, there may be certain wave frequencies that permit members of both sets of standing waves to exist at the same time. See Figure A.1 (c). Indeed very intricate and intriguing patterns can result from such combinations, but in every case no single set of integers is enough to describe the possible patterns. Two sets are always required.

Let us next think about a slightly more complicated situation that comes closer to the atomic model of interest to us. In a circular or ring-shaped ripple tank, standing waves like those of Figure A.1 (d) can be formed by waves which move back and forth along radii of the tank. In a ring tank formed between concentric circular walls of radius R_1 and R_2, the standing waves satisfy the equation

$$R_1 - R_2 = n(\lambda/2)$$

where n is any integer. It is also possible to form standing waves as in Figure A.1 (e) by using a straight generator with its edge along a radius. In this case the waves go around the circle and satisfy the equation

$$2\pi r + \lambda m$$

analogous to the standing electron waves discussed earlier. Here m is an integer and r must lie between R_1 and R_2.

Again it is found that two independent sets of integers are required in order to allow for all the possibilities in a two-dimensional medium. By independent sets it is meant that each set can exist without the other and that choice of a value from one set does not necessarily determine a value from the other. If, for example, we look for standing waves of the same frequency in both sets simultaneously, then there may be limits imposed on the possible choices by the particular shape of the medium.

If waves are produced in a three-dimensional medium such as a block of gelatin, three independent sets of standing waves can be produced and three sets of integers are required for a complete description of each "mode" of oscillation corresponding to a particular combination of standing waves. It is natural to expect, thus, that the mathematical solution for electron standing waves in an atom involves three sets of integers. As we shall see, these correspond to quantum numbers which label all the shells and subshells occupied ay an electron in a particular atomic state.

A.4 THREE-DIMENSIONAL STANDING WAVES AND THE ATOM

A detailed calculation of all the possible modes for a given three-dimensional medium can become rather complicated, particularly if the shape of the medium is not very simple. Such is the problem faced by an architect who wants to design an auditorium capable of transmitting all the frequencies of the orchestra equally to all the listeners in the audience. (In this case, he will want to avoid standing-wave patterns.) The problem may be so complicated that he will prefer to build a miniature or simplified model which he can test experimentally to obtain information that will guide his final design. The atomic scientist, too, can be guided by experimental observations such as those with spectra and thus be greatly assisted in his attempts to solve similar difficult problems.

The methods of wave mechanics developed in the 1920's make it possible in principle to compute the de Broglie standing-wave modes with the "medium" surrounding an atom. In this case the "shape" will be determined by the electric and magnetic fields in the vicinity of the atom, and the mathematical solutions will give the probability of an electron being found at any given point.

There are, unfortunately, some difficulties that make it hard to use the method. For one thing, the "shape" of a given atom is not often known in advance of the calculation. Furthermore all atoms except hydrogen contain more than one electron and the forces exerted by these electrons on one another greatly complicate the problem. However, since spectroscopic studies give information about the energy changes that do take place under various known conditions, part of the solution can be deduced and can be made by trying to work the problem backwards from this information. What arrangement of energy levels might allow for the changes that are observed? What "shape" of force fields might lead to these energies as a solution? The scientist may try to work out an idealized representation (a model) of the atom and then compare predictions based on his model with the experimental observations. In the next part of this course we will see some of the things that can be understood about chemistry by using one such atomic model, the "orbital model."

B QUANTUM NUMBERS

B.1 PRINCIPAL QUANTUM NUMBER

When the spectrum of hydrogen is observed carefully under various conditions including , for example, light from hydrogen atoms in an electric or magnetic field, it is found that the set of integer quantum numbers derived earlier (n = 1, 2, 3, 4) is not enough by itself to specify all the possibilities. Two additional sets are necessary. (This should be no surprise to you if you think of hydrogen atoms as "real" three-dimensional objects.) You have already met one of the sets, the principal quantum number, n. They specify major electronic states of the atom which, as you have seen, vary in energy inversely with n^2. In the orbital model we will be using, the principal quantum number is associated with the physical size of the "orbital," the region around the nucleus in which an electron in a particular energy state is most likely to be.

B.2 ORBITAL QUANTUM NUMBER

As we have seen, a complete description of the electron wave pattern in three dimensions cannot be obtained with only one quantum number. The principal quantum number is related to the size of the "orbital," i.e., to the size of the standing wave pattern which describes the probable locations of the electron in the vicinity of the nucleus. As for the shape of the orbital, a second quantum number designates this. It is called the orbital quantum number and is given the symbol l. That these two quantum numbers can exist simultaneously and refer to two distinct properties of the wave patterns might be seen by considering an analogous two-dimensional case which is easier to picture.

The two-dimensional example is that of the vibration of a drumhead. In Figure B.1 various modes are illustrated by picturing a top view of a drumhead in various states of vibration. At a particular instant of vibration portions of the membrane will either be above or below the flat stretched position; they are designated by + (above) or - (below). Lines separating these regions are positions of nodes, lines along which the membrane is not in motion. n gives the number of circular nodal lines and l gives the number of radial nodal lines. As we shall see these are analogous to the n and l quantum numbers of the atomic case.

The "flat stretched position" of the drumhead refers to the equilibrium point when the drumhead is stationary.

Notice that n more or less determines the way in which the vibration pattern stretches out from the center. Of course in a drumhead the actual size of the pattern is limited by the diameter of the hoop holding the membrane, whereas in the analagous three-dimensional atomic case the "medium" is defined only by the gradual tapering off of the electric field of the nucleus. Hence the size of the pattern depends on the value of n.

As to the value of l, it has to do with the

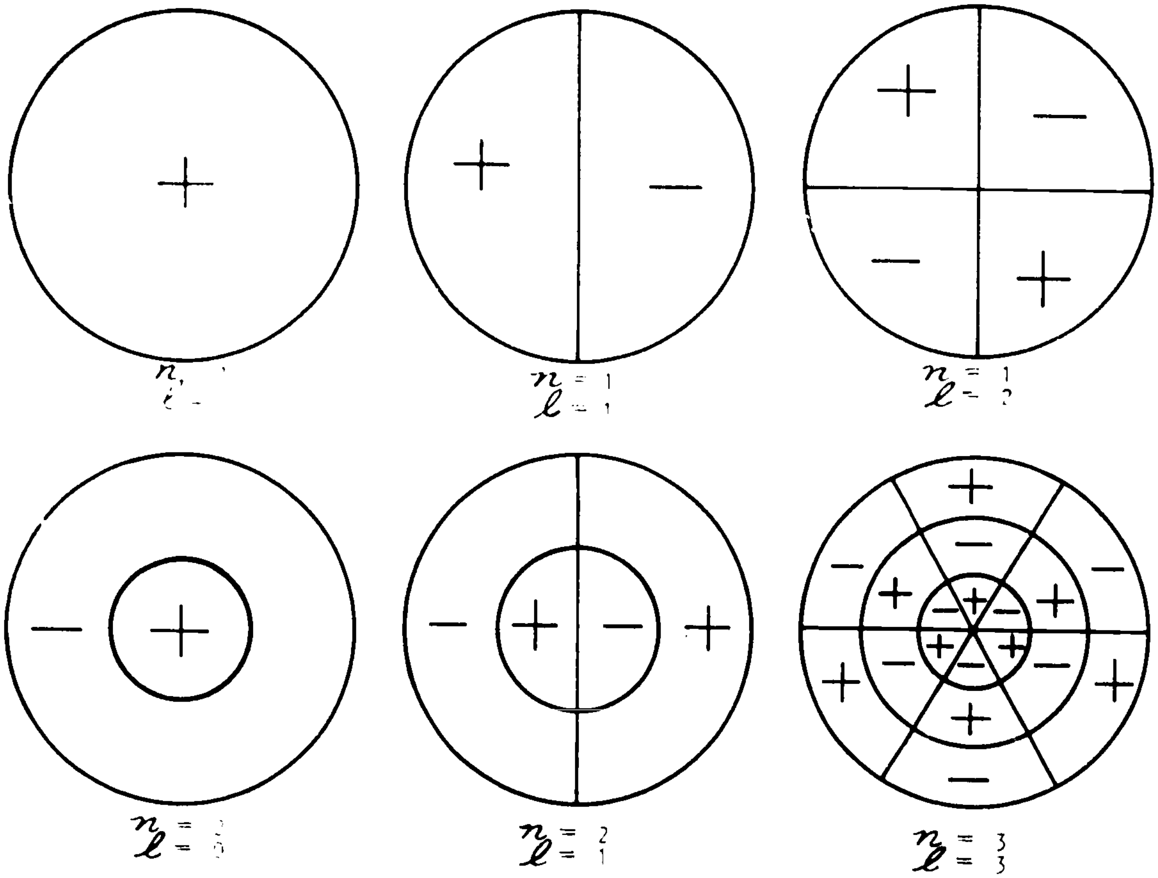


Figure B.1 - Various modes of vibration of a drumhead.

"directivity" of the pattern. When $l = 0$, there is no direction in which any part of the pattern points; for other values of l there are differences in the pattern when viewed along different directions. Likewise in the atomic case it will be seen that the orbitals have orientation in space for higher values of l. In terms of the motion of the electron it also turns out that specifies the number of units of angular momentum that the electron possesses.

There is one great difference between the drumhead vibrations and the corresponding atomic case. Whereas all possible combinations of n

and l are possible in the two-dimensional case, in an atom the orbital quantum number has a restricted set of values depending on the value of n with which it is associated. In fact, it is found that l can have the value 0 or any positive integer up to n-1. Thus if n is one, l must be zero. If n is 3, l can be zero, one or two. Successive values of l , starting from zero, are usually referred to by the letters *s, p, d* and *f*. The orbital quantum number is associated with the shape of the orbitals which will be described later.

B.3 MAGNETIC QUANTUM NUMBER

The third set of integers, called magnetic quantum numbers, are related to the possible orientations of the orbitals with respect to each other. Magnetic quantum numbers are designated by m and they can have any integer value from $-l$ up to $+l$. For example if $l = 2$, then m can have any of the values -2, -1, 0, 1 or 2. Hydrogen atoms can exist in any state (any standing-wave mode) described by any combination of possible values of n , l , and m. There is only one possible state for $n = 1$, since then both l and m can only be zero. This is the stable "ground state" of hydrogen having the lowest energy possible. If $n = 2$, there are four possible combinations of l and m: 0, 0; 1, -1; 1, 0; and 1, 1. You can readily show that for any value of n there are n^2 possible combinations of l and m.

B.4 ELECTRON SPIN

When electrons were first identified by J. J. Thomson and for a long time afterward, almost nothing was known about them except that they were very small charged objects. They could easily be considered as point charges without physical size or shape. Later it was found that in addition to having charge and mass, each electron behaved as if it were a tiny magnet. We cannot say even today how this magnetism is produced, but it is possible to think of it as though the electron is a small charged sphere spinning like a top, thus giving rise to magnetic fields similar to other cases of charges moving in a circle. The electron is referred to as possessing "spin."

In the presence of another magnetic field, the electronic magnet will tend to point along the field. When pointed in the "easy" direction (completely lined up with the field) the electron has the least magnetic energy. When pointed in a completely opposed direction it has the most magnetic energy. As in other atomic situations, only certain energies are allowed; for this magnetic case only these "parallel" and "anti-parallel" states are permitted.

In an atom, particularly one having several electrons, it is necessary to distinguish electrons whose moments are parallel to the magnetic field in the atom from those that are anti-parallel, as this may influence their behavior. A simple way to do so is to treat the spin orientation as another quantum number, one that can have only two possible values; a minus value for parallel and a plus value for anti-parallel. This spin "quantum number" is denoted by s, and its two possible values are often written as - and +. (For convenience in atomic calculations these are assigned the values $-\frac{1}{2}$ and $+\frac{1}{2}$.) Hence, for any value of n there are $2n^2$ possible combinations of l, m and s.

B.5 ATOMS WITH SEVERAL ELECTRONS

With these four sets of quantum numbers and information about their allowable values as a starting point, it has been possible to arrive at a satisfactory wave mechanical model of the hydrogen atom, which accounts very well for practically all of the observed behavior of hydrogen and hydrogen-like atoms (atoms or ions that consist of a nucleus and a single electron). Corresponding to each possible combination of quantum numbers, the model specifies an orbital which describes the region of high probability for the electron when it is in that particular energy state. What about the other atoms? Can a model based on similar reasoning be worked out for any atom?

One might start by assuming a model of the atom in which the forces exerted by all the electrons on each other are taken into account along with those forces exerted by the nucleus. Then the possible standing-wave patterns for this atom might be computed and an attempt made to find out how the electrons would arrange themselves among these states. Even if such a complex calculation could actually be carried out, however, there would be reasons to doubt its validity until certain questions are answered which come up because the various electrons cannot be distinguished from each other. If each electron simply finds a place within the possible states without regard to the others, wouldn't they all go into the lowest energy state? Wouldn't the whole collection collapse into a sort of modified hydrogen with all the electrons together in the 1s state? Yet every-thing we know about the spectra and chemical behavior of atoms denies this! Carbon does not behave like "modified hydrogen," nor does oxygen nor any other atom except hydrogen itself. Each element is unique-different from all others. Out of considerations of this kind, backed up by detailed study of the spectra of different elements, comes a rule known as the exclusion principle, which was first stated by Wolfgang Pauli in 1925. The exclusion principle states simply that two electrons in the same atom cannot have completely identical quantum numbers. This appears to be one of the fixed "ground rules" for atom building. It is a little bit like the common-sense rule that no two objects can be in exactly the same place at the same time. With the exclusion principle as a guide, it is possible to build up reasonable models for more complicated atoms. Exact solutions are so involved that they were not even attempted until after the invention of high-speed electronic computers. However, approximate solutions as well as the very few complete solutions that have been carried through all indicate that the wave mechanical model of an atom in terms of standing-wave "orbitals" is capable of giving a very good description of the real behavior of atoms.

The energy states that result from an atom consisting of several electrons and a nucleus are not identical to those for the one-electron hydrogen atom. Each combination will lead to its own unique set of states. Nevertheless, they all have some degree of similarity to the set for hydrogen. For example, the energy states always occur in groups that can be designated by four quantum numbers in the same manner as for hydrogen. It is convenient, therefore, to use exactly the same quantum number designations for corresponding energy states of any atom, even though the actual energy of the states may be different from one atom to another.

C THE ORBITAL MODEL

We have seen that four quantum numbers are needed to "describe" each energy level in an atom. Let us now use the four quantum numbers to build the orbital model of an atom which scientists may use to explain the bonding of molecules and the structure of matter. The first quantum number (n = 1, 2, 3, . . .) is associated with the size of the region in which there is a high probability of finding electrons. The second quantum number (l = 0, 1, . . . n-1) is associated with the shape of the orbital in which the probability of finding the electrons is high. The third quantum number ($m = -l, . . 0, . . +l$) is associated with the orientation of the orbitals with respect to each other. The fourth quantum number ($s = \pm 1/2$) is, as we have seen previously, dependent on the "spin" of the electron. Table C.1 illustrates the allowable values of l, m and s for several values of n. As an exercise, complete the table to $n = 5$.

Using these physical interpretations of the quantum numbers as a guide, we may now describe an orbital model for any atom. Our description will refer to the lowest possible total energy for the whole atom that is consistent with the Pauli exclusion principle. Thus, in an atom of say ten electrons, we assume that of all the energy states of this atom the electrons will be in those ten having the lowest total energy. Let us use the sodium atom as an example and describe each electron, starting with the least energetic. If $n = 1$, then $l = 0$ is the only allowable value for the second quantum number. $l = 0$ is the s orbital and is thought of as a sphere of high probability around the nucleus. If $l = 0$, then m can have only one value, 0, which means there is only one orientation of the *s* orbital in space. (Could a sphere have more than one orientation?) Since $s = \pm 1/2$, we have now provided for two electrons and have filled the first principal quantum level. If $n = 2$, then $l = 0$ or 1. We know that for $l = 0$ we are describing a spherical *s* orbital with only one orientation, which may contain two electrons ($s = \pm 1/2$). For $l = 1$, we think of a region shaped somewhat like a dumbbell, which is called a *p* orbital. The *p* orbital has three possible orientations, $m = -1, 0, +1$. These are arranged at 90° with respect to each other. Allowing two electrons ($\pm$ spin) in each of the *p* orbitals accounts for six more electrons.

We have now "described" two electrons in the 1*s* orbital, three in the 2*s* orbital, and six in the 2*p* orbitals for a total of ten electrons. All possible values for $n = 1$ and $n = 2$ have been used, so we now use $n = 3$ for which $l = 0, 1, 2$. Again $l = 0$ is the *s* orbital, which is spherical in shape and has only one orientation in space. Since sodium has an atomic number of 11, we need place only one electron in the 3*s* orbital to complete our model for sodium. 's this model consistent with the fact that the sodium ion has a charge of +1?

Relations Between Quantum Numbers

n	l	m	s
1	0	0	±1/2
2	0	0	±1/2
	1	1	±1/2
		0	±1/2
		-1	±1/2
3	0	0	±1/2
	1	1	±1/2
		0	±1/2
		-1	±1/2
	2	2	±1/2
		1	±1/2
		0	±1/2
		-1	±1/2
		-2	±1/2
4	0	0	±1/2
	1	1	±1/2
		0	±1/2
		-1	±1/2
	2	2	±1/2
		1	±1/2
		0	±1/2
		-1	±1/2
		-2	±1/2
	?	?	?

Table C.1

ATOMIC ORBITALS

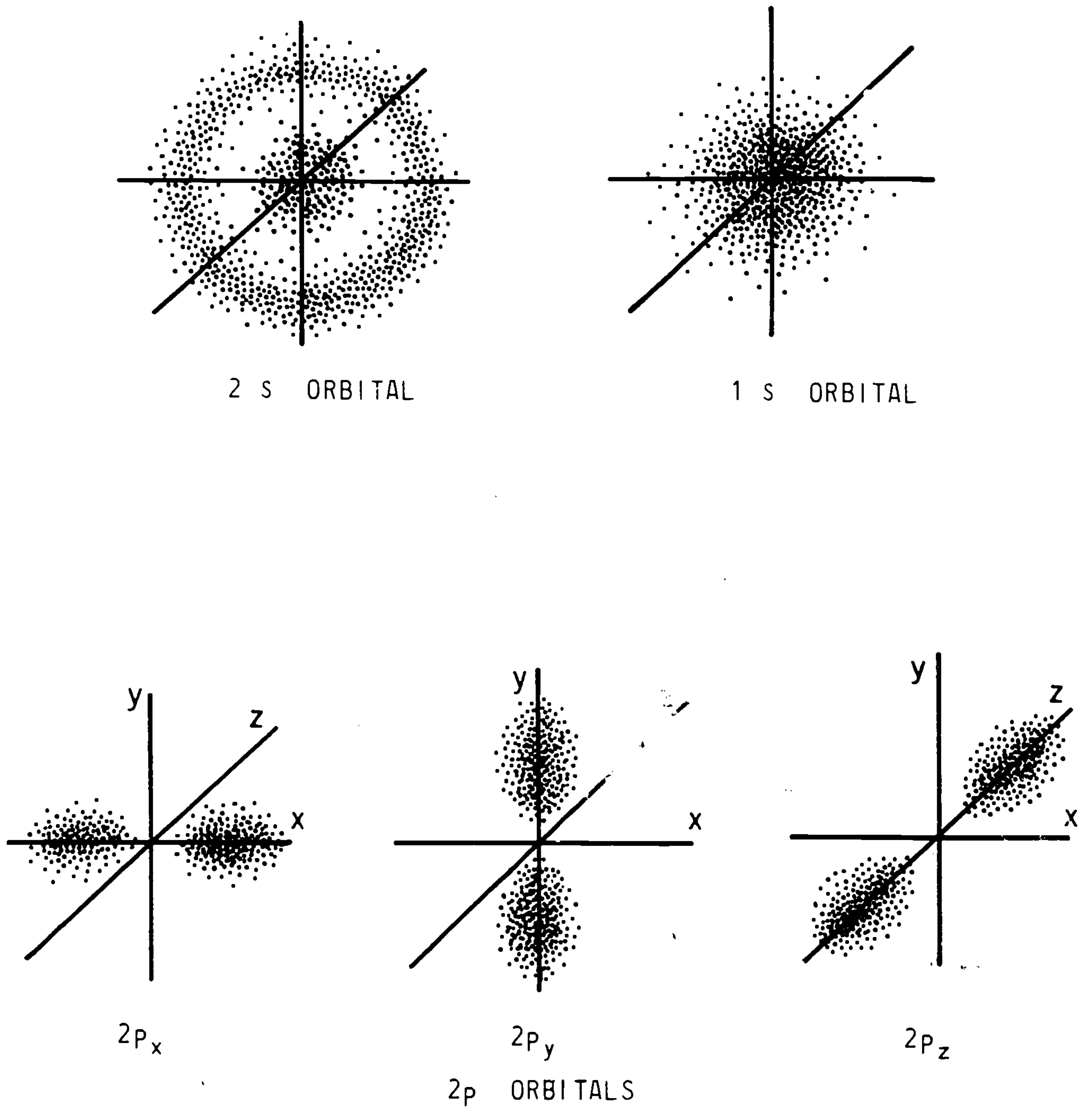


Figure C.1

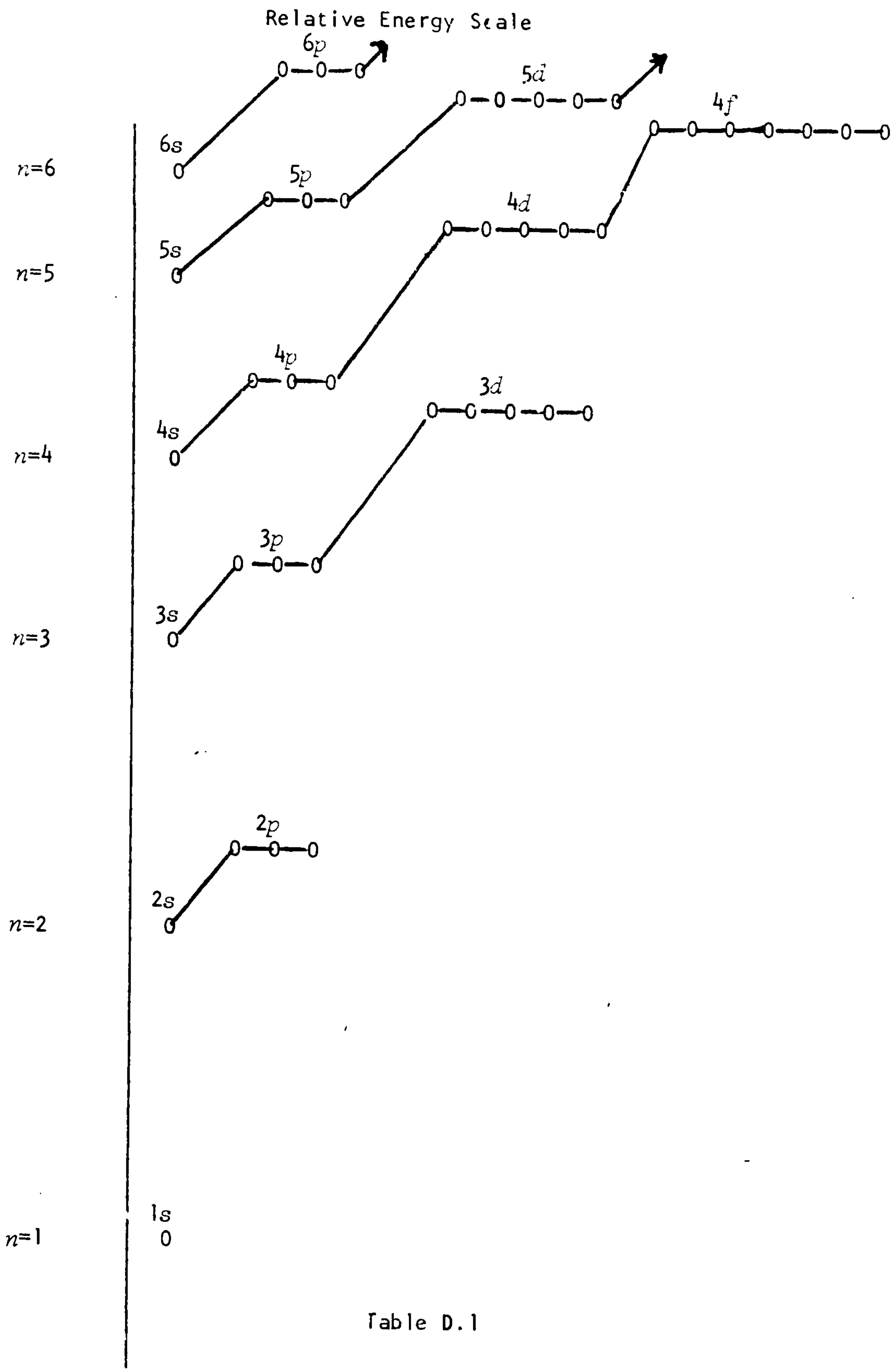

Relative Energy Scale
n=6
n=5
n=4
n=3
n=2
n=1
1s
2s
2p
3s
3p
3d
4s
4p
4d
4f
5s
5p
5d
6s
6p

Table D.1

If we were to continue with the $n = 3$ energy level, we would have, in addition to the *s* orbital ($l = 0$, $m = 0$) and the three orientations of the *p* orbitals ($l = 1$, $m = -1, 0, +1$), the $l = 2$ orbitals. When $l = 2$, m has five allowable values, -2, -1, 0, +1, +2. The $l = 2$ orbitals are called the *d* orbitals and the five values of m indicate that there are five possible orientations for the *d* orbitals. When $n = 4$, we again have the *s* orbitals ($l = 0$), the *p* orbitals ($l = 1$), and the *d* orbitals ($l = 2$). For $n = 4$, l can also have the value 3, for which there are seven possible values for m (-3, -2, -1, 0, +1, +2, +3). The $l = 3$ orbitals are called the *f* orbitals and the seven values for m indicate seven possible orientations of the *f* orbitals.

D RELATIVE ENERGY LEVELS

Since we use the rule that the electron is always "described" in the lowest available energy level, we must consider the relative energies of the orbitals before we continue with our model building. Actual mathematical analysis of the spectra of elements (using quantum mechanics) leads to the relative energy scale in Table D.1.

We see from Table D.1 that the 4*s* orbital is lower in energy than the $3d$ orbitals; the $5s$ orbital is below the $4d$ orbitals; the $5p$ orbitals are below the $4f$ orbitals, and the $6s$ orbital is less energetic than the $4f$ or $5d$ orbitals. With the relative energy scale to guide us, we can describe the orbital model for any atom. The common notation for orbital description is the nl^x notation, where n = the principal quantum number, l = the orbital shape (s, p, d, f), and x = the number of electrons (two allowed for each orientation of the orbital). As an example, iron (Fe) atomic number 26 would be written as follows:

Iron $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^6$

Notice that the sum of the superscripts is the total number of electrons. How would you write the orbital notation (sometimes called the electron configuration) for arsenic, element number 33?

The orbital model has provided the scientist with a powerful tool for explaining much of the behavior of the elements. As you continue in CHEMS chapters 15, 16 and 17, the model is used to explain periodic properties, chemical behavior and certain physical properties. However, as has been true of other models, we shall see that this model has limitations and must be revised and extended as more information becomes available. Remember a model is a concept, not a scale picture of a real object. A scientist should not hesitate to discard or revise a model to fit experimental facts. The best model, however, is one which is consistent with the most observations. To test the power of the orbital model, see if you can find any regularity between the organization of the periodic table and the notion that there are two electrons in each *s* orbital, six electrons in the three orientations of the *p* orbitals, ten electrons in the five available *d* orbitals and fourteen electrons in the *f* orbitals.

Exercises for Home, Desk and Lab (HDL)

(1) Explain the difference between the orbital model of the atom and the Bohr-Sommerfeld model of the atoms which postulated quantized orbits.

(2) Describe the locations of a 1*s* electron on the surface of a sphere concentric with the nucleus.

(3) The energy difference between the two electronic states is 46.12 kcal/mole. What frequency of light is emitted when the electron goes from the higher to the lower state? What wave

(1) The Bohr-Sommerfeld model describes the trajectory of the electron, while the orbital model describes the probability of finding the electron at any given time.

(2) There is an equal probability of finding an electron at any point on the surface of such a sphere.

(3) $E = h\nu$

$\nu = E/h =$

$$\frac{46.12 \text{ kcal/mole}}{9.52 \times 10^{-14} \text{ kcal-sec/mole}}$$

$\nu = 4.34 \times 10^{14}$/sec

(4) *Energy must be added to the atom to change an electron from the 1s to the 2s level.*

(5) $1s\ 2s^1$ *is Li*

$1s^2\ 2s^2$ *is Be*

$1s^2\ 2s^2\ 2p^3$ *is N*

$1s^2\ 2s^2\ 2p^6\ 3s^1$ *is Na*

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^7$ *is Co*

(6) *The student is expected to discover the general s, p and d "areas" of the periodic table.*

length does this light have? (How does the wave length compare to the approximate size of atoms?)

$h = 9.52 \times 10^{-14}$ kcal-sec/mole

(4) What happens when the electron in the hydrogen atom is to change energy levels from 1s to 2s? Can you specify this numerically?

(5) Name the elements that correspond to the following electron configurations.

$1s^2\ 2s^1$

$1s^2\ 2s^2$

$1s^2\ 2s^2\ 2p^3$

$1s^2\ 2s^2\ 2p^6\ 3s^1$

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^7$

(6) Make an outline of the periodic table and fill in the nl^x notation for the outermost electron for the first four periods. What regularity do you see? There are exceptions to this regularity which will be discussed in class.

Chapter 11: MANY-ELECTRON ATOMS

A ENERGY LEVELS OF MANY-ELECTRON ATOMS
Read section 15-2.1 CHEMS

B THE PERIODIC TABLE
Read section 15-2.2 CHEMS

SECTION	ROUGH TIME ESTI- MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS	OUTSIDE READING
-ELECTRON gy levels electron	1 Day					6	
periodic							

Chapter III: IONIZATION ENERGY AND THE PERIODIC TABLE

A MEASUREMENT OF IONIZATION ENERGY
Read section 15-3.1 CHEMS

B TRENDS IN IONIZATION ENERGY
Read section 15-3.2 CHEMS

C IONIZATION ENERGIES AND VALENCE ELECTRONS
Read section 15-3.3 CHEMS

D THE FOURTH ROW OF THE PERIODIC TABLE
Read section 15-3.4 CHEMS

XT SECTION	ROUGH TIME ESTI-MATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS	OUTSIDE READING
IZATION THE ABLE ement ion energy	↑			Film-Ioniza-tion Energy CHEMS			
in energy	2 Days					12, 13, 14	
tion nd valence						15, 16	
urth row iodic table	↓						

Chapter IV: MOLECULES IN THE GAS PHASE

A THE COVALENT BOND

1. THE HYDROGEN MOLECULE
   Read section 16-1.1 CHEMS

2. INTERACTION BETWEEN HELIUM ATOMS
   Read section 16-1.2 CHEMS

3. REPRESENTATIONS OF CHEMICAL BONDING
   Read section 16-1.3 CHEMS

4. THE BONDING OF FLUORINE
   Read section 16-1.4 CHEMS

B BONDING CAPACITY OF THE SECOND-ROW ELEMENTS

1. THE BONDING CAPACITY OF OXYGEN ATOMS
Read section 16-2.1 CHEMS

2. THE BONDING CAPACITY OF NITROGEN ATOMS
Read section 16-2.2 CHEMS

3. THE BONDING CAPACITY OF CARBON ATOMS
Read section 16-2.3 CHEMS

4. THE BONDING CAPACITY OF BORON ATOMS
Read section 16-2.4 CHEMS

5. THE BONDING CAPACITY OF BERYLLIUM ATOMS
Read section 16-2.5 CHEMS

6. THE BONDING CAPACITY OF LITHIUM ATOMS
Read section 16-2.6 CHEMS

7. VALENCE
Read section 16-2.7 CHEMS

C TREND IN BOND TYPE AMONG THE FIRST-ROW FLUORIDES

1. THE BONDING IN GASEOUS LITHIUM FLUORIDE
   Read section 16-3.1 CHEMS

2. IONIC CHARACTER IN BONDS TO FLUORINE
   Read section 16-3.2 CHEMS

3. IONIC CHARACTER IN BONDS TO HYDROGEN
   Read section 16-3.3 CHEMS

4. BOND ENERGIES AND ELECTRIC DIPOLES
   Read section 16-3.4 CHEMS

D MOLECULAR ARCHITECTURE

1. THE SHAPES OF H_2O AND F_2O

   Read section 16-4.1 CHEMS

2. THE SHAPES OF NH_3 AND NF_3

   Read section 16-4.2 CHEMS

3. THE SHAPES OF CH_4 AND CF_4

   Read section 16-4.3 CHEMS

4. THE SHAPE OF BF_3

   Read section 16-4.4 CHEMS

5. THE SHAPE OF BeF_2

   Read section 16-4.5 CHEMS

6. SUMMARY OF BONDING ORBITALS AND MOLECULAR SHAPE
   Read section 16-4.6 CHEMS

7. MOLECULAR SHAPE AND ELECTRIC DIPOLES
   Read section 16-4.7 CHEMS

E DOUBLE BONDS

1. BONDING IN THE OXYGEN MOLECULE
Read section 16-5.1 CHEMS

2. ETHYLENE: A CARBON-CARBON DOUBLE BOND
Read section 16-5.2 CHEMS

2.a Experiment: CIS-TRANS ISOMERS
CEx 26

TEXT SECTION	ROUGH TIME ESTI-MATE	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS	OUTSIDE READING
CHEMS Ch 16 1.1.2	1 day			Film - Chemical bonding		1, 2, 3	
16,1.3 - 1.4	1 day					4, 5	
16,2 - 2.7	1 day					6, 9, 10, 11	
Problems	1 day						
16,3 - 3.4	1 day					12, 13	
16,4 - 4.7	1 day			Film - Shapes and polarities of molecules		14, 15, 16 17, 18, 19	
16,5 - 5.2	1 day	Start Ex 26				20, 21	
Review	1 day	Finish Ex 26				Quiz	

Chapter V: THE BONDING IN SOLIDS AND LIQUIDS

A THE ELEMENTS

1. VAN DER WAALS FORCES
   Read section 17-1.1 CHEMS

2. COVALENT BONDS AND NETWORK SOLIDS
   Read section 17-1.2 CHEMS

2.a Experiment: PACKING OF ATOMS
   CEx 27

3. METALLIC BONDING
   Read section 17-1.3 CHEMS

B COMPOUNDS

1. VAN DER WAALS FORCES AND
MOLECULAR SUBSTANCES
Read section 17-2.1 CHEMS

2. COVALENT BONDS AND NETWORK
SOLID COMPOUNDS
Read section 17-2.2 CHEMS

3. METALLIC ALLOYS
Read section 17-2.3 CHEMS

4. IONIC SOLIDS
Read section 17-2.4 CHEMS

5. EFFECTS DUE TO CHARGE SEPARATION
Read section 17-2.5 CHEMS

6. HYDROGEN BONDS
Read section 17-2.6 CHEMS

TEXT SECTION	ROUGH TIME ESTIMATES	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	OTHER STUDENT ACTIVITIES	PROBLEMS	OUTSIDE READING
CHEMS Ch 17,17.1-17.2	1 day					1	
	1 day	C Ex. 27 Parts I-V					
17, 1.3	1 day					2, 3, 4, 5	
17, 2-2.3	1 day					6, 7, 8	
17, 2.4	1 day						
	1 day	C Ex. 27 Parts VI, VII				9, 10, 11	
17, 2.5-2.6	1 day					12, 13, 14 15, 16	
Review	1 day			Film Crystals and their structure		Quiz	