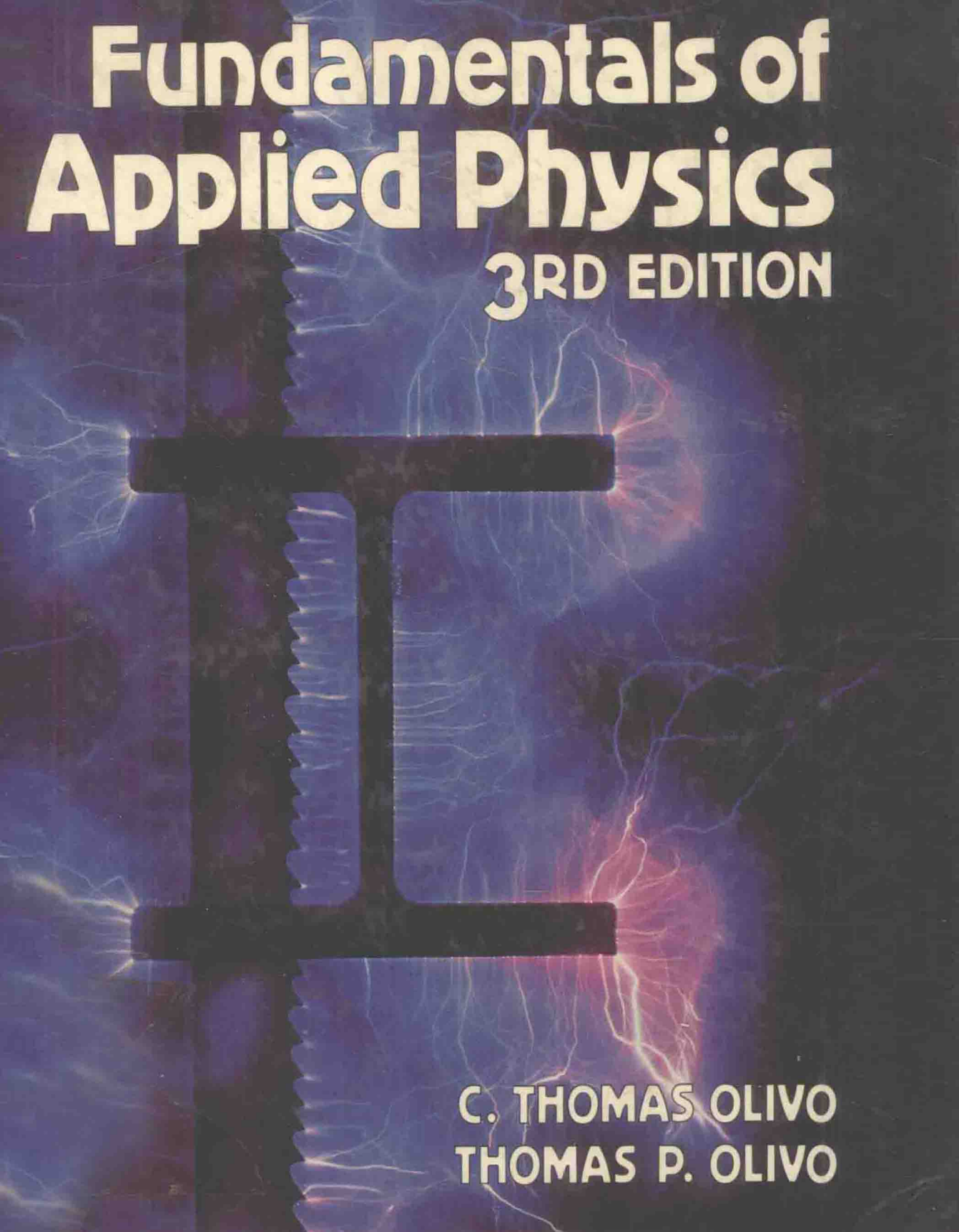
Fundamentals of Applied Physics

3RD EDITION



C. THOMAS OLIVO
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DELMAR PUBLISHERS INC.

This volume is dedicated to Mr. and Mrs. Peter Olivo, the parents of the senior author, as a tribute to their drive, encouragement, and convictions about the tangible value to youth and adults of perserverance, industriousness, and the ever-present spirit of inquiry into the Why and How.

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PREFACE

The productivity, pattern of living, and culture of America depend on the extent to which the simple basic scientific truths about matter, energy, space, and time are applied to produce new substances, new parts, and ingenious mechanisms. Science, which at one time was largely an avocation of learned people, is today a planned, purposeful, intensive application of invention and technology by an individual, a group, or an institution. Each one seeks to translate and control the physical world by shaping it to meet the growing needs of today's society.

The scientist uses two powerful tools to control and use matter and energy. The first tool is that of reliable knowledge which has been verified and organized. The second tool relates to the acquiring and organizing of new knowledge and generalizations. Each scientist builds on the accumulated knowledge and work of others. The scientist establishes theories by designing scientific investigations, conducting experiments or demonstrations, making accurate observations, and interpreting and recording the results according to scientific and precise methods.

Scientific concepts revealed by investigation, exploration, and demonstration are utilized by skilled individuals who translate theory into fact. It remains for physicists, astronomers, engineers, technologists, skilled craftspersons and others to transform the generalizations into inventions, products, and processes which have widespread use.

This text is the end product of years of extensive inquiry, study, experimentation, and analysis of the fundamental understandings about science needed by all persons. It helps provide an answer to the question "To what extent and in what areas should a person study the physical sciences to prepare for a vocation, to become an intelligent consumer, to contribute as an informed member of society, and to meet the needs of industry?"

The units in each section were selected to provide instructional material for a well-balanced coordinated course based on life needs. The scope of the units is such that the contents may be adapted to meet the special needs of students/trainees, and to allow for progress according to varying individual abilities and desires. The *Summary* for each unit is followed by a series of practical problems and applications of each basic principle.

Recognition is made in each unit of the value of organized laboratory work as an essential part of learning experiences. This edition was changed to provide greater flexibility in adapting laboratory work. The laboratory experiments, which formerly were included in this text, are now contained in a new *Student's Guide.* The worksheets identify the required equipment for each experiment, procedures, and tables for recording data and interpreting the results. Also, the two units on *Applications of Physical Science to Consumer Needs, Career Planning, and Development*, which comprised *Section 11* in previous editions, are now included in the *Student's Guide.*

Based on new, recent extensive studies of physical science requirements of industry and as preparation for a career, the contents of this edition are changed significantly.

Some of the major changes, consistent with evolving scientific and other technological developments, include the following:

- *Section 2* on *Systems of Measurement in Science* is simplified to reflect current movements in industry and by the public in the continuing acceptance of the customary United States and British system of measurement in preference to SI Metrics or other European metric systems.
- *Section 4* on *Magnetism and Electrical Energy* now includes applications of electricity which depend on thermal effect. Fusing for electrical circuits, induction heating, and microwave heating are examples. Other applications of electricity are made to the fusion of metals by electrical resistance and electric arc welding.
- *Section 5* dealing with *Heat Energy and Heat Machines* is expanded to include principles, constants, and applications of solar energy.
- *Section 6* on *Light Energy* now covers optical instruments. Phenomena, principles, and formulas for optics are related to simple cameras, projectors, and industrial and other high-powered microscopes.
- *Section 8* on *Electronics* places equal emphasis on communications and industrial electronic applications. Scientific foundations for the design and operation of automated machines and other instrumentation equipment are covered. Principles are described for computer-assisted numerical control machines. Basic open- and closed-loop systems are treated.
- *Section 10* on *Direct Conversion of Energy* introduces microprocessors and microminiaturized applications.
- *Former Section 11*, relating to *Applications of Physical Science to Consumer Needs, Career Planning, and Development*, as stated earlier, is now contained in a new *Student's Guide.*
- The sixteen *Technical Reference Tables* in the *Appendix* of previous editions are reduced to twelve. The former tables of *Conversion Factors* and *Symbols and Derived Units of Physical Quantities* have been expanded to permit easy conversion of a unit of measurement from either the United States Customary and British System or the SI Metric system to the other system. Using simple arithmetic processes, it is practical (whenever needed) to simply use a conversion factor to change a value to whatever unit of measurement is required.
- The *Glossary* and *Index* still include current major measurement quantities and accepted SI Metric terms. Changes were made to update the contents to parallel the new material in the text.
- Solutions to all *Practical Problems*, consistent with changes and additions within each unit, are included in the *Instructor's Guide.*

One final point is in order. The measurement systems and standards that are emphasized throughout the text correspond with those most widely used by industry, other occupational groups, and the public. It must be understood that although SI Metrics is accepted by legislation, the dominant system of measurement is still the Customary United States and British system.

Conversion to SI Metrics is to be voluntarily accepted by industry, professional bodies, and other users. SI Metrics, like all current and previous measurement systems, is a constantly evolving, coherent system of measurement units. The standards are accepted over a period of years by the *General Conference on Weights and Measures.* The standards reflect compromises among scientific, engineering, technological, and other learned groups.

In the light of daily practices, this edition of *Fundamentals of Applied Physics* treats measurements and standards in the context in which they are applied. Sufficient information is given, conversion tables are provided, and modern practices are suggested within the text to permit the student to solve problems in the Customary United States and British system of measurement or in SI Metrics.

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1984

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INTRODUCTION

Fundamentals of Applied Physics serves three basic purposes.

- The content and organization provide a broad background of scientific information. This material was selected from modern technology as being important to the development of social competency in all individuals.
- The instructional units are written so as to present in a clear, functional way those principles and applications of physical science which are needed as preparation for a vocation.
- The units provide the student with fundamental understandings which are essential to the pursuit of advanced studies in related technologies.

■ ORGANIZATION AND SCOPE OF THE INSTRUCTIONAL MATERIAL

Fundamentals of Applied Physics contains ten sections. These are: Science and Matter (1); Systems of Measurement in Science (2); Mechanics, Machines, and Wave Motion (3); Magnetism and Electrical Energy (4); Heat Energy and Heat Machines (5); Light Energy (6); Sound Energy (7); Electronics (8); Nuclear Energy (9); and Direct Conversion of Energy (10). A concluding section (11) in previous editions on Applications of Physical Science to Consumer Needs, Career Planning, and Development is now contained in the Student's Guide.

■ BASIC PRINCIPLE UNITS

Each Basic Principle Unit is introduced with a brief statement giving the importance and relationship of each new topic or area of scientific investigation. This is followed by a planned presentation of background information which provides a base for formulating whatever scientific laws are considered in the unit. Examples are given to show how a law or physical condition may be applied in a practical way, thus giving meaning to each new principle.

The line drawings which appear throughout the units serve as teaching-learning devices either to place emphasis on an important point or to simplify a description.

Summary

Important new items are summarized at the end of each instructional unit for emphasis. The statements are brief and may also serve as a guide to the instructor in preparing each lesson.

■ ASSIGNMENT UNITS: Textbook and Student's Guide

Practical Experiments: Student's Guide

The assignment for almost every unit may consist of either one or two parts. Laboratory experiments (which may be included as the first part) are contained in the *Student's Guide.* The practical experiments for laboratory work or demonstrations are used when the instructional program is organized to permit hands-on learning experiences. Such participation produces data from which quantitative relationships are established for interpreting the results. Experimental experiences permit personal validation of the basic principle involved.

Practical Problems

The second part of the Assignment Unit contains a series of Practical Problems which also seek to apply each Basic Principle. For the most part, the problems are of the objective type and are arranged from the simple to the more complex. While computations are required to determine quantitative values, all such problems have been kept comparatively simple. In this form, the problems emphasize and clarify specific principles and concepts and do not consume time in lengthy mathematical processes which may not strengthen the learning of a scientific principle. The units of measurement and the standards used throughout the text include the Customary United States and British system and the evolving SI Metric system. The use of these measurement systems is consistent with current practices.

In the explanations and examples provided in the text, measurements are converted between systems of measurement from Customary units to SI metric units. Generally, the exact values given in Table II in the Appendix are rounded off. In other cases, exact values are used where large quantities are involved and/or precise measurements are required.

■ ACHIEVEMENT REVIEWS AND COMPREHENSIVE REVIEW

Where there is more than one Basic Principle Unit in a Section, an Achievement Review is provided to serve as both test and review material. The sequence of the problem material on each Achievement Review follows the same order as the Basic Principle and companion Assignment Units in that Section. The Instructor may use the Achievement Reviews as pretests to measure student comprehension of certain basic concepts of science and their application in practical situations.

In addition to the *Section Achievement Reviews* in this text, there is a final *Comprehensive Review* in the *Instructor's Guide.* The *Comprehensive Review* provides a reservoir of supplemental test items for each unit in the ten sections of the textbook and the two units of former *Section 11* now in the *Student's Guide.*

■ RESOURCE TABLES, GLOSSARY, AND INDEX

The Appendix contains three items: (1) A Glossary in which the major technical terms used in the text are described; (2) a series of selected Reference Tables which

make the text self-contained, insofar as they provide technical data required in the solution of problems or as a basis of comparison of experiment results, and (3) an Index to assist in locating material within the text.

SUGGESTED APPLICATIONS FOR FUNDAMENTALS OF APPLIED PHYSICS

Each teaching-learning situation requires a different emphasis and presents a different need in the use of instructional materials.

The following are ways in which the material in this text may be used effectively.

- As a science textbook in schools where the learner must develop functional skills in science and must learn how to apply these skills in practical problems that have meaning in career planning and development.
- As a basic science textbook in vocational-industrial schools and technical institutes, and to fulfill other technical education and community college requirements for organized class instruction for homogeneous groups or individualized self-paced instruction.
- As a basic practical science textbook for apprentice and technical training and other in-plant occupationally oriented courses.
- As a basic science textbook for cooperative work-experience classes within business or industry.
- As a textbook or source book for adult programs and occupational extension classes where a sound practical working knowledge of science gives meaning to the technologies which are related to processes, tools, and materials.
- As a resource book in teacher-training classes for preparing courses of study and for studying the organizational pattern and the teaching content.

STUDENT'S GUIDE

To summarize, the practical experiments which complement practically all of the basic principles in Sections 1 through 10 in the textbook are contained in the *Student's Guide.* This arrangement provides flexibility and enriches the learning experiences where laboratory work is an integral part of the physical science program.

Further enrichment is provided by the inclusion of former Section 11 in the *Student's Guide.* The two units in this section show the importance of physical science to consumer needs, career planning, and development.

INSTRUCTOR'S GUIDE AND ANSWER BOOK

The *Instructor's Guide* (which is a companion publication) contains the solutions to the objective questions in both the Assignment Units and the Achievement Reviews. This guide is intended to conserve valuable teaching time and provide uniformity to the solutions of the problem material. A Comprehensive Examination is included in this Instructor's Guide as a final integrating experience covering all of the instructional units.

Fundamentals of Applied Physics incorporates a number of tested teaching-learning techniques for mastering basic scientific principles through simple, direct, and meaningful experiences. The instructional units develop an orderly working concept of the importance of science. They show how fundamental scientific laws, principles, and understandings may be applied with success to new technical developments that contribute so much to the attainment of higher standards of health, living, and welfare for all people.

CONTENTS

APPENDIX

Section 1
Science and Matter — Basic Principles

Unit 1 Science and the Scientific Method

Our technological age is being built by the peoples of all lands who seek to learn and apply fundamental scientific principles. It is this seeking out of truths and their applications which provides the scientist, the inventor, the technologist, and others with the basic knowledge which each needs to make possible experimentation, new developments, or production.

■ THE MEANING AND IMPORTANCE OF SCIENCE

The impact of science is evident everywhere. Disease has been controlled to such an extent that in the last fifty years the average life expectancy at birth has increased twenty years. Today, there is a greater abundance and variety of food; better transportation made possible by advances in design, materials, and fuels; faster communications; more comforts of life; better clothing; and better shelter. All of these improvements were made possible through new findings and gains in science.

Scientific *know-how* helps the artisan and technologist to manufacture materials and then shape or form them into parts which are useful in the home or on the farm; or into more complex or heavier mechanisms for use in business, industry, or research.

Science provides each person with simple truths about cause and effect. Each ingenious mechanism or new substance can be traced to a scientific beginning where some basic truths, proven through experimentation, were applied.

Science forms the foundation on which new substances and materials are produced and new products are built. The development of nylon, as shown in figure 1-1, is an example of the application of scientific facts.

Once the basic scientific fact was established that a fiber such as nylon was theoretically possible, continued laboratory experimentation produced the fiber; specialists and technicians developed the required plant and production facilities; and finally, nylon became a marketable product.

Within this framework, industry's principal contribution is to bring together three different areas of human effort — fundamental scientific knowledge, invention, and technology. Each of these areas is becoming increasingly more complex and specialized.

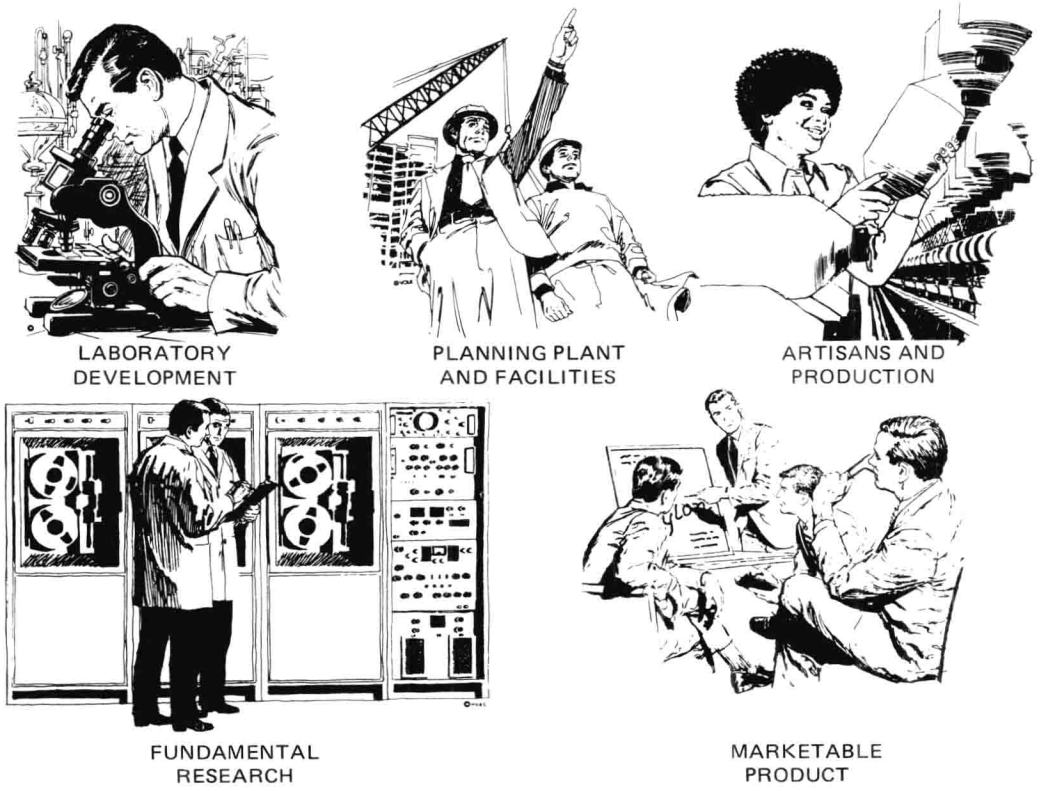

Fig. 1-1

For example, consider a single product such as a chemical weed destroyer. To produce this chemical, scientists, inventors, and technologists from many different branches of science, such as biochemistry, plant physiology, pathology, soil chemistry, and others, must work together. Such combinations of people are common and are needed to create, test, experiment, produce, and market the goods of the world. Continuous production is another example of how science is combined with experimentation and manufacturing capability.

■ BRANCHES OF SCIENCE

Communication, transportation, manufacturing — physical, chemical, and biological developments — all depend on science and the application of the scientific method.

Science is *organized knowledge* derived from the use of a systematic approach to a problem and the application of the scientific method. Physical science requires planning, experimentation, observation, analysis, and problem solving under controlled conditions. Scientific principles, laws, and philosophy are based on broad generalizations.

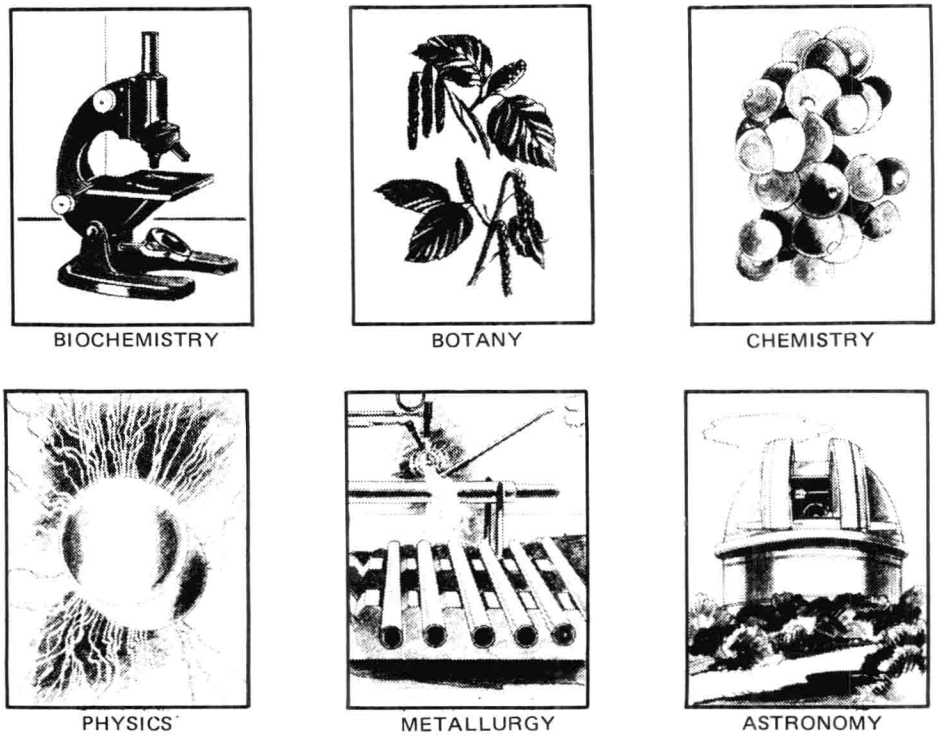

Fig. 1-2

Every generalization is subject to modification. Prior deductions must be continuously assessed in the light of new evidence. Thus, science is a living and evolving body of information.

Scientific knowledge is classified into specific groupings, figure 1-2. *Biology* or the *biological sciences* deal with life and living things. *Botany* is a branch of biology dealing with plant life. *Zoology* is a scientific study of animal life.

Scientific knowledge may also be grouped around nonliving things like the sun, moon, stars, and planets. Information about these celestial bodies belongs in the area of study called *astronomy*.

Chemistry deals with the changes that occur in the composition of matter. *Physics* is a study of matter. (Matter is anything that takes up space and has mass and energy. Energy is the ability to produce work.) *Metallurgy*, another branch of the physical sciences, deals with the study of the properties of metals, their grain structure, and the effects of adding metals to one another.

The student should be aware of the dependence on science of engineering and technological developments, the national economy and security, standards of living, and life itself. In particular, the science of physics is considered to be the basic science whose principles and concepts are drawn upon by many other fields of science.

THE SCIENTIFIC METHOD

The *scientific method* is a systematic procedure for discovering basic truths. There are five simple steps to the scientific method.

- Recognize the problem to be solved and the essential parts of the problem.
- State a set of hypotheses to solve the problem. *Hypotheses* are possible explanations or scientific conditions which are the cause of the observed results.
- Collect facts to test each possible explanation or hypothesis. These facts may be obtained by experimentation or any other method.
- Analyze and interpret the data (facts) to determine the correctness of each possible explanation (hypothesis).
- Test conclusions in enough new situations to be sure they are correct.

The scientific laws of physics, chemistry, biology, and the other sciences, which are widely used and accepted today, are the result of experimentation and tests based on the scientific method.

SYSTEMATIC APPROACH TO PROBLEM SOLVING

Scientific investigation requires that specific procedures be followed in an orderly manner. This practice enables the investigator to analyze a problem, to gain a perspective of the magnitude and conditions of the problem, to prevent errors, and to save time. Scientific problem solving also requires the systematic processing of data to a specified degree of accuracy. The solutions are stated in a significant number of figures. Alternate computational methods are used to recheck the solutions.

The following steps are recommended for the solution of physical science problems. In addition, these steps can be applied effectively to the solution of other practical occupational problems.

1. Read the statement of the problem carefully.
2. Determine the nature and degree of accuracy required in the solution. This step is necessary to avoid extra numerals in a computation.
3. Draw an appropriate diagram, listing the given data.
4. Determine and state the physical principles which appear to be relevant to the solution of the problem.
5. Determine if all of the required data are available. Identify the sources or methods that may be used to obtain missing data.
6. When using formulas, determine if the mathematical processes are to be carried out by first using symbols and, later, substituting numerical values, or if number values are to be used immediately.
7. Check the units for each quantity to be used in the problem to insure that all units are in the same system of measurement.