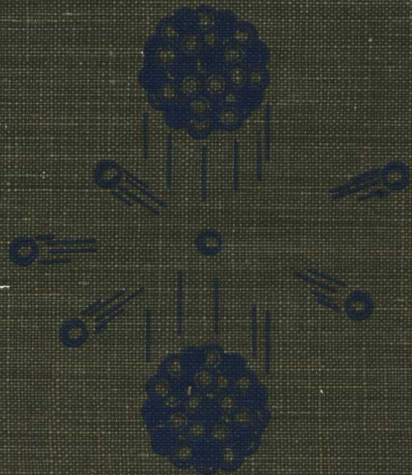
MODERN COLLEGE PHYSICS

HARVEY E. WHITE



MODERN COLLEGE PHYSICS

By

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Third Edition

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Preface to Third Edition

In this third edition, as in the second, the author has attempted to bring the subjects of atomic and nuclear physics up to date, and to make other changes or modifications in response to suggestions made by some of the many instructors and students using the book as a text. Such changes, for example, are to be found in the treatment of magnetism at the end of Chapter 51, in electromagnetism in Chapters 53 and 55, and in optics in Chapter 44.

Over two hundred new problems have been added to those already given in the second edition bringing the total to well over one thousand. In keeping with previous practices answers are given to all even-numbered problems.

The author wishes to thank the many teachers and students who have written him; their comments and criticisms have been most heartily welcomed.

Harvey E. White

Berkeley, California,
November, 1955.

Preface to Second Edition

In this edition the attempt has been made to improve the text without changing the general outline and scope of the contents of the first edition. The author has been guided principally by the suggestions of the many teachers and students who have used the book as a text; grateful acknowledgment is made here.

Of primary interest to many teachers will be the fact that completely new problems are given at the end of each chapter. The answers to the even-numbered problems only are included; these have been independently checked for accuracy.

Several of the eight chapters on electricity and magnetism have been rewritten, and two additional chapters have been added. These changes are in compliance with numerous requests for a considerable expansion of alternating-current theory and the use of the mks system of units in electricity and magnetism. To compensate for this expansion the three chapters on sources of light and their spectra have been condensed into one. It is sincerely hoped that teachers introducing the mks system for the first time will be as pleased with its success and simplicity as was the author when he tried it for the first time.

The location of the presentation of trigonometry in the treatment of vectors has been shifted from chapter three to chapter eight for the benefit of those students who begin their mathematics course in trigonometry at the same time they begin their physics course. Such students, as well as the others, will have time now to learn, or "brush up" on, the principles of the simplest trigonometry functions.

Perhaps the most difficult task confronting beginning students in college physics courses today is the acquisition of a clear understanding of the difference between weight and mass. Many articles have been written on this subject and there are "pros and cons" for one method or another. To the author it seems pedagogically sound that, because the pound is so commonly used as a unit of weight, and weight is a force, the concept of mass is new and the introduction of the slug as a unit of mass greatly simplifies the problem. This is the procedure that has been followed in this revision, and it is the author's opinion that a difficult subject has been made easier for the student and teacher alike.

Minor changes have been made in the chapters on friction, projectiles, and sound. The last chapters on cosmic rays, nuclear physics, and atomic energy have been brought up to date. I wish to express my sincere thanks to Mr. Herschel Snodgrass for his valuable criticisms of the new material, particularly the chapters on electricity and magnetism.

The frontispiece is used through the courtesy of *Scientific American* (color photograph by Union Carbide and Carbon Corporation).

HARVEY E. WHITE

Berkeley, California,
February, 1953.

Preface

This book is designed to be used as a text in the standard one-year college physics course required by most colleges and universities as part of the basic training of students planning to major in one of the physical or life sciences.

The main objective in preparing the manuscript was to bring together under one cover the elementary principles of *classical physics* as well as that branch of modern science called *atomic and nuclear physics*. Two ideas were followed: first, the confinement of all problems and mathematics to elementary algebra, plane geometry, and trigonometry; and second, the inclusion, wherever convenient, of illustrations from the biological and medical sciences as well as from engineering and physics. All too often physics texts present practically all illustrations from the field of engineering in spite of the fact that a relatively large proportion of students planning to major in one of the life sciences is enrolled in most introductory physics courses. As a consequence the pre-medical student, as a typical example, finds little to hold his interest. It appears to him that each new principle encountered and developed applies only to engineering when in reality most physical concepts have some direct application to some phase of medicine or medical research.

The increasing importance of electronics, as well as atomic and nuclear physics, through their application to other branches of knowledge, has given rise to a growing demand for the inclusion of these subjects in the introductory college physics course. Consequently, the last quarter of the book is devoted to an introductory treatment of these subjects. To alleviate the difficulty of having too much material to cover in a one-year course, there are two obvious alternatives. One is for the author to eliminate those subjects in classical physics which he considers of lesser importance, and the other is to retain the standard subjects and let each instructor make his own selections. The author has chosen the second alternative, because instructors differ widely in their ideas as to which subjects are most important and which are not. To this end the book is divided into many chapters, making it possible to eliminate a subject by skipping an entire chapter.

The author wishes to take this opportunity of thanking his colleagues Messrs. L. Alvarez, R. T. Birge, R. B. Brode, D. Cooksey, F. A. Jenkins, E. O. Lawrence, V. F. Lenzen, L. B. Loeb, E. M. MacMillan, J. R. Oppenheimer, G. T. Seaborg, L. L. Skolil, and C. D. Shane, for their valuable criticisms of various portions of the manuscript.

My sincere thanks are also extended to Mr. J. G. Brohl to whom I am indebted for the drawing of many of the diagrams, and to Mrs. R. C. Archibald, Mrs. Caroline Lanham, Mrs. Bay Muldoon and Miss Rebekah Young, for the typing of the manuscript. I also wish to thank the various publishers and commercial laboratories for their permission to reproduce certain illustrations used in the book.

HARVEY E. WHITE

Berkeley, California,
July, 1947.

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IN the early dawn on the morning of July 16, 1945, there occurred in a remote spot on the desert sands of Almagordo, New Mexico, a man-made explosion of enormous magnitude. This, the explosion of the first atomic bomb, marked the culmination of a five-year coordinated research program the size of which in terms of manpower and material is best expressed by its total cost to the United States government of approximately two billion dollars. With the ending of World War II and the subsequent dissemination of many of the scientific and technical developments made during that war the civilized world awakened to the realization that we stand today on the threshold of a scientific era. This is the beginning of an era in which the wonders of television, radar, electronics, atomic energy, jet propulsion and rocket ships will become a commonplace reality.

In all of these developments in the physical sciences, as well as many others in the field of medicine and the life sciences in general, the subject we call physics has played a most important role. So important is this role that many authorities in other fields of knowledge and endeavor consider physics to be the most basic of all the sciences. Certainly a knowledge of the fundamental principles of physics is today an essential part of the education of all who desire to become proficient in the physical and medical professions.

One of the reasons physics is called an exact science is that reproducible experiments are performed and observations are made with high precision measuring instruments. Laws and theories are formulated from the measured results of these experiments and then used to predict the results of new experiments. If these new experimental results do not agree with theory, the theory is either modified and brought into agreement or it is discarded for a new and better theory. Physics may be defined as that branch of knowledge treating the inanimate world and its phenomena and includes the subjects of *mechanics, properties of matter, heat, sound, light, electricity and magnetism, atomic and nuclear structure.*

1.1. Physics as an Objective Method. It has long been known that when experiments are to be performed one cannot rely too much upon the human senses of touch, sight, hearing, etc., to make accurate observations. Methods of measurement which rely upon the senses entirely are called *subjective methods.* Methods which make use of scientific instruments are generally called *objective methods.*

In the early history of science laws were frequently discovered by the use of subjective methods. Progress was slow, however, until such methods were replaced by objective methods using measuring instruments devised to give greater and greater precision.

It is true that many scientific discoveries have been made in the past with what we now would call the crudest of apparatus and equipment. It is the development of precision instruments and apparatus, however, which has, particularly within the last several decades, led to discoveries which are far-reaching in their theoretical implications and are of extreme practical importance to the advancement of civilization.

As an introduction to the subject of physics we will first consider a number of experiments illustrating the false impressions so easily arrived at from the use of subjective methods of observation. Although these experiments are of the nature of an entertainment, they do have more serious aspects, for they demonstrate the necessity for using objective methods in advancing science.

1.2. Subjective Methods. If someone asks you to determine the temperature of a pan of water, your first impulse, if the water is not too hot, is to use your hand or your finger-tips and not to bother looking for a thermometer. To illustrate the gross inaccuracy of the touch in determining temperature, consider the three pans of water as shown in Fig. 1A. If the hand is first held for some little time in the pan containing *cold* water and then plunged into the *warm* water, the senses tell you it is hot. If, however, the hand is first held in the *hot* water and then plunged into the *warm* water, your senses tell you it is cold. Your conclusion in either case is thus influenced by your experiences immediately preceding your determination of the temperature of the middle pan. When a thermometer is used in this experiment the same temperature will be arrived at in either case. Although this latter would be called an objective method of measurement one still relies upon the senses to obtain a reading of the thermometer scale.

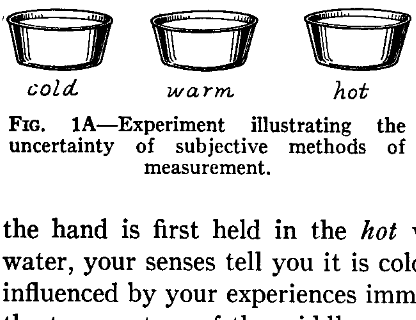

FIG. 1A—Experiment illustrating the uncertainty of subjective methods of measurement.

If the length and breadth of a table top are to be measured, a *foot rule,* a *yardstick,* or a *meter stick* should be used and not the *span of a hand.* In a similar way the time that it takes a sprinter to run the *"one-hundred yard dash"* is measured by a *clock,* a *watch,* or a *chronometer* and not by the *heart beat* or *pulse.*

1.3. The Eye. In making many scientific measurements the eye is considered as the most useful of all recording instruments. In some instances, however, the eye is not and should not be used directly in making observations, since it cannot be relied upon to observe what is really there. To illustrate how unreliable the sense of vision can be in some cases we will consider in the next section a number of examples commonly referred to as "optical illusions."

Despite its many and sometimes serious imperfections and limitations the human eye is a marvelous optical instrument. It is nature's priceless gift to man enabling him to enjoy the beauties of form, color, and motion made

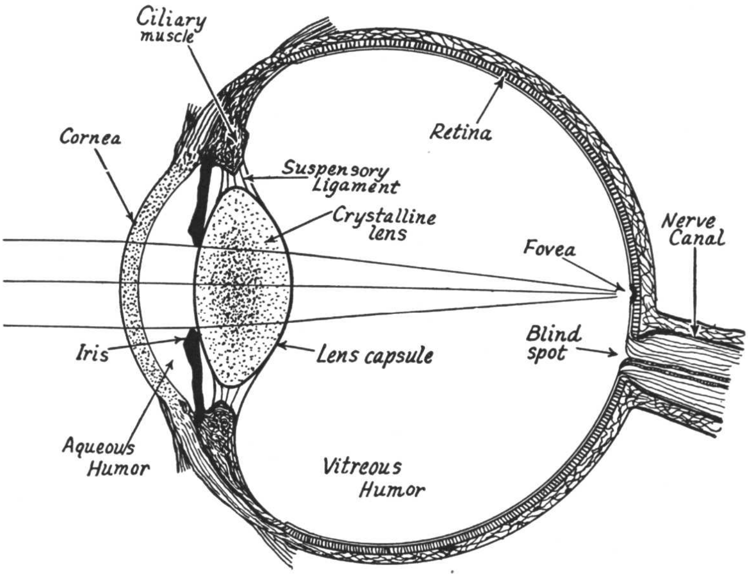

FIG. 1B—Cross-section diagram of the human eye.

possible by light. Optically the eye is like an exceptionally fine camera with an elaborate lens system on the one side and a sensitive screen or photographic film, called the *retina,* on the other. See Fig. 1B. The refracting media of the eye consists of the *cornea,* the *aqueous humor,* the *crystalline lens,* and *vitreous humor,* and its function is to focus an image of the objects to be seen on the retina. Like a camera, the eye contains an *iris diaphragm* which opens wider for faint light and closes down to a bare pinhole opening for very bright sunlight. It is this iris that contains the pigment determining the color of the eye.

In the retina of the eye the light pulses are received by tiny *cones* and *rods* whose function it seems to be to change the light into electricity. Each cone and rod is connected with an individual nerve which conducts the electricity through the nerve canal to the brain. Just how these electrical impulses are produced by the cell-like structures, the cones and rods, and how they are interpreted by the brain as vision is still but vaguely understood by scientists. Experiments seem to indicate that the cones respond only to bright light and are particularly responsible for the detection and distinction of color whereas the rods are sensitive to very feeble light, to motion, and to slight variations in intensity.

At the very center of the retina is a small yellowish-looking spot called the *fovea*. This small region contains a large number of cones, but no rods. It is on this spot in each eye that the words and letters of this page are focused one after the other when reading. Note when scrutinizing one word or particularly a single letter in a word that the rest of the page and even the words and letters close by appear indistinct.

It is customary to divide all sensory data, that contribute to sight perception of any object, into two parts; first, the formation of the retinal image by the light coming from the object, and second, the integrative property of the brain to interpret this image.

1.4. The Blind Spot. Not far from the fovea on the retina of the eye is a small region called the *blind spot*. This spot, which is insensitive to light, is where the nerve canal joins the eyeball. The existence of the blind spot can be demonstrated by closing the right eye, and holding the book at arm's length, looking continuously at the center of the circle of Fig. 1C with the left eye. Both the circle and square will be seen from this distance. If the

FIG. 1C—Experiment illustrating the blind spot of the eye.

book is now moved slowly toward the eye, still fixing the eye upon the circle, a position (about 8 to 10 inches from the eye) will be reached where the square disappears. When both eyes are open no position will be found where either the cross or the square disappears. One eye always sees that part of an object to which the other eye is blind. A similar experiment with the right eye focused on the square will cause the circle to disappear. A further discussion of the human eye and how it functions as an optical instrument is given in Chap. 44.

1.5. Optical Illusions. Of the hundreds of well known optical illusions only a few of the most interesting ones will be presented here. In Fig. 1D is a group of six figures classified as illusions due to *lines* and *angles*. In (a),

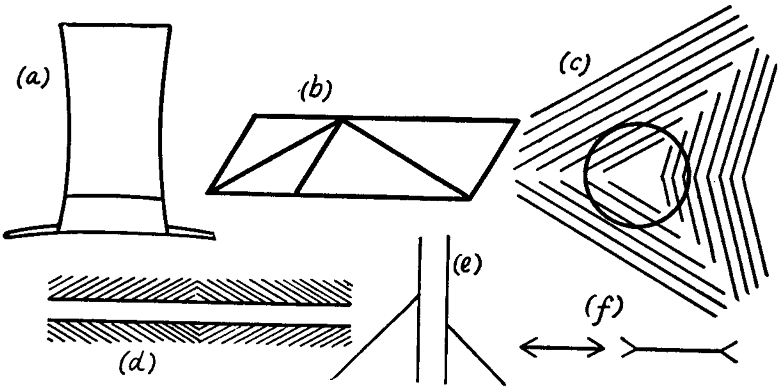

FIG. 1D—Optical illustrations with lines and angles.

the first figure, the brim of the hat is as long as the hat is high; in (b) the diagonal lines of each parallelogram are of the same length; and in (c) the perfect circle appears to be distorted. In figure (d) the two horizontal lines are parallel and straight and in (f) they are of equal length. In (e) the lower right-hand line if extended will intersect the left-hand line where it joins the vertical.

Fig. 1E is an example of *perspective,* an illusion suggesting depth to the picture when in reality it is flat. Actually this figure is a rectangle enclosing three pillars of equal height. By means of slanting lines these pillars are made to appear to have different heights. Experiences from early childhood have trained us to interpret the slanting lines as depth.

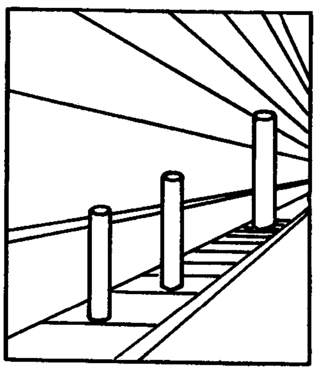

FIG. 1E—Optical illustration in perspective.

The next set of illusions, shown in Fig. 1F, are classified as *equivocal figures.* These illustrate the phenomenon of the *fluctuation* of the process of vision. In figure (a) six cubes may be seen stacked three, two, one, or seven cubes may be seen stacked two, three, two. In (b) a folded sheet of paper is seen opening either toward or away from the reader. In (c) is a flight of steps seen from above looking down, or from below looking up.

Fig. 1F(d) is one of the most interesting of all illusions. To fully appreciate the effect one must himself perform the experiment with a small wire cube about one inch in size. The cube is held by a small handle at one corner and viewed with one eye at a distance of from 1 to 2 ft. By the principle of fluctuation the observer next tries to make the farthest corner of the cube appear as the nearest corner. When this condition is attained the cube upon being turned about a horizontal or vertical axis will appear to turn in the opposite direction. A little practice in the fluctuation of the visual senses is required in this experiment and it is well worth performing.

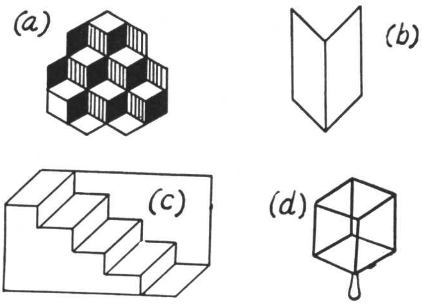

Fig. 1F—Optical illusions illustrating fluctuation of the attention.

In Fig. 1G are two pairs of similar figures of equal area. The slanting lines at the ends make the lower figure in each case appear to be larger than the one immediately above. Such figures should be cut from white cardboard and held one above the other. When the upper figure is interchanged with the corresponding lower figure, one figure seems to grow and the other to shrink before your eyes.

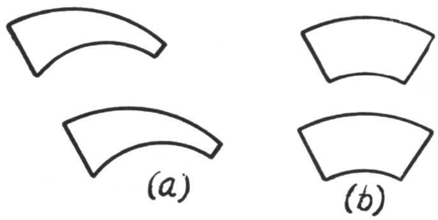

Fig. 1G—Optical illusions of area.

In Fig. 1H(a) are two small squares of equal size, a white square on a black background, and a black square on a white background. When an image of this is formed on the retina of the eye the cones and rods just beyond the white edges are stimulated by those nearby, thus causing the white

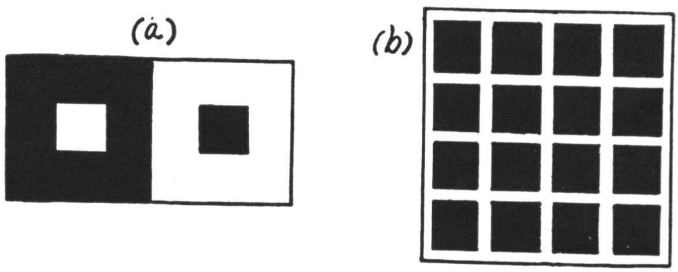

Fig. 1H—Light and dark objects illustrating the phenomenon of irradiation.

square to be larger than the black one. This phenomenon is called *irradiation* or *brightness contrast.* A similar phenomenon is illustrated in Fig. 1H(b) where grey spots are seen at the intersections of the white lines.

1.6. Fatigue and Color Illusions. All of the illusions above have been confined to figures in black and white. There exists a large number of illusions which are classified as *color illusions.* Two of these are diagrammed in Fig. 1I. A disk painted black and white as shown in (a) will appear to be colored when set rotating at a relatively low speed. The colors to be seen are rather faint pastel shades of violet, blue, green, yellow, and pink. The speed of the wheel should be from about 4 to 15 revolutions per second. The explanation usually given for the phenomenon is that the retina of the eye responds more quickly to some colors than to others. Since the white image of the disk moves around on the retina and since white light contains all the colors of the rainbow, some colors are perceived at each given spot on the retina sooner than others and the effect of color is produced.

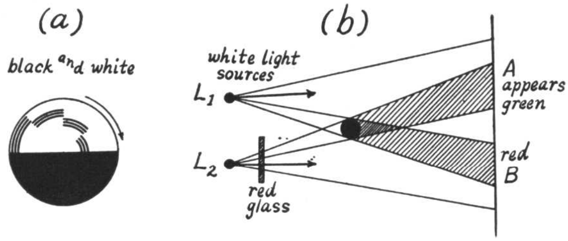

FIG. 1I—Diagrams of experiments demonstrating color illusions.

The second diagram (b) in Fig. 1I illustrates the appearance of color by virtue of contrast. If a white patch of light, for example, is seen on a background of red it will appear to be pale green. If, on the other hand, a white patch is seen on a background of green it will appear to be pink. The experiment may be performed with two similar arc lights producing white light. Each of these is made to cast a shadow of the same rod R on a white screen. If a piece of red glass is placed in front of Light L_2 as shown in the figure, the white patch of light at A will appear to be pale green. If a green glass is inserted in its place the region A will appear pink. In each case, A receives light from L_1 only and must therefore be really white. Red and green of the proper shades are complementary colors and when they are added together produce white light. The subject of the mixing of colors will be taken up in detail in Chap. 45.

1.7. Complementary Images. When the eyes are subjected to bright light for some little time the retina seems to show tiring or *fatigue.* Further-