MODERN COLLEGE PHYSICS

FOURTH EDITION

HARVEY E. WHITE

D. VAN NOSTRAND COMPANY, INC.

MODERN COLLEGE PHYSICS

HARVEY E. WHITE, Ph.D., Sc.D.

Professor of Physics and
Director of the Lawrence Hall of Science
University of California

FOURTH EDITION

D. VAN NOSTRAND COMPANY, INC.
PRINCETON, NEW JERSEY
TORONTO · LONDON · NEW YORK

To my son
DON

D. VAN NOSTRAND COMPANY, INC.
120 Alexander St., Princeton, New Jersey (*Principal office*)
24 West 40 Street, New York 18, New York

D. VAN NOSTRAND COMPANY, LTD.
358, Kensington High Street, London, W.14, England

D. VAN NOSTRAND COMPANY (Canada), LTD.
25 Hollinger Road, Toronto 16, Canada

Published simultaneously in Canada by
D. VAN NOSTRAND COMPANY (Canada), LTD.

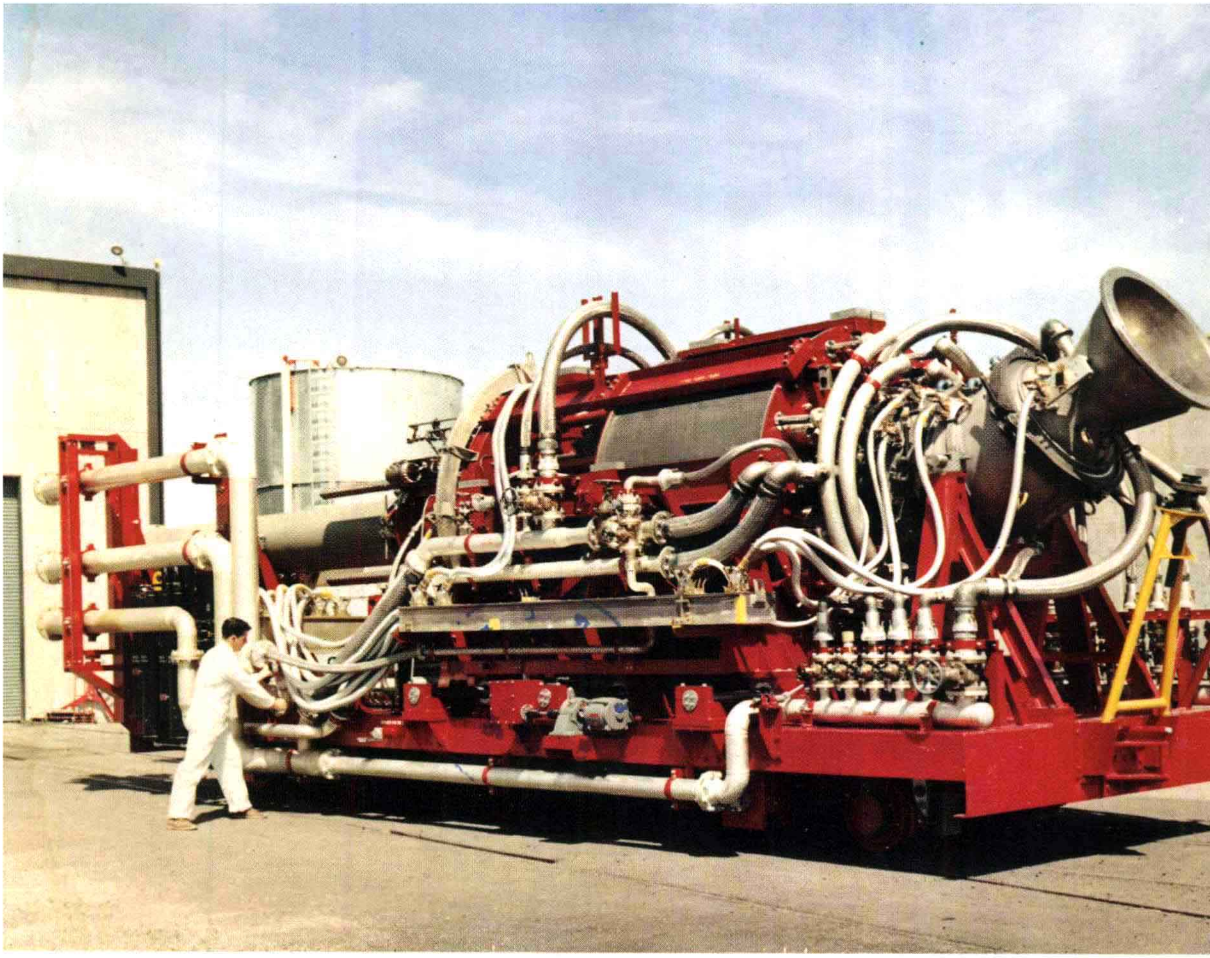
First Published February 1948
Second Edition March 1953
Third Edition January 1956
Fourth Edition May 1962
Reprinted October 1962

PRINTED IN THE UNITED STATES OF AMERICA

Modern

College

Physics



Nuclear Ramjet Engine "TORY II A," developed under Project Pluto by the University of California's Lawrence Radiation Laboratory. This is an experimental nuclear reactor designed for the propulsion of aircraft at supersonic speeds, and is under study by the U.S. Airforce at the Atomic Energy Commission's test site near Las Vegas, Nevada.

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 who plan to major in one of the physical or life sciences.

Originally published in 1947, the book has been revised twice prior to this, its 4th edition. Here, for the first time, a double-column text page is used and accents of red color appear in most of the line diagrams to clarify the basic principles illustrated.

The main objective in originally preparing the manuscript was to unite under one cover the elementary principles of classical physics and that branch of modern science called atomic and nuclear physics. The ever-increasing importance of satellites and space ships, of electronics, atomic structure, and nuclear physics has led to the extensive revision of many chapters and to the addition of new ones. Included in the new material are discussions of the basic principles of planetary motion, gravitational fields, space flight, Einstein's theory of relativity, and elementary atomic particles.

The mathematics of this text is confined to elementary algebra, plane geometry, and trigonometry. Although the cgs and English system of units are often used in sample calculations, the mks system is emphasized throughout the book.

Even though a large number of students who plan to major in one of the life sciences are enrolled in physics courses, the illustrations in many physics texts are almost entirely selected from the fields of engineering. It is for this reason that the author has introduced, wherever it has been convenient, illustrations of basic principles of physics from the biological and medical sciences as well as engineering.

Since instructors differ widely in their decisions as to which subjects to include or to emphasize in an introductory physics course, the book has been divided into many chapters, thus making it possible to eliminate a subject by omitting an entire chapter.

The answers to even-numbered problems have been determined and checked by the author. Yet whenever a human being is involved mistakes can be made and a recorded answer may be in error. The author would, therefore, greatly appreciate his being notified of any errors, as they can be corrected in succeeding printings of this edition.

The author wishes to thank his colleagues, Messrs. L. Alvarez, R. T. Birge,

R. B. Brode, R. R. Brown, O. Chamberlain, D. Cooksey, W. B. Fretter, E. W. Friesen, V. F. Lenzen, L. B. Loeb, E. M. McMillan, W. M. Powell, G. T. Seaborg, E. Segre, C. D. Shane, H. Shugart, L. L. Skolil, H. Snodgrass, and E. Teller, for their valuable contributions to this text through discussions with the author of various special subjects. The author also wishes to thank the many teachers and students whose written comments have been most helpful throughout the years, and also the various publishers and research laboratories whose permission to reproduce certain illustrations has been so kindly granted.

Sincere thanks are also extended to my wife for the proofreading of the entire book, and to Mrs. Polly Thomas for the typing of all the new material.

Berkeley, California HARVEY E. WHITE
March, 1962

Contents

SOUND

LIGHT

ELECTRICITY AND MAGNETISM

ATOMIC PHYSICS

NUCLEAR PHYSICS

Chapter 1

Optical Illusions

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 are already 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	**Electricity**
Properties of matter	**Magnetism**
Heat	**Atomic physics**
Sound	**Nuclear physics**
Light	**Quantum theory**

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 that rely upon the senses entirely are called *subjective methods.* Methods that 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, that has led, particularly within the last several decades, to discoveries that 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

Fig. 1A *Experiment illustrating the uncertainty of subjective methods of measurement.*

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 indicated 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.

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 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.

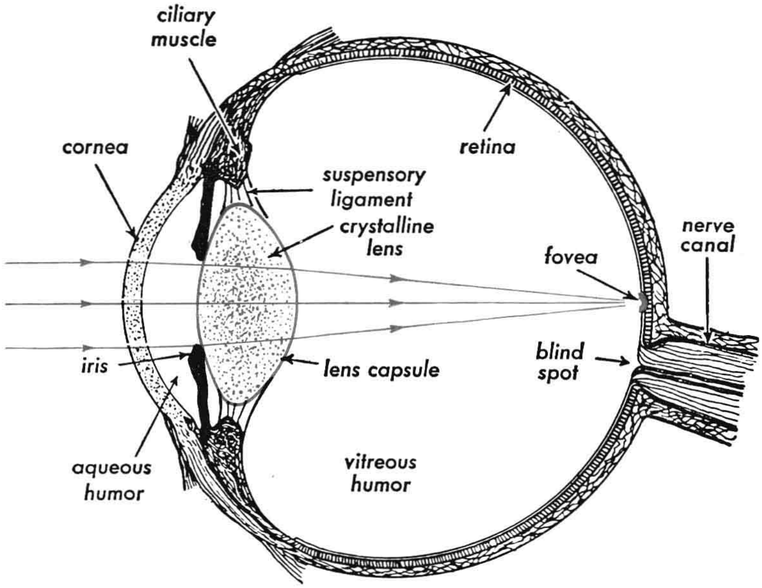


Fig. 1B *Cross-section diagram of the human eye.*

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 into two parts all sensory data that contribute to sight perception of any object: 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 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. 41.

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), 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

Fig. 1C *Experiment illustrating the blind spot of the eye.*

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 building showing three figures of equal height. By means of slanting lines these figures are made to appear to have different heights. Experiences from early childhood have trained us to interpret the slanting lines as depth.

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 3, 2, 1; or seven cubes may be seen stacked 2, 3, 2. 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 appreciate the effect fully, one must himself perform the experiment

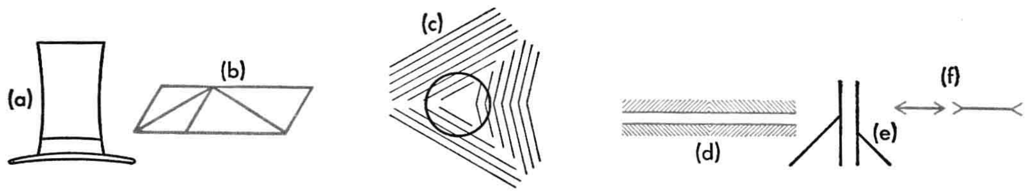


Fig. 1D *Optical illusions with lines and angles.*

Fig. 1E *Which figure is tallest? Measure them.*

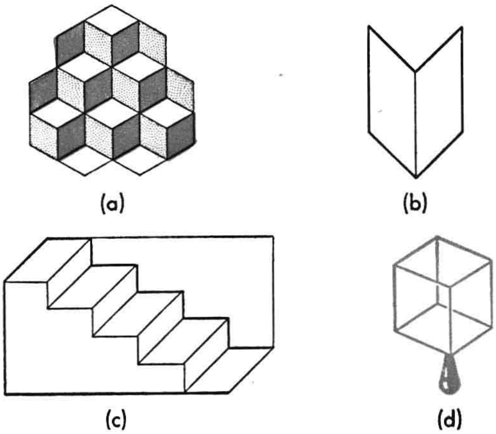


Fig. 1F *Optical illusions illustrating fluctuation of the attention.*

with a small wire cube about 1 in. 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.

In Fig. 1G are two pairs of similar figures

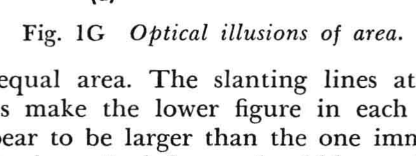


Fig. 1G *Optical illusions of area.*

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.

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 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 gray spots are seen at the intersections of the white lines.

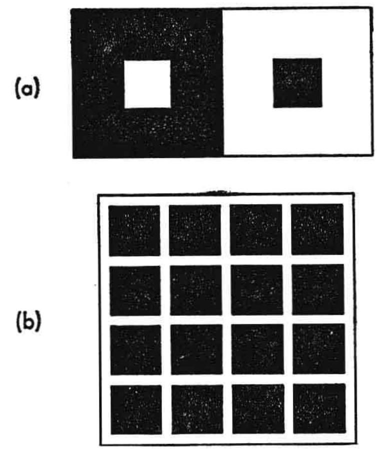


Fig. 1H *Illustrations of irradiation.*

1.6. Fatigue and Color Illusions. There exists a large number of illusions that are classified as *color illusions*. Two of these are diagramed 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 sec. 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.

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. 42.

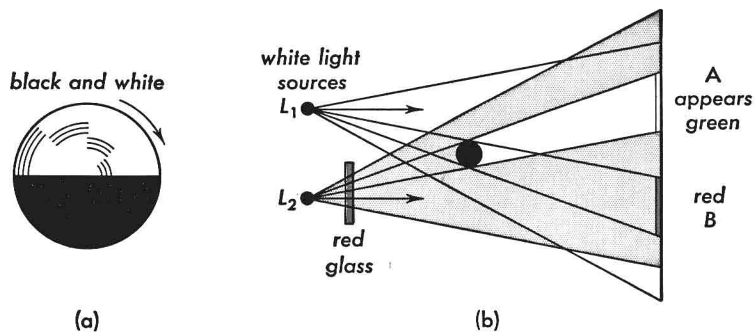


Fig. 1I *Diagrams of experiments demonstrating color illusions.*

1.7. Complementary Images. When the eyes are subjected to bright light for some little time, the retina seems to show tiring or *fatigue*. Furthermore, continued subjection of any part of the retina to one particular color causes only those cones sensitive to that color to tire. When the same retinal area is subsequently subjected to white light, the previously inactive cones respond more strongly than those originally stimulated and a complementary color is seen.

To observe these colored images, fix the attention on the black star in the lower right-hand corner of the field of the flag in Fig. 1J and keep it there for about 15 to 20 sec. Then turn the eyes toward a white wall of the room, or toward the open sky, and in one or two seconds the American flag will appear in all of its true colors. Similar effects can be observed with other color photographs.

Delayed images of this kind are always complementary in color to the original pictures, black becomes white, yellow becomes blue, green becomes magenta, magenta becomes green, etc. (For an explanation of complementary colors, see Chap. 42.)

1.8. The Stroboscopic Effect. In moving pictures, when a wagon with spoked wheels is coming to a stop, the wheels are often noticed to stand still, then turn backward, stop, turn forward, and then stop again. This phenomenon, known as the "stroboscopic effect," is due to interrupted illumination of the moving-picture screen and can be illustrated in many ways. An interesting experiment illustrating the phenomenon is shown in Fig. 1K. Two disks are mounted on the shafts of two separate motors. The smaller disk A with a narrow slot is used to interrupt the light beam illuminating the larger disk. The disk B is white with black circles and dots arranged exactly as shown. Suppose now that disk A makes 16 revolutions per second, thus illuminating disk B with 16 short flashes of light per second. Suppose also that B makes only one revolution per second, and that one flash of light comes when the disk has the position shown in the figure.

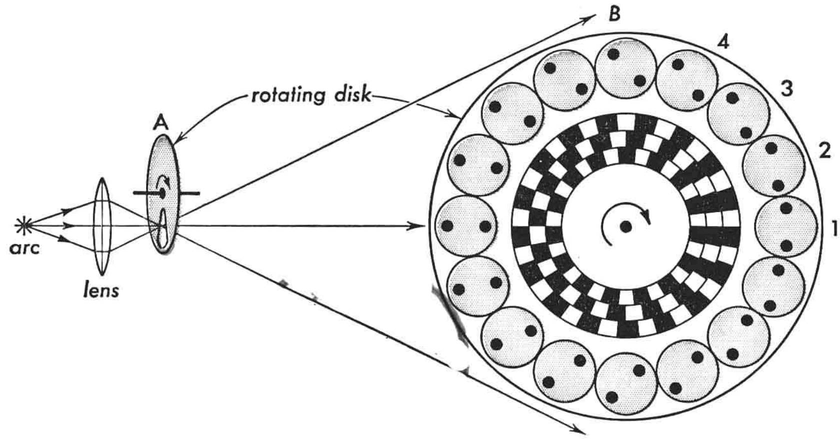


Fig. 1K *Experimental arrangement for demonstrating the stroboscopic effect.*

If the attention is confined to the circle at position (1), the two enclosed dots are one above the other. When the second flash of light appears, the circle (2) will be in position (1) and the two dots will appear to have shifted slightly clockwise. When the next flash of light comes, the circle (3) will be in position (1) and the two dots will have shifted still farther. This process continued shows that the circles will appear to stand still and the dots to rotate within them.

If the light flashes in any such experiment as the one described above are slower than 16 per sec, the illuminated object will appear to flicker badly. If, however, the flashes come at an increasingly higher rate, the flicker will soon disappear entirely and the illumination will seem to be steady. The reason for this is that each retinal image is somehow retained by the vision mechanism for about $\frac{1}{16}$ of a second. This is called the *persistence of vision*.

1.9. Circles and Spirals. If this page of the book is held about 1 ft in front of the observer's eyes and the book moved rapidly in a circle about 2 to 3 in. in diameter, the spiral in Fig. 1L will appear to rotate in the direction of motion. A set of alternately dark and light concentric circles will show the same effect, the apparent rotation being due to the persistence of vision.

We have seen in the previous illustrations how some optical illusions break down or diminish under critical inspection. There are others, however, that persist. No amount of staring or thought will teach you to see the circles of Fig. 1M as anything other than spirals.

Fig. 1L *Illusion of rotation.*

1.10. The Trapezoidal Window. One of the most striking optical illusions in perspective is that of a slowly rotating window having the design shown in Fig. 1N. This device is cut from a single sheet of $\frac{1}{4}$-inch plywood, painted white, grey, and black on

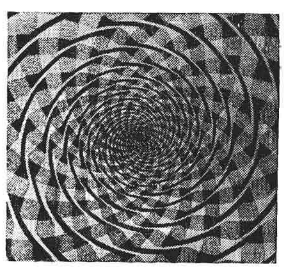


Fig. 1M *Circles appear to be spirals.*