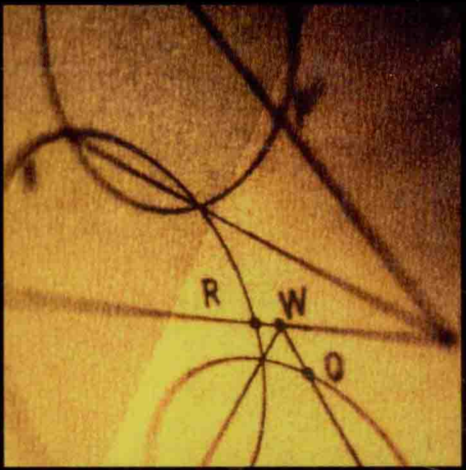
GEOMETRICAL and VISUAL OPTICS

a clinical introduction



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A Clinical Introduction

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Preface

The goal of this book is to demystify geometrical and visual optics. It is intended to be a concise and learner-friendly resource for clinicians as they study optics for the first time and subsequently prepare for licensing and qualifying examinations. The emphasis is on those optical concepts and problem-solving skills that underlie contemporary clinical eye care and refraction.

The book stresses a vergence approach to geometrical and visual optics. Schematic figures and clinical examples are used throughout the text to engage reader interest. Every effort is made to provide the reader with an intuitive and clinical sense of optics that will allow him or her to effectively care for patients.

To develop competence and facility in geometrical and visual optics, it is necessary to solve problems. Each chapter provides problems of varying complexity, with worked-out solutions given at the end of the book. The reader should make every attempt to solve the problems before resorting to the solutions.

Despite careful review and editing, mathematical errors are bound to occur in a text of this nature. Please send any corrections or comments to the author at <*opticsbook@aol.com*>.

This book grew out of my experiences as an educator and practitioner. Over the years, I have been afforded the opportunity to work with talented colleagues, teach motivated students, and provide care to a diverse spectrum of patients. My colleagues, students, and patients all, in their own ways, motivated this book and for this I am most thankful.

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GEOMETRICAL AND VISUAL OPTICS

Contents

1

Basic Terms and Concepts

At any given moment, our eyes are inundated by an enormous quantity of electromagnetic radiation. This radiation ranges from short-wavelength gamma and x-ray radiation to longer-wavelength radar and radio waves. *Light* is the portion of the electromagnetic spectrum that is visible (Fig. 1-1).

Electromagnetic radiation is typically specified by its wavelength or frequency. Wavelength and frequency are inversely proportional and related to each other as shown by the following equation:

$$\nu = c/\lambda$$

where

ν = the frequency of light
c = the speed of light
λ = the wavelength of light

The wavelength of light ranges from about 380 to 700 nanometers (nm).[1] It is emitted in discrete packages of energy referred to as *photons* or *quanta.* The amount of energy in a photon is given by the following relationship:

$$E = h\nu$$

where

E = the amount of energy per photon
h = Planck's constant

[1]One nanometer (nm) is equal to 10^{-9} meters (m).

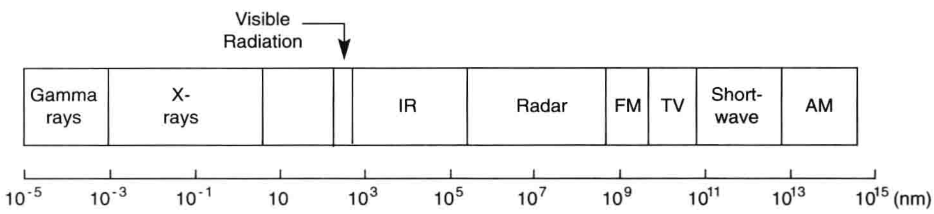

FIGURE 1-1. Light (visible radiation) is a small portion of the electromagnetic spectrum. (*From Schwartz SH.* Visual Perception: A Clinical Orientation. *Copyright 1999.Reprinted by permission of McGraw-Hill, Inc.)*

By substitution, we have:

$$E = \frac{hc}{\lambda}$$

As the wavelength decreases, the amount of energy per photon increases. For this reason, the absorption of short-wavelength radiation by body tissues is typically more damaging than the absorption of longer-wavelength radiation. The development of cataracts and basal cell carcinoma is promoted by exposure to short-wavelength, high-energy ultraviolet radiation.

OBJECTS, LIGHT RAYS, AND PENCILS

We see *objects* because they emit or reflect light, and this light is focused on our retina. A *point source* of light, such as a star, emits waves of light in much the same way that a pebble dropped into a quiet pond of water generates waves of water (Fig. 1-2). Light *rays* are perpendicular to light wavefronts and are represented by arrows.

A bundle of rays is called a *pencil* (Fig. 1-3). The light rays that form a pencil can be diverging, converging, or parallel. A *diverging pencil* is produced by a point source of light, such as a star. When light rays are focused at a point, they create a *converging pencil.* A converging optical system (e.g., a magnifying lens) is required to create converging light. An object located infinitely far away forms a *parallel pencil.*[2]

An *extended object,* such as an arrow, is composed of an infinite number of point sources (Fig. 1-4). Diverging light rays emerge from the point sources.

[2]Consider the waves that are created when a pebble is dropped into a quiet pond of water (Fig. 1-2). The wavefronts closest to the source (the pebble) are more curved than the wavefronts further from the source. At very far distances, the wavefronts are flat. Since rays are perpendicular to wavefronts, the rays are parallel to each other.

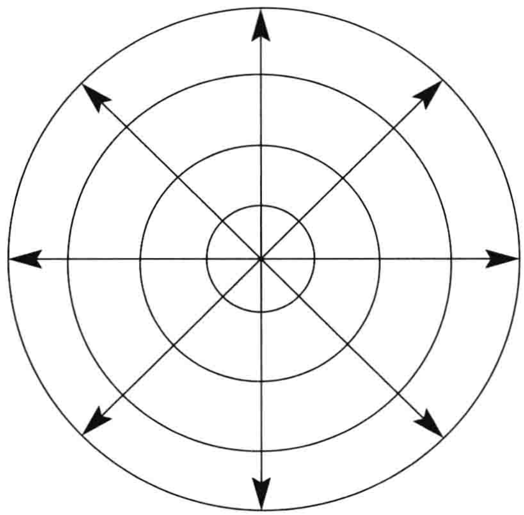

FIGURE 1-2. A point source of light emits concentric waves of light in much the same way a pebble dropped into a quiet pond of water produces waves of water. Light rays, represented by arrows, are orthogonal to the wavefronts.

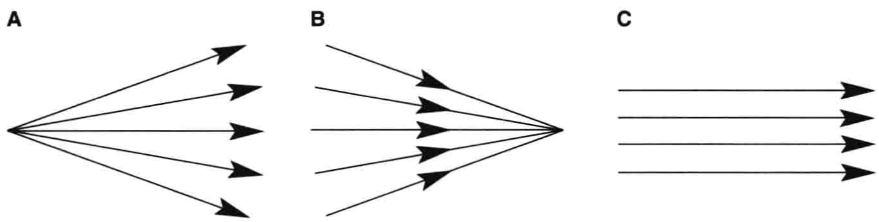

FIGURE 1-3A. A diverging pencil of light rays emerges from a point source. **B.** A converging pencil of light rays is focused at a point. **C.** An object located at infinity produces a parallel pencil of light rays.

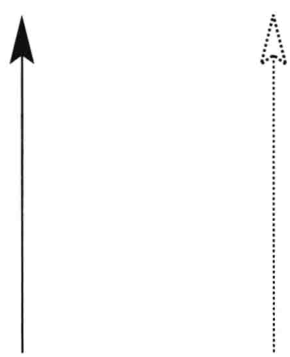

FIGURE 1-4. An extended object, such as an arrow, may be considered to consist of an infinite number of point sources. Each point emits diverging light rays.

VERGENCE

For solving clinical optical problems, it is useful to quantify the convergence or divergence of light. **The amount of convergence or divergence of light rays (i.e., the *vergence* of the light) is (1) the reciprocal of the distance to a point source or (2) the reciprocal of the distance to a point of focus. To arrive at the correct units for vergence—*diopters (D)*—the distance must be in meters. By convention, diverging light is always labeled with a negative sign and converging light with a positive sign.**

Consider Figure 1-5, which shows diverging light rays. At a distance of 10.00 cm from the point source, the vergence is – 10.00 diopters, or – 10.00 D.[3] At distances of 20.00 and 50.00 cm, the vergence is –5.00 and –2.00 D, respectively. The further the distance from the point source, the less the (absolute) magnitude of the divergence.[4]

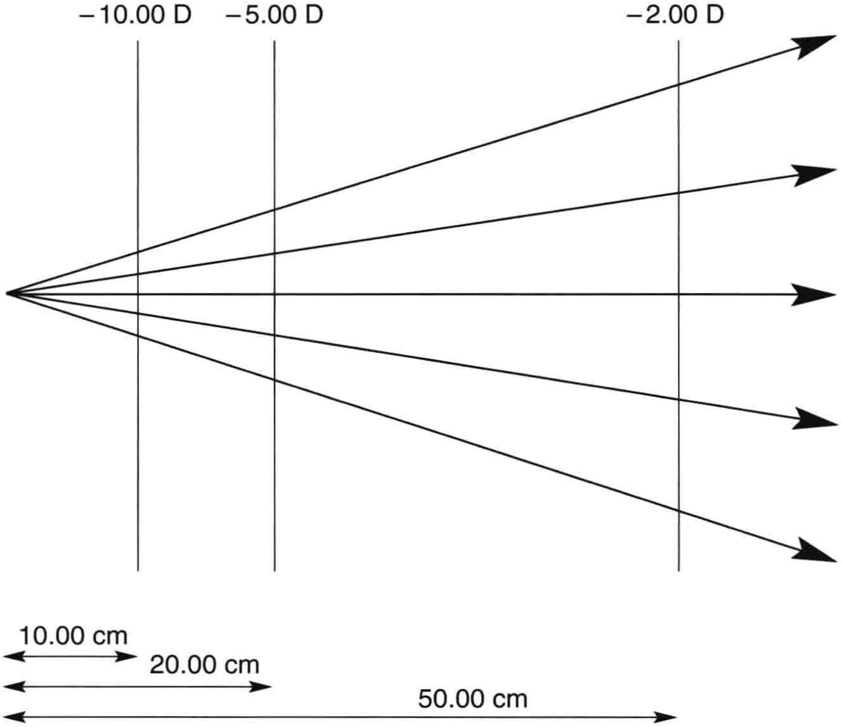

FIGURE 1-5. Diverging light rays have negative vergence. The absolute magnitude of the divergence *decreases* as the distance from the object *increases*.

[3]The reciprocal of 0.10 is 10.00.

[4]Returning to Figure 1-2, the wavefronts that are closer to the source are more curved than those further from the source. You can think of the curvature of a wavefront as a measure of vergence—the more curved the wavefront, the greater the vergence. In the extreme case—at an infinite distance from the source—the wavefront is flat (the rays are parallel), and the vergence is zero.

In Figure 1-6, converging light rays are focused at a point. With respect to this point of focus, the vergence at 50.00 cm is +2.00 D. Likewise, at distances of 20.00 and 10.00 cm, the vergence is +5.00 and +10.00 D, respectively. As the distance from the point of focus increases, the magnitude of the convergence decreases.

What is the vergence of parallel light rays? These rays originate from an object at optical infinity; the reciprocal of infinity is zero.[5] Or think of it this way: since the rays are neither diverging nor converging, their vergence is zero.

REFRACTION

When light travels from one transparent material (e.g., air) to a more optically dense transparent material (e.g., water), its velocity decreases. This decrease in velocity can cause light rays to deviate from their original direction, a phenomenon referred to as *refraction.* In Figure 1-7A, a light ray traveling through air

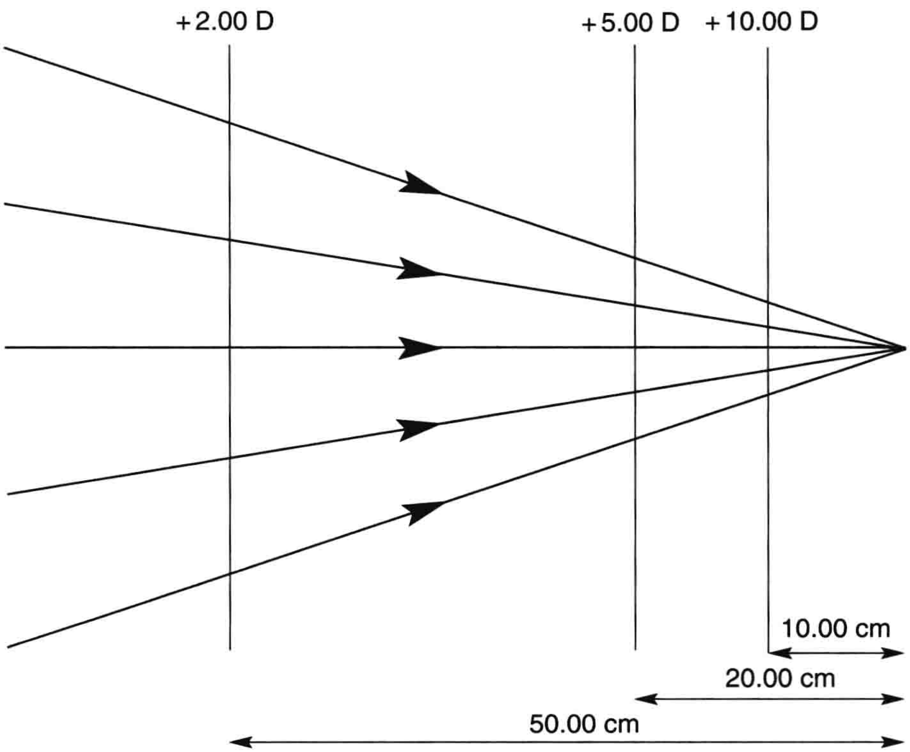

FIGURE 1-6. Converging light rays have positive vergence. As the distance from the point of focus *increases*, the absolute magnitude of the convergence *decreases.*

[5]In clinical practice, optical infinity is typically a distance of 20 ft (or 6 m).