PART THREE

Optics and Sound

OPTICS

chapter fifteen

Introduction

IF you wear spectacles you will appreciate particularly that the science of Light, or *Optics* as it is often called, has benefited people all over the world. The illumination engineer has developed the branch of Light dealing with light energy, and has shown how to obtain suitable lighting conditions in the home and the factory, which is an important factor in maintaining our health. Microscopes, used by medical research workers in their fight against disease; telescopes, used by seamen and astronomers; and a variety of optical instruments which incorporate lenses, mirrors, or glass prisms, such as cameras, driving mirrors, and binoculars, all testify to the scientist's service to the community.

In mentioning the technical achievements in Light, however, it must not be forgotten that the science of Light evolved gradually over the past centuries; and that the technical advances were developed from the experiments and theory on the *fundamental* principles of the subject made by scientists such as NEWTON, HUYGENS, and FRESNEL.

Light Travels in Straight Lines. Eclipses and Shadows

When sunlight is streaming through an open window into a room, observation shows that the edges of the beam of light, where the shadow begins, are straight. This suggests that *light travels in straight lines*, and on this assumption the sharpness of shadows and the formation of eclipses can be explained. Fig. 15.1 (i) illustrates the eclipse of the sun, S,

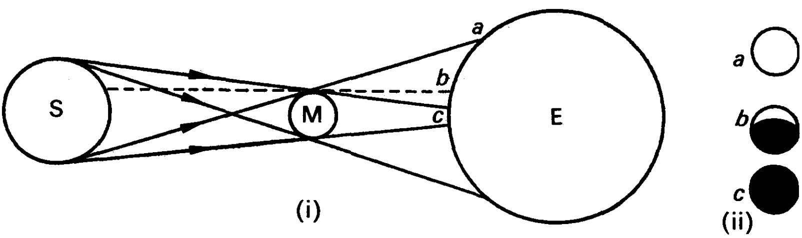


FIG. 15.1. Eclipse of Sun (*not to scale*).

our natural source of light, when the moon, M, passes between the sun and the earth, E. The moon is a non-luminous object which does not allow light to pass through it, and hence the boundaries of the shadows formed by M on the earth are obtained by drawing lines from S which touch the edge of M. Consequently there is a total eclipse of the sun at *c* on the earth, a partial eclipse at *b*, and no eclipse at *a*. Fig. 15.1 (ii) illustrates the appearance of the sun in each case.

Light Rays and Beams

Light is a form of energy. We know this is the case because plants and vegetables grow when they absorb sunlight. Further, electrons are ejected from certain metals when light is incident on them, showing that there was some energy in the light; this phenomenon is the basis of the *photoelectric cell* (p. 1077). Substances like wood or brick which allow no light to pass through them are called "opaque" substances; unless an opaque object is perfectly black, some of the light falling on it is reflected (p. 391). A "transparent" substance, like glass, is one which allows some of the light energy incident on it to pass through, the remainder of the energy being absorbed and (or) reflected.

A ray of light is the direction along which the light energy travels; and though rays are represented in diagrams by straight lines, in practice a ray has a finite width. A **beam** of light is a collection of rays. A search-light emits a *parallel beam* of light, and the rays from a point on a very distant object like the sun are substantially parallel, Fig. 15.2 (i). A lamp

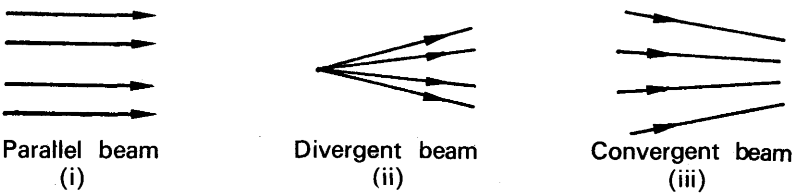


FIG. 15.2. Beams of light.

emits a *divergent beam* of light; while a source of light behind a lens, as in a projection lantern, can provide a *convergent beam*, Fig. 15.2 (ii), (iii).

The Velocity of Light

The velocity of light is constant for a given medium, such as air, water, or glass, and has its greatest magnitude, about $3{\cdot}0 \times 10^8$ metres per second, in a vacuum. The velocity of light in air differs only slightly from its velocity in a vacuum, so that the velocity in air is also about $3{\cdot}0 \times 10^8$ metres per second. The velocity of light in glass is about $2{\cdot}0 \times 10^8$ metres per second; in water it is about $2{\cdot}3 \times 10^8$ metres per second. On account of the difference in velocity in air and glass, light changes its direction on entering glass from air (see *Refraction*, p. 679). Experiments to determine the velocity of light are discussed later, p. 551.

The Human Eye

When an object is seen, light energy passes from the object to the observer's eyes and sets up the sensation of vision. The eye is thus sensitive to light (or luminous) energy. The eye contains a *crystalline lens*, L, made of a gelatinous transparent substance, which normally throws an image of the object viewed on to a sensitive "screen" R at the back of the eye-ball, called the *retina*, Fig. 15.3. Nerves on the retina

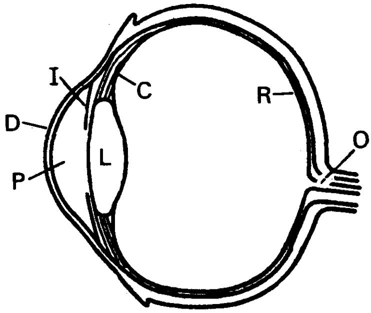


FIG. 15.3. The eyeball.

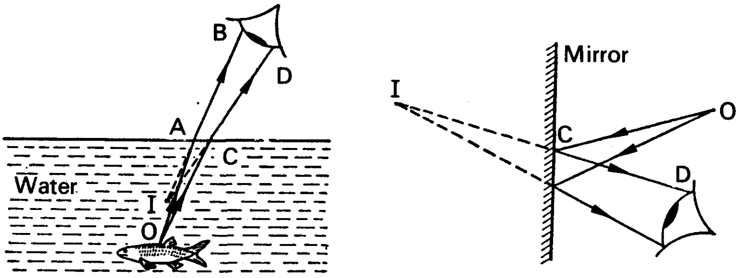
are joined to the *optic nerve*, O, which carries the sensation produced by the image to the brain. The *iris*, I, is a diaphragm with a circular hole in the middle called the *pupil*, P, which contracts when the light received by the eye is excessive and painful to the eye. The colour of a person's eyes is the colour of the iris; the pupil is always black because no light returns from the interior of the eye-ball. A weak salt solution, called the *aqueous humour*, is present on the left of the lens L, and between L and the retina is a gelatinous substance called the *vitreous humour*. The transparent spherical bulge D in front of L is made of tough material, and is known as the *cornea*.

The *ciliary muscles*, C, enable the eye to see clearly objects at different distances, a property of the eye known as its "power of accommodation". The ciliary muscles are attached to the lens L, and when they contract, the lens' surfaces are pulled out so that they bulge more; in this way a near object can be focused clearly on the retina and thus seen distinctly. When a very distant object is observed the ciliary muscles are relaxed, and the lens' surfaces are flattened.

The use of two eyes gives a three-dimensional aspect of the object or scene observed, as two slightly different views are imposed on the retinæ; this gives a sense of distance not enjoyed by a one-eyed person.

Direction of Image seen by Eye

When a fish is observed in water, rays of light coming from a point such as O on it pass from water into air, Fig. 15.4 (i). At the boundary of the water and air, the rays OA, OC proceed along new directions AB, CD respectively and enter the eye. Similarly, a ray OC from an object O observed in a mirror is reflected along a new direction CD and enters the eye, Fig. 15.4 (ii). These phenomena are studied more fully later, but



(i) (ii)

FIG. 15.4. Images observed by eye.

the reader should take careful note that the eye sees an object *in the direction in which the rays enter the eye*. In Fig. 15.4 (i), for example, the object O is seen in the water at I, which lies on BA and DC produced slightly on the right of O; in Fig. 15.4 (ii), is seen behind the mirror at I, which lies on DC produced. In either case, all rays from O which enter the eye appear to come from I, which is called the image of O.

Reversibility of Light

If a ray of light is directed along DC towards a mirror, experiment shows that the ray is reflected along the path CO, Fig. 15.4 (ii). If the ray is incident along OC, it is reflected along CD, as shown. Thus if a light ray is reversed it always travels along its original path, and this is known as *the principle of the reversibility of light*. In Fig. 15.4 (i), a ray BA in air is refracted into the water along the path AO, since it follows the reverse path to OAB. We shall have occasion to use the principle of the reversibility of light later in the book.