CHAPTER I

CONCERNING LIGHT

SIGHT is a very wonderful sense indeed. Touch and taste demand actual contact with something if they are to give us any information about it. Our sense of smell can sometimes be used over a short distance, and hearing may even be used over some miles. Sight shows us things and events at distances almost too great to imagine. In a pitch-dark room you see nothing, for sight depends upon light. When a match is struck it somehow causes disturbances called light waves and these, like water waves from a fallen stone, spread out in all directions, until they meet your eye. The eye is sensitive to light, the optic nerve communicates the impression to the brain, and you become aware that in a certain place a match is burning.

This book is mainly concerned with other worlds than ours, bodies very many thousands of miles away, and our knowledge of them comes to us as light messages affecting our sense of sight. Thus a study of astronomy is closely allied with a study of light, and it is therefore desirable to become familiar with the chief properties of the latter before proceeding to the former.[1]

It is necessary to be reminded, right at the beginning, of one important property. That we cannot see around corners is a common experience, and the reason is that the light by which we see travels in straight lines. Notice the beam of light entering a dim and dusty room, or a motor-car headlight on a slightly misty night, or the sunlight shining through a rift in the clouds, and there will be no doubt about the reality of these straight lines. Thus when we want to show on a diagram the direction in which light is travelling we just rule a straight line and call it a 'ray', and to show the direction in which we can see we rule such a line

[1] Readers who have already done a course of light up to the standard of the General Certificate may skip the rest of this chapter if they wish, but those who have not are advised not only to persevere with it but to read also a text book on Light. *Light*, by A. E. E. McKenzie (Cambridge University Press), can be recommended as being in sympathy with the present work.

and call it the 'line of sight'. It is therefore important to remember that *light travels in straight lines*.

Reflection. When light falls on any ordinary surface, such as the page of this book, it is reflected in all directions, perhaps not quite equally, but sufficiently so for the surface to be seen from any angle. When it falls on a highly polished one, such as a mirror, it is reflected in one direction, and the *laws of reflection* are best understood by trying two simple experiments.

Expt. 1. Project a narrow streak of light across a sheet of paper by putting a lamp behind a vertical slit in a piece of cardboard, or shining it between two rectangular objects.[1] Let it strike a plane (i.e. flat) mirror standing up at right angles to the paper. This ray *AB* (Fig. 1) is the *incident ray*, and the ray *BC* is the *reflected ray*. Rule lines along them, and along the back of the mirror if a glass one or the front if a metal one. Draw *BN* at right angles to the mirror; it is called the *normal*. The angles *ABN* and *NBC* are called the *angle of incidence* and *angle of reflection*; measure them with a protractor, and if you have done your experiment carefully they will be found to be equal.

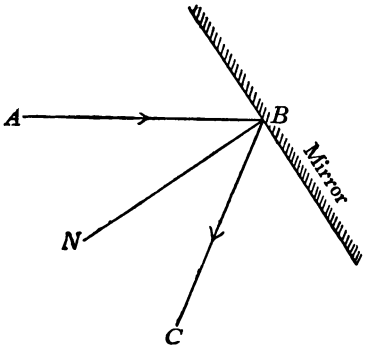

FIG. 1. The laws of reflection

Expt. 2. Now tilt the mirror slightly so that it is no longer at right angles to the paper; what happens to the reflected ray? The paper on which you are working is a plane, and the incident and reflected rays lie in that plane. So does the normal, because it is perpendicular to the mirror and the mirror is perpendicular to the paper. When the mirror is tilted the normal is moved out of the plane, and you find that the reflected ray moves too and disappears.

[1] Simple methods of projecting rays will be found in *The Science Masters' Book*, Series 1, Vol. 1.

Thus the laws of reflection are (i) the incident and reflected rays and the normal to the surface are all in the same plane, and (ii) the angle of reflection is equal to the angle of incidence.

The reflection of an object in a mirror is called its *image*, and, as it is behind the glass and the light has not really passed through it, it is said to be *virtual*. It can be shown quite easily that the image appears to be, not on the glass, but as far behind the plane mirror as the object is in front.

Have you ever stood in front of a mirror and shaken hands with yourself? You use the right hand and your image uses the left, and this is another rule about a plane mirror. This changing over of right and left is called *lateral inversion*.

Expt. 3. Set up Expt. 1 and rule along the incident and reflected rays and along the mirror. In Fig. 2 *MB* is the position of the mirror and *ABC* the path of the light. Turn the mirror through a small angle into a new position *NB* and mark the new position *BD* of the reflected ray. Measure the angles *NBM* and *CBD*. You will find that the ray has moved twice as much as the mirror, a fact that will occur in a later chapter in connection with the sextant.

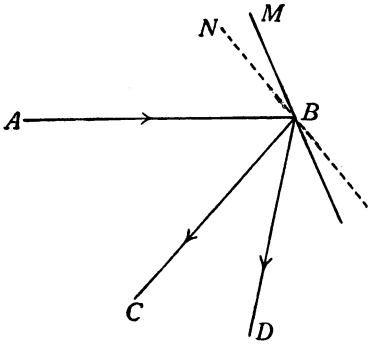

FIG. 2. Effect of rotating a mirror

A *concave mirror* is a part of a sphere, reflecting on the inside of the curve, and those used in telescopes are not sharply curved, like half a tennis ball, but are nearly flat. Again it is easier to understand its properties if you can handle one, so, if such a mirror is available, here are two more simple experiments.

Expt. 3. Place the mirror half way through a slot in a piece of white card, the mirror being perpendicular to the card, and project on to it several rays by passing the light through several slits or a coarse comb. Note that the reflected rays meet at one

point; if the incident rays are parallel (Fig. 3) the point is called the *principal focus*, and its distance from the mirror its *focal length*.

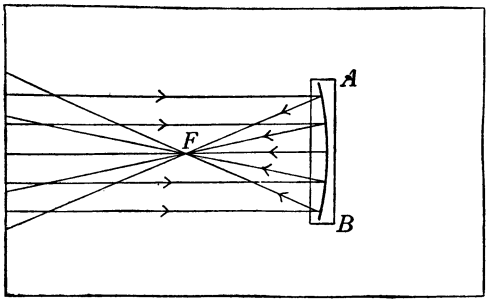

FIG. 3. A concave mirror

Expt. 4. Hold the mirror facing a window, and hold a piece of card so that the reflected light falls upon it. Vary the distance and you will find a position in which an inverted reproduction of the window frame appears on the card. This is called a *real image*, as the light really does fall on the screen. Now hold the mirror close to your face: as the object (the face) is very near the mirror the image is now upright and virtual.

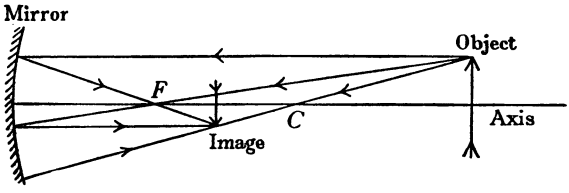

FIG. 4. Formation of a real image by a concave mirror

The formation of a real image can be illustrated by a drawing, for light rays can be represented by straight lines. In Fig. 4 C is the centre of the circle of which the mirror forms a part, and the principal focus F lies half way between C and the mirror. From the top of the object a ray is drawn parallel to the axis; the reflected ray will pass through the focus. A ray drawn through the focus will reflect parallel to the axis. A ray through the centre of curvature will be at right angles to the mirror and will therefore

reflect back along its own path. The three rays meet at a point; this is the head of the image.

Refraction. Have you ever noticed any of these things: the appearance of your fingers through a filled tumbler in your hand; a flight of steps leading down into a swimming pool; the bottom of a clear stream seen from a boat; someone moving in the garden seen through very ordinary window glass? If so, you are already familiar with the subject of this section, for the various effects referred to are due to *refraction*, which is the bending of light as it passes from one transparent medium into another.

Expt. 5. Put a coin at the bottom of a basin, move away until the coin is *just* hidden by the edge of the basin, and then watch carefully while a friend pours water in without disturbing the coin.

The reason for the reappearance of the coin is that the light reflected from it is bent when it leaves the water and enters your eye as if it had come from *B* instead of *A* (Fig. 5). Thus you see the coin apparently at *B*. It is important to note that light bends away from the normal on leaving the more dense water and entering the less dense air; it would bend towards the normal on entering a more dense medium.

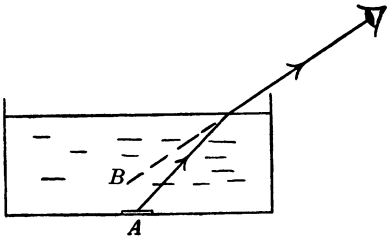

FIG. 5. Refraction in water

The laws of refraction are not quite so simple as those of reflection, and the reader is referred to text books on light. There are a few facts about refraction that should be noted, however. When light passes through a parallel slab of glass it emerges parallel to its original direction but *laterally displaced* (Fig. 6). If the glass is thin and the angle of incidence is small, this displace-

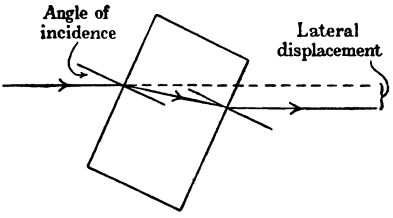

FIG. 6. Refraction through a glass slab

ment is also small. In the case of a triangular prism the light will be *deviated* towards the wider part of the prism (Fig. 7), the angle D being called the angle of deviation. If the angle of incidence inside the glass is large,[1] i.e. very oblique incidence, refraction does not occur and the light is *internally reflected*, shown in Fig. 8. This internal reflection is important, as in the construction of optical instruments right-angled isosceles prisms are frequently used instead of mirrors; one way of using such a prism is shown in Fig. 9.

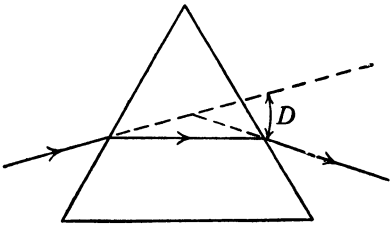

FIG. 7. Refraction through a prism

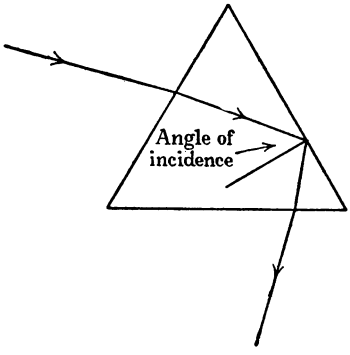

FIG. 8. Internal reflection

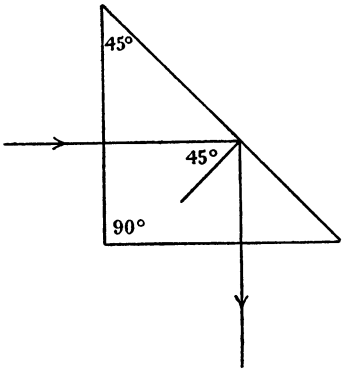

FIG. 9. A reflecting prism

Expt. 6. Using a ray and a sheet of paper as in Expt. 1, try to verify the phenomena illustrated in Figs. 6–8.

Atmospheric Refraction. Although our study of astronomical phenomena has not yet begun, this is a convenient point at which to insert this topic; if preferred, the paragraph could be omitted until reading chapter VII. The Earth's atmosphere does not go on for ever; it is a layer something over 100 miles thick, and beyond

[1] 42° and above for ordinary glass.

it is empty space. When light from the Sun and stars enters the atmosphere it is refracted, because it is entering a denser medium, and this affects astronomical observations. When light from a star *S* (Fig. 10) enters the atmosphere it reaches an observer at *O* as if the star were at *A*. Then the altitude as measured by a sextant would be *HOA* instead of the true altitude *HOB*, and therefore sextant readings have to be corrected for refraction. Similarly when the Sun is in the direction of *C*, just below the horizon, it appears to be at *D*, just above the horizon; thus refraction lengthens the day. Again, during an eclipse of the Moon some

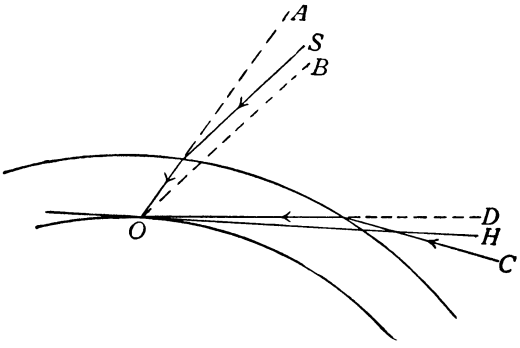

FIG. 10. Atmospheric refraction

light is refracted by the atmosphere into the Earth's shadow and illuminates the Moon enough to make it visible. Finally, refraction is partly responsible for morning and evening twilight. Needless to say, the atmosphere does not begin suddenly; the density of it becomes lower as height increases. Hence the light rays do not make one sharp turn as shown in Fig. 10, but follow a curved path, being only slightly deviated when they first enter the very rare upper layers.

Lenses. Most people are familiar with the common magnifying glass; it is a convex or converging lens, thicker in the middle than at the edge.

Expt. 7. Repeat Expt. 3, using a convex lens in the slot. Note that the refracted rays meet at a point beyond the lens. The terms

principal focus and focal length have the same meaning as in the case of the concave mirror (Fig. 11).

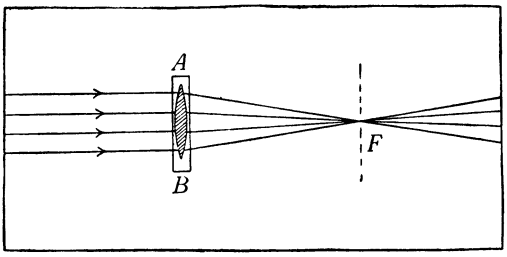

FIG. 11. A convex lens

Expt. 8. Repeat Expt. 4 with the lens. This time a real image will be obtained by holding your screen on the side of the lens away from the window.

Light from a very distant object can be regarded as being parallel; thus a real image of the Sun will be formed at the principal focus, and this gives a simple method of measuring focal length. Strictly speaking, the 'hot spot' given by a burning glass is not a point, but a disc of measurable size formed in the *focal plane*; this plane is shown dotted in Fig. 11.

The formation of a real image is illustrated in Fig. 12, which is drawn as follows: a ray parallel to the axis will refract through

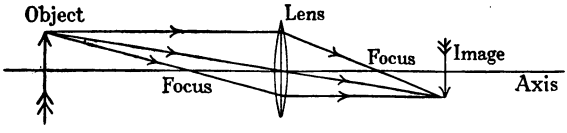

FIG. 12. Formation of a real image by a convex lens

the focus on the far side; one through the near focus will refract parallel to the axis; one through the centre of the lens will go straight on, for here the lens acts like a thin parallel plate.

When a convex lens is being used as a magnifying glass the object, like that in the mirror case previously mentioned, is so close to the lens that it is within its focal length, and a virtual image is given. This is illustrated in Fig. 13, which is drawn

according to the same rules as Fig. 12 except that the rays had to be produced backwards to locate the virtual image.

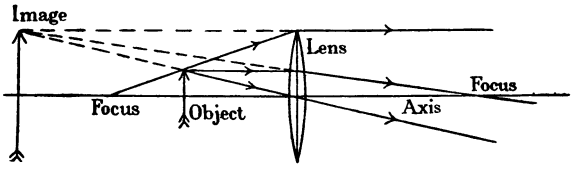

FIG. 13. Formation of a virtual image by a convex lens

A *concave lens* is thinnest in the middle and it *diverges* the light instead of converging it. The only kind of image that it can give by itself is a small, upright and virtual one.

Dispersion. If a triangular glass prism be placed in the path of direct sunlight shining into the room, a patch of coloured light can be obtained on the wall or ceiling. The light is said to have been *dispersed* into a *spectrum*. The colours can be more conveniently examined if a strong source of light, such as a motor-car bulb, with a straight vertical filament, be placed behind a narrow vertical slit so that a narrow beam of light falls on a 60° prism (Fig. 14).

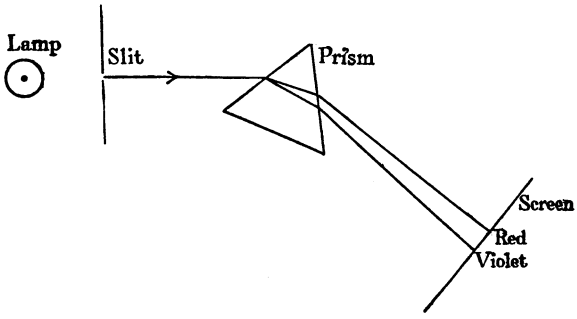

FIG. 14. The dispersion of light

An important point to realise is that the prism does not actually make the colours. The colours are already in the light, and they differ from one another in the same way as the wireless transmission from different stations. Light waves were mentioned in the opening paragraph; each colour has its own particular wave-

length, and when the waves fall on a prism the deviation produced depends on the wave-length. White light is a mixture of many wave-lengths, and the prism, by turning each wave-length through a different angle, sorts them out and we can see the colours separately. An experiment of this kind was performed by Sir Isaac Newton in 1666, using sunlight from a hole in a shutter, and is described in his *Opticks*. The colours of the spectrum usually quoted are red (the least deviated), orange, yellow, green, blue, indigo (deep blue) and violet. *Spectroscopes* and *spectrometers* are instruments for producing and examining spectra; their design

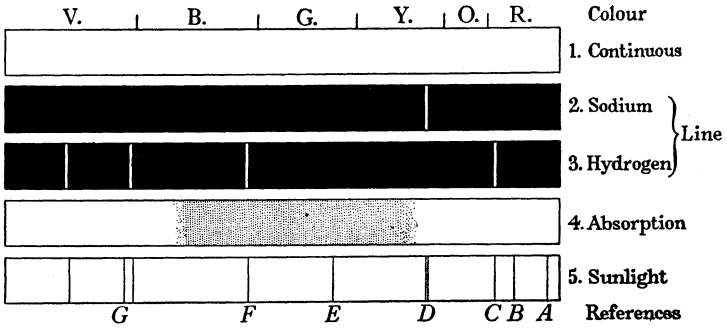

FIG. 15. Types of spectra

varies considerably according to the precise purpose for which they are to be used. If the source of light is an incandescent solid, such as an electric lamp, a gas mantle, or the hot carbon particles in a candle flame, the spectrum will be a complete band of colour, merging gradually one into the next from red to violet. This is called a *continuous spectrum*, illustrated by a white strip in Fig. 15.

When a lump of common salt is held in the flame of a Bunsen burner an intense yellow light is produced. The heat divides up the salt into the elements of which it is composed, and at the temperature of the flame the sodium vapour produced emits a yellow light. If this light be examined with a spectroscope, in place of a continuous spectrum there is just one yellow line (really two close together) as shown in Fig. 15, 2. When an electric current is passed through a gas at a low pressure,