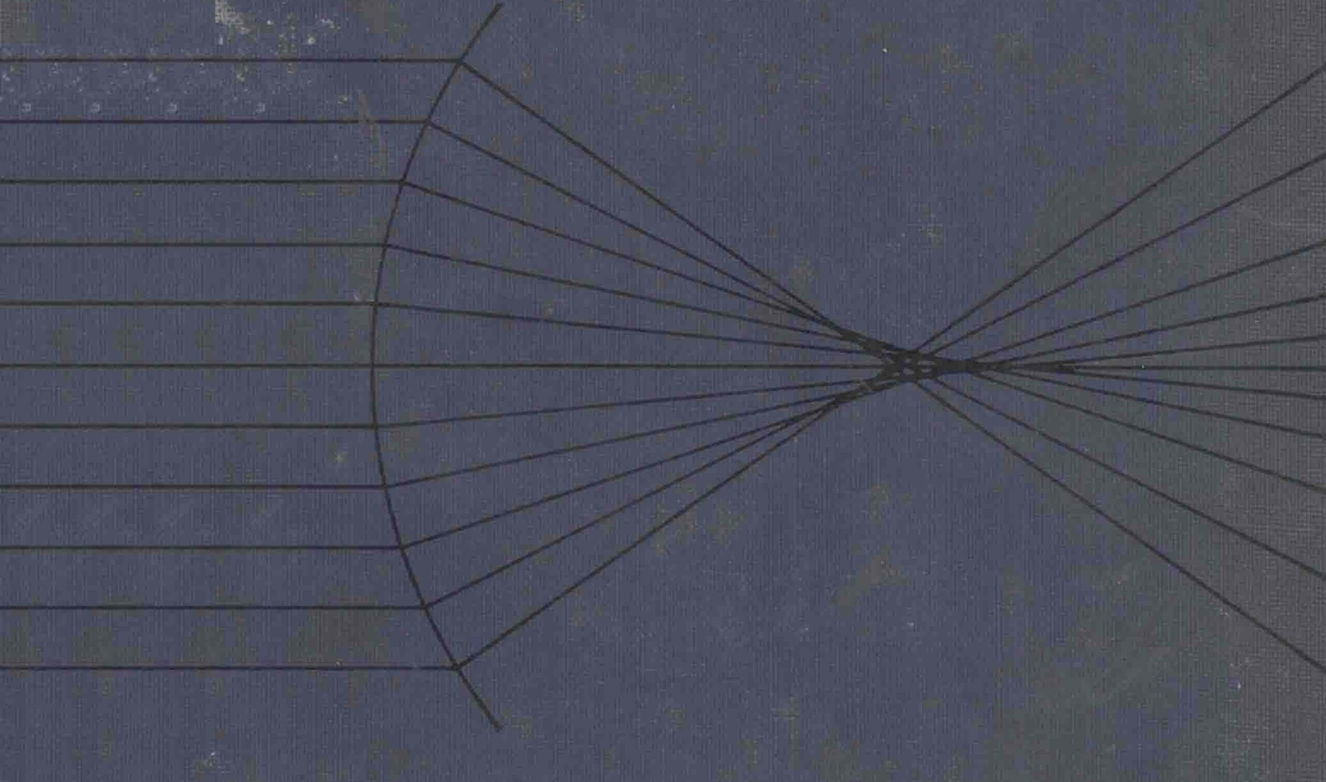
NINTH EDITION

DUKE-ELDER'S PRACTICE OF REFRACTION

REVISED BY
DAVID ABRAMS



CHURCHILL LIVINGSTONE

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Duke-Elder's Practice of Refraction

Preface

The purpose of this book is to present in a manner suitable for the student and the practitioner the essential principles of the theory and practice of the correction of defects in the optical system of the eyes and their associated muscles. A simple and essentially non-mathematical form of presentation has been adopted wherein all that is necessary for the clinical routine of refraction is described and explained without burdening the reader with innumerable mathematical proofs. The book is thus clinical rather than theoretical, and its object is essentially practical; and, while theoretical matters are dealt with sufficiently to make their application to actual problems understandable and are explained in words rather than formulae, no attempt has been made to enter into the mathematical foundations of the subject.

The mathematical theory of the subject is already dealt with most competently and fully in several publications so that their reiteration in a handbook which is intended to be essentially clinical is unnecessary. Excellent expositions of this branch of the subject are to be found in such books as those by Fincham and Emsley or the section on visual optics by Bennett and Francis in the fourth volume of Davson's *The Eye*; the recent book by Campbell, Kiester, Rittler and Tackaberry is a very readable basic text on physiological optics. Reference to other branches of the subject of the theory of ophthalmic lenses can be obtained from Emsley and Swaine's *Ophthalmic Lenses* and Sasieni's *The Dispensing and Fitting of Spectacles*. As far as contact lenses are concerned, the most comprehensive source is the volume edited by Ruben, *Contact Lens Practice, Visual, Therapeutic and Prosthetic*, and Bennett's shorter *Optics of Contact Lenses* will also be found helpful.

Whatever the type of book the would-be refractionist uses, it cannot be insisted upon too strongly that the art of refraction cannot in any sense be learned by reading. There is only one way of attaining efficiency therein, and that is by assiduous and painstaking practice in the clinic of a hospital, where large numbers of cases of all kinds are available, where the findings can be supervised and corroborated, and where long practice makes the interpretation of results instantaneous. If these pages serve as a guide in this they will have achieved their aim.

It is now 50 years since the first edition of this book appeared, and 9 years since the last edition was published. This edition has been carefully revised and brought up to date, with the inclusion of new material—particularly in the section on Contact Lenses—by David Abrams, who I hope will continue to look after future editions.

Mr Abrams has had the helpful assistance of Mr Ian Mackie, who supplied contact lens photography; Mr Michael Ham of Keeler Instruments Ltd., who has contributed the illustrations of modern sight-testing equipment; his daughter, Janet, who has redrawn several of the old illustrations and provided a number of new ones; his secretary, Daphne Morgan; and my secretary, Rosamund Soley. To all of these we are both very grateful.

London, 1977 Stewart Duke-Elder

I regretfully record the death of Sir Stewart Duke-Elder on 27th March while this edition was in the final stages of preparation.
London, 1978 David Abrams

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SECTION 1

Introduction

1. The clinical importance of the refraction

The methods of evaluating the optical state of the eye, *the refraction*, and the means employed to correct it when abnormal, play an important part in the management of many ophthalmic conditions. As an introduction to the description of these techniques, it is therefore pertinent to review the clinical circumstances in which it is important to estimate the refraction.

VISUAL FAILURE

Anomalies of the optical state of the eye, *refractive errors*, are by far the commonest cause of defective vision; they must be looked for in any patient complaining of inability to see clearly. The various types of refractive error and the distinctive ways in which they affect the vision will be considered in subsequent chapters.

While the short sighted child unable to see the blackboard clearly at school, or the presbyope finding it difficult to read a telephone directory in poor light may make direct complaint of their disability, refractive errors may be discovered in other ways. Thus, reviews of vision at schools and places of work, or parental observation of visual inadequacy may also prompt an examination of the optical state of the eyes.

Apart from an initial examination, defective vision may occur in subjects known to have refractive errors who may already be using an optical correction, whether spectacles or contact lenses. Again, such a defect may be noticed by the patient or simply be brought to light during routine re-examination of the eyes. Myopia increasing in degree during adolescence, and under-corrected hypermetropia of middle age are examples of this.

Indeed, not only may a spectacle correction be inadequate, it may be wrong giving rise to poor vision on its own account. Thus in all who wear spectacles, the complaint of blurred vision is an indication for a re-examination of the refraction. The same considerations apply to the wearers of contact lenses; here, however, the additional possibility of some corneal upset must be borne in mind as a possible cause of visual disturbance.

It is also important to remember that the refraction of the patient may be of great significance when visual failure is *not* due primarily to a refractive error. No assessment of visual capacity is possible without an estimation of the visual acuity in optimal optical conditions.

The interaction between optical anomalies and ocular disease has both diagnostic and therapeutic implications. Thus the ophthalmoscopic view may give rise to doubt as to the health of the macula; such a situation may be regarded less seriously if the examination of the refraction shows the corrected vision to be normal. Again, the decision to advise surgery in a case of cataract will always be influenced by the acuity obtained with the best optical correction. Finally, we may note the importance of the examination of the refraction after ophthalmic surgery.

DISTURBANCES OF THE MUSCLE BALANCE

The co-ordination of the ocular movements and the ocular refraction are inter-related. This relationship derives from a flexible but far from haphazard association between accommodation, the alteration in focus from far to near, and convergence—the movement in which each eye turns nasally to look at some close object. We will examine the implications of this situation in later chapters. Suffice it to point out here that this association between accommodation and convergence may be put in jeopardy if the optical state of the eyes requires an abnormal degree of accommodation in order to obtain clear vision. For this reason hypermetropic refraction is often accompanied by a tendency to an excess of convergence; indeed, hypermetropia is frequently found in children with concomitant convergent strabismus.

It is clear that in any ophthalmic problem which involves the muscle balance, an examination of the refraction is mandatory and may indicate both the pathogenesis of the condition and its proper treatment.

EYE-STRAIN, HEADACHE AND PSYCHOLOGICAL FACTORS

In the grosser degrees of refractive error, visual failure is the cardinal presenting symptom. In lesser degrees, however, visual failure may be only one of a number of complaints a patient may make. Indeed, the symptom of inability to see clearly may be a negligible part of the symptomatology. Other symptoms arise as a result of the effort made to overcome or compensate for the visual defect. Conditions of sustained excessive accommodation as may be found in some hypermetropes, or attempts to stimulate accommodation when it is becoming a physiological impossibility in presbyopes, are circumstances typically productive of non-visual symptoms with or without visual complaints. Similarly, anomalies of the binocular state may also give rise to symptoms which are not primarily visual. Examples of this are disturbance of the accommodation-convergence association and disparities between the refractive states of the two eyes.

The notion of effort and the fact that the pathological basis of the symptoms may depend on the ocular musculature, internal and external, has led to the mechanical concept of strain, hence *eye-strain*.

The symptoms which this term embraces are diverse and as some are neither visual nor ocular the condition may go unsuspected. The difficulty which this presents is aggravated by the fact that the symptoms do not by any means appear in proportion to the gravity of the causal defect. They vary from individual to individual to the most surprising degree without any apparent cause, this one showing no sign of trouble, and that one, with apparently equal cause and seemingly equally constituted, complaining bitterly; but as a general rule two types of case are strikingly common. The first of these are subjects of a neurotic disposition or even normal people during a period of prolonged mental worry and anxiety. To many of these, spectacles are a help since they remove one cause of irritation from an over-taxed nervous system. Secondly, in the debilitated and in those convalescing from an acute illness, or in women after a confinement and during lactation, fatigue which in normal circumstances would be barely appreciated readily manifests itself, and an optical error which would give rise to no symptoms of discomfort were they in robust health may become acutely felt, and may necessitate the use of spectacles which may frequently be discarded at a later date in happier circumstances. Indeed, in some such cases the ciliary muscle may not be able to perform a normal amount of work without showing signs of distress, and symptoms of eye-strain may make themselves evident in the absence of any appreciable error in the optical system.

The symptoms themselves are conveniently considered in the following groups:

1. *Visual symptoms*

The characteristic feature of these is their intermittent nature. It may thus be taken that in the case of small refractive errors the actual visual acuity forms little or no reliable guide to the ocular condition, for the defect may be compensated more or less completely by the patient at the time it is assessed and indeed at many other times. In fact, it is sometimes true that the symptoms are most marked in those cases wherein for this reason the vision remains good. One person will live placidly and comfortably with a small degree of astigmatism and considerably reduced vision, while another more highly organised, suffering the same disability, will attain normal or supernormal sight—and pay for it. There frequently comes a time, however, either in periods of unusual strain or during a temporary deterioration of the general health or vitality, when fatigue comes on and the visual acuity fails. This is especially seen in those who use the eyes much for reading or the study of small objects over long periods of time, while fine sewing, the cinema, motor driving in the distractions of confusing traffic, or any relaxation or employment which calls for a high degree of visual acuity combined with attention or anxiety, is frequently the cause of such a breakdown. A sense of confusion and a temporary blurring of vision are experienced, the letters when reading, for example, appearing to run together. Here the ciliary muscle gives up any attempt to focus and the image becomes indistinct, or the ocular muscles slip back into their condition of rest and diplopia results. This may be momentary and pass off, to recur again at more frequent intervals, the eyes gradually becoming tired and the lids heavy, while a sensation of weariness or drowsiness makes itself progressively felt and renders continued attention difficult or impossible. A relaxation of attention brings relief, but a resumption of the matter at hand induces a repetition of the trouble, until ultimately the individual is tempted to give up from annoyance or exhaustion.

2. *Ocular symptoms*

The symptoms which affect the eye itself are sometimes spoken of collectively as *asthenopia*.

The ocular symptoms associated with eye-strain are directly due to the increased muscular work which the defect invokes and the discomfort of the resultant muscular fatigue, to which may be added the effects of a condition of vascular engorgement determined by this state of sustained and forced activity. Subjectively, especially after long periods of close application to work, the eyes feel tired, hot and uncomfortable; temporary relief is obtained by resting or by rubbing them, but if the work is continued, the vague discomfort gives place to a feeling of actual strain and this may develop into pain. Pain in the eyes unconnected with inflammation is generally due to eye-strain and rarely to any deep-seated disease. It is usually mild and aching, but may on occasion be severe and acute; it may be situated in the eyes themselves or be located more deeply in the orbits, or spreading therefrom become referred as a general headache.

Objectively, the eyes frequently have a typical appearance. The continued state of irritability and congestion brings about an unhealthy condition of the lids and conjunctivae with a characteristic look, watery, suffused and bleary. This is especially notable in children, in whom an intractable blepharitis or conjunctivitis should always suggest an examination of the refraction. Such low-grade infections are probably accentuated and prolonged by the child constantly rubbing his eyes with his fingers; the eyes feel strained and sore, and a child's hands are rarely clean.

Eye-strain has at one time or another been credited with a share in the aetiology of almost every ophthalmic disease. Frequent mention is made of it in association with iritis and iridocyclitis, with glaucoma, and even with cataract. The factors determining the incidence of these diseases are usually complex and often not a little obscure; but to ascribe to eye-strain an important or determining share in the aetiology of any of them seems to be laying undue stress on what should more reasonably be regarded as coincidence.

3. *Referred symptoms*

The commonest symptom associated with eye-strain is *headache*. This occurs in a multitude of varieties. It is most commonly localised around the region of the eyes; it may be frontal or temporal but it may occasionally be vertical or occipital.

Eye-strain is traditionally thought to embrace every imaginable type of headache, of whatever distribution. Its nature is said to be dull, aching, boring, superficial, deep-seated or migrainous; its time of occurrence as constant, intermittent, related or unrelated to the use of the eyes. Aggravating factors such as fatigue or poor illumination are said to be common.

It is only reasonable to conclude that the headache of eye-strain is difficult to diagnose with certainty; the rational course to adopt is to examine the eyes as a matter of routine in all cases wherein such an origin might be suspected. No case of obscure headache should be treated on general medical lines without first eliminating the possibility of eye-strain as being at least one of the factors in its aetiology.

The mechanism of the headache is not fully understood, but presumably it rests upon the same basis as other referred pain of visceral origin. It is now generally accepted that visceral pain is referred to the area which shares a common segmental origin with the viscus concerned, and in the same way as overstrain of the cardiac muscle produces angina which spreads over the shoulder, down the arm and up the neck, so ciliary pain is referred to the areas associated with the cervical segments which connect with the superior cervical ganglion, the somatic outflow from which is represented by the bulbo-spinal root of the trigeminal and the upper cervical nerves. It will be remembered that the early metameric arrangement of the fifth nerve is maintained whereby the ophthalmic division is represented most caudally, so that ciliary pain is primarily frontal and occipital in distribution.

The other general symptoms of eye-strain are of more uncertain status. Digestive upsets such as dyspepsia and nausea, vague 'nervous' disorders such as dizziness, insomnia and depression, these and many others have all in the past been variously attributed to eye-strain. The aggravation of neurological or mental disorders and the causation of general debility have been explained on this or a similar basis.

While there is little doubt that these attributions are to be considered exaggerated, eye-strain does probably have some effect on the general health and mental well-being of those who, from instability of temperament or from overwork, are living too freely upon the margin of their reserves. It is not only in the neurotically inclined that it makes its influence felt, but also in those highly organised individuals who enrich more particularly the intellectual spheres of life and find happiness only when they are lavishly spending themselves. In these the wasteful expenditure of energy in the continuous attempt at correction may act as the final straw in bringing about a condition of nervous exhaustion. Even in those not so highly strung, eye-strain may have a similar result in circumstances of mental or physical stress.

Nevertheless it is probably true to say that ophthalmologists and others have in the past attributed to eye-strain more evils than can reasonably be laid to its account. We have seen that neurotic temperament is frequently associated with the condition, and we have noted that anomalies in the optical mechanism may well be the means of the aggravation and prolongation of such psychopathological states. But it happens, perhaps more commonly in women, that functional troubles which are without any reasonable organic basis are often referred persistently to the eyes. Such patients will insist that they cannot use their eyes for any length of time, or that when they attempt to do so they cannot see at all. Frequently they see spots floating about in front of them. Sensitivity to light is especially marked, and they are quite unable to bear illumination of any unusual intensity; even in diffuse daylight they prefer to go about in dark glasses. Headache is the most frequent symptom, and its neurotic origin can frequently be recognised from the sensations they describe. A patient with a true organic headache rarely hesitates to describe his sensations as those of pain pure and simple; they, on the other hand, with no evidence of emotion, will describe a sense of pressure, of emptiness, of the head opening or shutting, or of its being bored through by a nail, or being constricted by a band. These, and many more: but whatever it is, the impression is given that it is horribly unpleasant. There may be an optical anomaly, or there may not; but in either case, producing a host of spectacles obtained from as many surgeons and opticians—each of which they have worn punctiliously—they will declare in a firm and quiet voice that none of them is of any use. Usually some muscular imbalance is present, and reading presents the greatest difficulty, intense discomfort coming on so that near work has to be discontinued after a few minutes' application. The real trouble is a pathological attitude of mind, none the less real, it is to be noted, because it is so, and treatment should be directed thereto with all sympathetic consideration and forbearance.

Indeed, as a final comment on the place of eye-strain in the symptomatology of refractive errors, we should remind ourselves that the abolition of symptoms by therapy directed at any supposed cause is *not* proof of causation. Many headaches and other vague ocular complaints may be relieved in whole or in part by the wearing of a weak spectacle correction. But here the treatment could well be exerting the well-recognised placebo effect and the cause of the symptoms may lie quite elsewhere than in the ocular or refractive state. An important part of the clinician's role will therefore always be the decision as to the relevance of optical treatment. Admittedly it may act as a beneficial prop to the mentally ill, deferring or preventing a serious breakdown. But its effect in organic disease arising elsewhere in the body could be to delay appropriate investigation and treatment.

The taking of the correct decision clearly involves the consideration by the clinician of the whole patient, his general and mental health, his life-style as well as his optical and ocular states. It is evident that the art of refraction is acquired only with long experience.

SECTION 2

Refraction and its Application to the Eye

2. The principles of refraction—general optics

THE NATURE OF REFRACTION

It may be said, in general terms, that light travels through space in straight lines. It is true that recent advances in physical science have shown that this is not strictly accurate; but for the purposes of the optical problems which we propose to consider, it may be taken to be the case. If, however, a ray of light meets a body in its passage through space, one of three things may happen to it. Some substances, for example, black bodies, *absorb* the light which falls on them; these are called opaque. Others such as mirror surfaces *reflect* the light backwards; while others such as glass which are described as transparent allow the light, or at any rate a considerable proportion of light, to pass through them. In space, light maintains a constant speed of about 186,000 miles per second, but as it travels through the substance of such a transparent body it is obvious that it will encounter more resistance than previously, and, as we would expect, this retards its progress.

In such a case, if a beam of light enters a transparent body perpendicularly to its surface, its progress will be retarded. The condition of affairs may be gathered from Fig. 2.1. But, on the other hand, if the beam strikes the body obliquely, one edge of the advancing beam will enter the body before the other, and consequently will be retarded earlier. The condition of affairs in this case will best be understood from Fig. 2.2. At the position AB the entering beam is beginning to meet with the resistance offered by the transparent body at A, and for the next part of its course the part of the beam which is within the body will necessarily travel more slowly than that which, being outside, is still unimpeded. The distances travelled in the same interval of time are therefore unequal, AD being less than BC, and consequently the front of the beam is swung round and its direction is changed. This phenomenon of the bending of light as it passes from one transparent medium to another of different density is known as *refraction*.

The amount by which the beam of light is bent depends on three factors. In the first place, since the bending is dependent upon the retardation of the light, the more resistance the body offers, the more slowly will the light be made to travel and consequently the more acutely will the rays of light be bent. This property of offering resistance to light is known as *optical density*, and it varies within wide limits between different substances. For practical purposes the universal medium through which light travels is the air, and so the optical densities of different substances are usually compared with that of air taken as a standard. The refractive power of a substance in comparison with that of air is spoken of as its *refractive index*: thus the

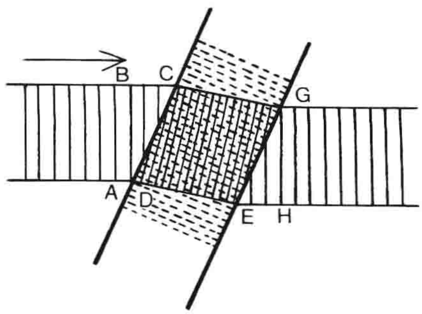

Fig. 2.2 Refraction of light through a glass plate.
When a beam of light strikes a glass plate obliquely, the portion which enters first at A meets with resistance. The beam is therefore bent during its course AD, BC. After the position DC is reached it travels as a parallel beam through the substance of the plate. At EF an opposite process takes place, involving an equal amount of refraction, with the result that at GH the beam travels on in the same direction as before, but displaced from its original path

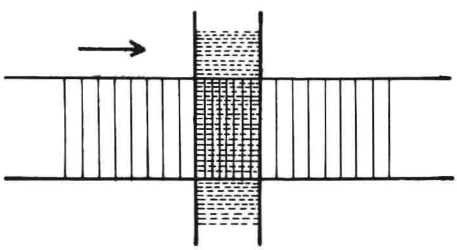

Fig. 2.1 Passage of light through a glass plate.
When a beam of light strikes a glass plate with parallel sides normally, it is retarded while traversing the plate, and then travels on unaffected.

refractive index of air is 1, that of water 1·33, that of crown glass is 1·5, and so on (see Table 1—Appendix).

The refractive index is worked out from the relationship of the angle of incidence to the angle of refraction (*i* and *r* respectively in Fig. 2.3). We know that $\sin i / \sin r$ is constant for all angles of incidence (Snell's Law) and this constant factor is the refractive index, when the first medium is air.

Because of this relationship, it follows that a second important factor affecting the amount of bending is the angle at which the rays strike the surface between the two media; the more oblique this is, the greater will be the bending.

The third factor influencing the degree of bending is the wavelength of the light, blue light for example is more bent in the conditions of Figure 2.2 than red. The differences, however, are small and we can simply speak of 'light' being the composite white light of common experience. We shall see, later, that we cannot completely ignore this factor.

By making use of refraction light can be manipulated to a considerable extent, and instead of travelling, as it ordinarily does, in defined straight lines, its directions can be made to alter into well-defined paths. It is the essential function of all optical systems to turn the course of rays of light from their original indiscriminate directions into definitely determined paths, and we will proceed to study the methods used for this purpose by the refractive system of the eye.

REFRACTION BY A PLATE WITH PARALLEL SIDES

When parallel rays of light fall perpendicularly upon a glass plate, the front of the beam will be equally retarded throughout its extent; no deviation therefore occurs, and consequently when it leaves the plate on the other side the beam proceeds unaffected (Fig. 2.1).

But when parallel rays fall obliquely upon a glass plate, we have seen that their direction is changed on account of the retardation of one edge of the beam (A, Fig. 2.2) before the other (B). When the entire width of the beam has entered the substance of the glass at CD, all rays will be equally retarded throughout, and consequently, travelling at a uniform, though lessened speed, they will once more proceed as a parallel beam, running, however, in a different direction through the thickness of the plate until the other surface is reached. Here exactly the opposite process takes place. At the position EF the edge of the beam at E, on entering the air, at once regains its original velocity, while at F the resistance of the glass is still felt. This inequality of speed obtains until the position GH is reached, when the entire beam once more travels on as before. Since the processes at either side are exactly the reciprocals of each other, the beam is bent to

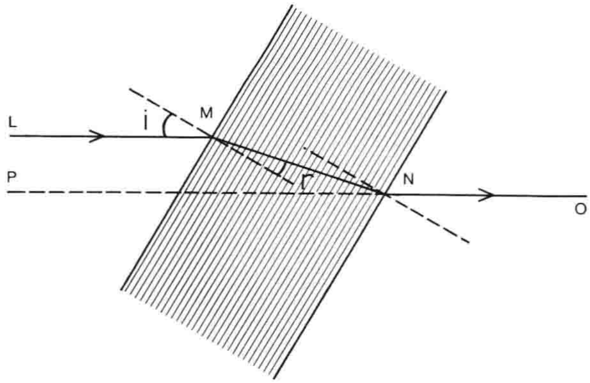

Fig. 2.3 Refraction of a ray of light by a glass plate.
The ray of light LMNO is refracted at M as it passes from air to glass, and N as it passes from glass to air.
When an eye is situated at O, the source of light, L, appears to come from P. For *i* and *r* sec. text.

an equal and opposite degree, and therefore, although its path has been changed, the emergent light is parallel to the incident light.

If we consider the course of a single ray (Fig. 2.3), and draw perpendiculars at the two points M and N where it cuts the surfaces of the plate, it becomes evident that when light passes obliquely from a medium of less density to one of greater density, it will be refracted towards the perpendicular; if it passes from one of greater to one of less density it will be refracted away from the perpendicular, the amount of refraction depending on the difference between the densities of the two media. Since the degree of refraction in passing between the same two media is always the same, the emergent ray, although it is displaced, runs parallel with the incident ray. Now the phenomena of refraction enter but little into our everyday experience and so we tend to ignore the optical effects to which they give rise, and are accustomed to project objects visually along the direction of the rays of light as they enter the eye. Consequently, if L be a luminous object and O the observer's eye, the object will appear to be situated at P.

REFRACTION BY PRISMS

We have seen that when light passes through a medium with parallel sides, the incident rays and the emergent rays are parallel; but if the sides of the medium are not parallel, the direction of the rays must also change. Thus in Figure 2.4 the incident beam of light is retarded at A so that AD is shorter than BC; it is therefore bent round and runs through the substance of the glass until it reaches the position EF. Here the upper part of the beam (FG) accelerates on entering the air, while the lower part

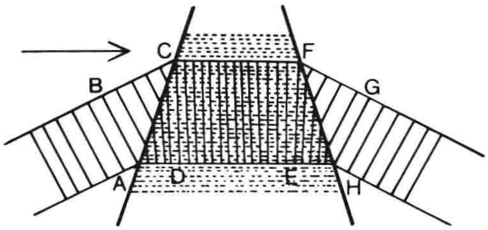

Fig. 2.4 Refraction by a glass plate with non-parallel sides. The two sides AC and HF are not parallel. The beam is therefore bent from the position AB to DC on entering the plate, and from the direction EF to HG on leaving the plate. Its original direction is thus completely changed.

(EH) is still retarded; consequently the beam is bent round further in the same sense and is deviated out of its original path altogether.

Such a medium is typified in the *prism* (Fig. 2.5). It is made up of two sides, AB and AC, meeting at an apex, A, joined by a base, BC. The angle between the two sides at A, which denotes the angle at which the two refracting surfaces are inclined, is called the *angle of refraction*. Since a ray of light is bent towards the perpendicular on entering a dense medium (glass) from a rare one (air), the incident ray will be bent towards the base as it enters the prism, as is seen in the figure, and since refraction away from the perpendicular occurs on re-entering the rarer medium, the emergent ray will be further bent towards the base as it leaves the prism. The path of the ray is thus seen as DEFG, where it is evident that the entire deviation is towards the base. The total amount of the deviation between the incident ray (DE) and the emergent ray (FG) is called the *angle of deviation*, and is

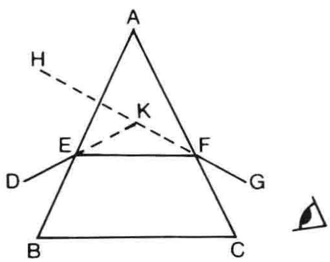

Fig. 2.5 Refraction by a prism.
ABC is a prism with the apex at A, the base BC, and the sides AB and AC. The angle of the prism is BAC.
A ray of light DEFG is refracted at E and F as in Fig. 2.4. The total amount of refraction, that is, the difference in direction between DE and FG, is represented by the angle DKH (the angle of deviation). If the eye is at G, the source of light, D, will appear to be at H. The angles made by the incident ray (DE) and the emergent ray (FG) with the normals to the surfaces at E and F are called the angles of incidence and emergence; and when these are equal the deviation produced by the prism is minimal. A ray suffering *minimal deviation* in this way is said to traverse the prism *symmetrically*.

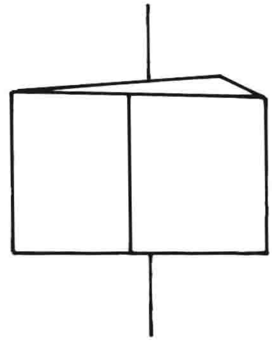

Fig. 2.6 The deviation produced by a prism.
An object viewed through a prism is always deviated towards the apex of the prism.

represented by the angle EKH. If an observer is at G and a luminous body is placed at D, it will appear to be in the position H; thus while the light is deviated towards the base, the image is displaced towards the apex of the prism (Fig. 2.6).

The detection and measurement of prisms

By utilising this phenomenon we are able to detect the presence of a prism in an optical system. We hold the glass up between the eye and any object which forms a straight line, and if the continuity of the straight line is broken, as is seen in Figure 2.6, we know that a prism is present; and since the line appears to be deviated towards the apex, we know in which direction the apex of the prism lies. The amount of displacement which is produced is an index of the strength of the prism, and this can be measured by neutralising the unknown prism with which we are dealing by placing in contact with it other prisms of known strengths facing the opposite direction.

This principle is seen in the effects produced by *rotating prisms*. If two equal prisms are placed base to apex, a plate with parallel sides is formed with no prismatic action; if now these be rotated upon each other in reverse directions they produce the effect of a single prism of gradually increasing strength, until eventually, when they are apex to apex, a maximum effect is obtained equal to the sum of the single prisms.

The nomenclature of prisms

From our consideration of the principles of refraction it follows that the amount of deviation produced by any prism depends on the refractive index of the substance of which the prism is made, the manner in which the light strikes the prism, and the size of the refracting angle. In ophthalmological practice, prisms are usually made of crown glass, and we assume that the rays fall upon the prism symmetrically (see Fig. 2.5); consequently the amount of deviation usually depends on