REFRACTION OF THE EYE

MORTON.

SECOND EDITION.

REFRACTION OF THE EYE.

REFRACTION OF THE EYE

ITS DIAGNOSIS

AND THE

CORRECTION OF ITS ERRORS

WITH CHAPTER ON

KERATOSCOPY

BY

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PREFACE TO SECOND EDITION.

In this edition, though the first three chapters have been transposed, the general plan adopted in the former issue has been retained. The subject matter remains also materially the same though, in hope of increasing the usefulness of these pages, some slight alterations and additions have been made to the text, and a few portions have been partially re-written.

Welbeck Street, W.
Dec. 1882.

PREFACE TO FIRST EDITION.

These notes are published with a view of enabling Practitioners to diagnose, and correctly estimate the value of, the phenomena indicating the state of a patient's refraction. They are intended to furnish a basis for observation: and it is hoped that they will make evident the necessity which exists for *personally working out* a large number of refraction cases in order to acquire anything like proficiency in prescribing correct glasses.

To those friends who have aided me by their suggestions I would take this opportunity of expressing my best thanks.

Welbeck Street, W.
March, 1881.

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REFRACTION OF THE EYE.

INTRODUCTION.

THESE pages are intended for beginners, and for those, such as Physicians or general Practitioners, who, systematically using the Ophthalmoscope in their investigation of disease, wish to avail themselves of the information thereby afforded regarding the patient's refraction, the errors of which they must be able to detect in order to make due allowance for them. If the patient can assist by his answers, many valuable indications are afforded by the use of test-types and glasses, a description of which, with the information derived therefrom, is therefore introduced.

Some hints are given as to glasses required in the more *ordinary* cases, but for the various diseases which accompany and complicate many of the errors of refraction and modify the ordering of spectacles, the reader is referred to the works already published on this subject, to the study of which these notes are intended to prepare the way.

So essential is the remembrance of some of the facts hereafter mentioned, that, at the risk of tautology, they have been kept constantly before the reader. The plan which has been found so useful in other branches of medical study has been adopted here, viz., to work out from the *symptoms* the nature of the *defect* rather than to name the defect and then describe the symptoms accompanying it.

In examining refraction it is especially necessary to proceed *systematically*. On a patient complaining of bad sight we should examine him somewhat in the following manner:—

1. Listen carefully to the nature of his complaint.

2. Test and note the *near* and *distant* vision *without* glasses.

3. Examine the refraction with the ophthalmoscope, and then, having by these means arrived at a conclusion, proceed to confirm the opinion by means of test-glasses.

Two methods of measuring refraction are at present in vogue (*vide* Chap. III.). The new system of numeration is the one which has been adopted in the text. The *approximately* corresponding measurements in *English* inches have, however, in all cases been given in *brackets* for the convenience of those who prefer the old method.

Only so much ophthalmoscopy has been introduced as was necessary to explain the phenomena of refraction.

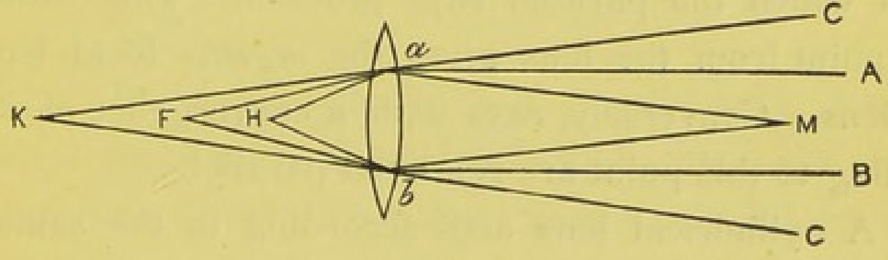
CHAPTER I.

Action of Rays and Lenses.

a. Rays of light issuing from every point of any object diverge in *all* directions. The *nearer* an eye is to such an object the *more* of its *di*verging rays does it intercept, and *vice versa,* the further the eye is removed, the fewer are the divergent rays which reach it: *i.e.,* the more parallel are the rays which enter it. Only from objects at an *infinite* distance do we *theoretically* get absolute parallelism of the rays.

For *practical* purposes, however, we may *consider* those *parallel* which reach the eye from an object situated at a distance of 6 metres (20 ft.) or more.

Fig. 1.

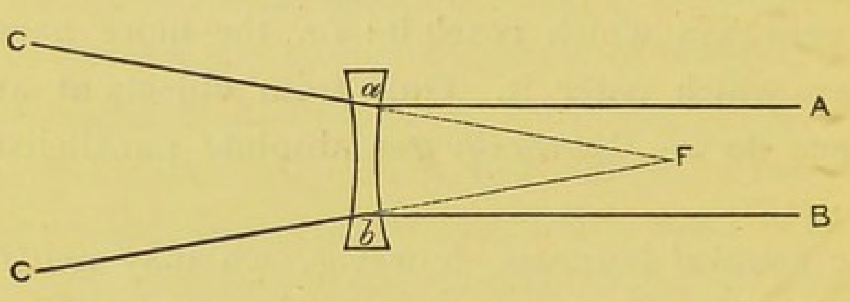


b. Parallel rays (Fig. 1., A*a*, B*b*), falling on a convex spherical lens come to a focus at a point, F., on the other side of the lens called the "principal focus." Conversely, rays from a point at the principal focus of the lens emerge parallel.

c. Diverging rays (Fig. 1., M*a*, M*b*) meeting such a lens unite at a point, K, which is *behind* the principal focus. Conversely, rays from a point further from the lens than its principal focus emerge as convergent rays.

d. Converging rays (Fig. 1., C*a*, C*b*) falling on a convex lens meet at a point H, *nearer* the lens than its principal focus. Conversely, rays from a point *within* the principal focus are, on emerging from the lens, *still* divergent, though *less* so than before meeting it.

FIG. 2.



e. Parallel rays (Fig. 2., A*a*, B*b*) falling on a *concave* spherical lens acquire a *di*vergence (*a*C, *b*C) as if proceeding from a point, F, on the *same* side of the lens as that from which the parallel rays proceed. The distance of this point from the lens gives the *negative* focal length of the lens. Conversely, rays with a convergence as if proceeding to this point are rendered parallel.

f. A cylindrical lens acts according to the same rules as a spherical, but *only* in a direction at *right angles* to its axis.

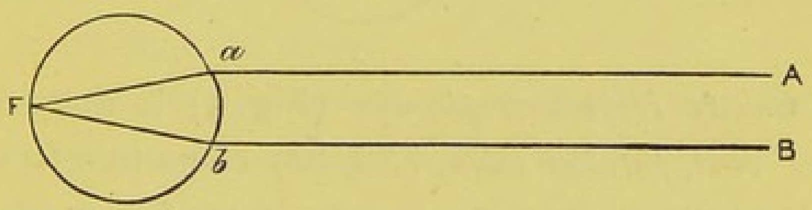
CHAPTER II.

DEFINITIONS.

DEF. 1. The refracting surfaces of the eye are, according to Donders—*a*, the anterior surface of the cornea; *b*, the anterior surface of the lens; *c*, the anterior surface of the vitreous. The transparent media together form the "*Dioptric system*" of the eye, which has an action similar to that of a biconvex lens.

DEF. 2. "*Refraction of the eye*" means the effect which, by reason of its form and structure, this organ exerts upon rays of light entering it when *completely at rest*.

FIG. 3.

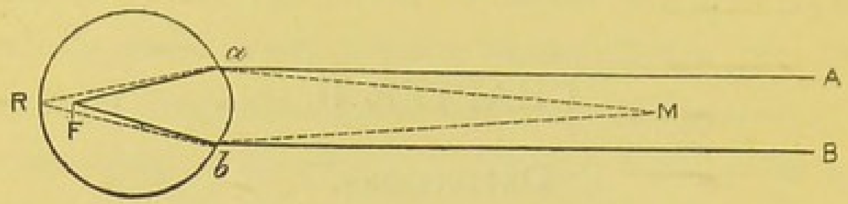


DEF. 3. In *Emmetropia* (Fig. 3) *parallel* rays, A*a*, B*b*, come to a focus *upon* the retina, F, when the eye is at rest. Conversely, rays from the retina emerge parallel from the eye.

DEF. 4. An *Ametropic* eye is one in which, when at rest, *parallel* rays do *not* come to a focus upon the retina. As will be seen from the four following definitions, it may be either Myopic, Hypermetropic or Astigmatic.

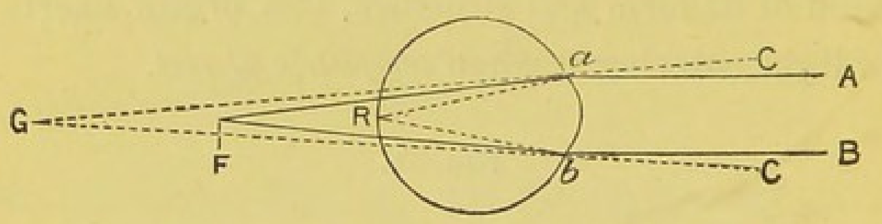
DEF. 5. A *Myopic* eye (Fig. 4) is that in which, when at

FIG. 4.



rest, *parallel* rays come to a focus in *front of* the retina, as at F. Conversely, rays issuing from the retina, R, which is behind the focus of the dioptric system, emerge as convergent rays (Chap. I., *c.*) which meet at a point M, in front of the eye. Further, it is evident that rays from this point (called the "*far point*") would meet upon the retina.

FIG. 5.



DEF. 6. A *Hypermetropic* eye (Fig. 5) is that in which, when at rest, *parallel* rays, (A*a*, B*b*) come to a focus at F, *behind* the retina. Conversely, rays from F, would emerge from the eye parallel. Rays, therefore, from R, which is *within* the focus of the dioptric system, (*vide* Def. 1) emerge from the eye with a divergence (Chap. I. *d.*) such that, if prolonged back, they would meet behind it at a point G.

The *distance* of this point *behind the front part of the eye* will, in any case, be *equal to the focal length of the convex lens which, when held close to the eye with its accommodation suspended, brings parallel rays to a focus on the retina.* For, since the rays from the retina have, on emerging from the eye, a divergence as if issuing from G, it follows, that rays with a convergence, as if proceeding to G, would meet on the retina at R. Consequently, the convex lens which, with the aid of the dioptric system of the eye, brings parallel rays to a focus at R, would also bring them to a focus at G. This latter point is therefore at the principal focus of the lens (*vide* Chap. I. *b.*).

DEF. 7. A *regularly* astigmatic eye is that in which there is a difference of refraction in different meridians; the two *principal* meridians being always at *right angles* to each other.

Astigmatism may exist in five different forms.

a. Simple myopic = one meridian emmetropic, the other myopic.

b. Simple hypermetropic = one meridian emmetropic, the other hypermetropic.

c. Compound myopic = both meridians myopic, one more that the other.

d. Compound hypermetropic = both meridians hypermetropic, one more than the other.

e. Mixed = one meridian myopic, the other hypermetropic.

DEF. 8. An *Irregularly Astigmatic* eye is one in which there are different degrees of refraction in different parts of the various meridians.

DEF 9. A *Presbyopic* eye is that in which, owing to physiological changes, produced by advancing age, there is an inability to define small objects nearer to the eye than 22 cm. or about 9 *English* inches, (*vide* Presbyopia

Chap. XII.). It may exist with any of the above named conditions.

From what has been stated in this and the preceding chapter we may get the following

Deductions.

Deduction 1. That for *parallel* rays to be brought to a focus on the retina of a myope, they must have given to them a divergence as if proceeding from the "far point" (*vide* Def. 5). This is effected by the *concave* lens whose negative focal length equals the distance of this point, (Chap. I., *e.*) The amount of the Myopia is said to be equal to the refracting power (Chap. III.) of this lens.

Deduction 2. That to bring *parallel* rays to a focus on the retina of a hypermetropic eye at rest, we require a *convex* lens such that it gives to parallel rays a convergence as if proceeding to the point behind the eye from which rays appear to issue, (p. 6, fig. 5, G.). The *amount* of the Hypermetropia is equal to the refracting power of such lens.

Deduction 3. That in a regularly astigmatic eye the *two principal* meridians must be corrected by means of cylindrical lenses or a combination of these with sphericals.

CHAPTER III.

Old and New Systems of Measurement.*

In the old system, the lenses were numbered according to their focal lengths in inches. Their *refracting* power, being the *reverse* of their focal lengths, was represented by a *fraction*, of which the numerator was 1 and the denominator was the focal length in inches. Thus, a lens of 6 ins. focus had a refracting power of $\frac{1}{6}$, *i.e.*, $\frac{1}{6}$ the refracting power of a lens whose focal length was 1 in. $\left(\frac{1}{1 \text{ in.}}\right)$: this latter was therefore the *unit* of measurement.

The intervals between the lenses were irregular and the difference between the refracting powers of any two lenses had to be calculated by means of *fractions*.

In the new or *Dioptric* system the *unit* of measurement is a lens whose *focal length* = 1 metre or *Dioptre* $\left(\frac{1 \text{ m.}}{1}\right)$ with a *refracting power* consequently $= \frac{1}{1 \text{ m.}} = 1$ D. Two such lenses have double the refracting power or $\frac{2}{1 \text{ m.}} = 2$ D. with a focal length $\frac{1 \text{ m.}}{2}$ or $\left(\frac{100 \text{ cm.}}{2}\right) = 50$ cm. Ten such lenses have ten times the refracting power $\frac{10}{1 \text{ m.}} =$ 10 D. and a focal length $\frac{1 \text{ m.}}{10}$ or $\left(\frac{100 \text{ cm.}}{10}\right) = 10$ cm.

* *Vide Roy. L. Ophth. Hospital Reports*, vol. viii., p. 632, translation of an article by Dr. Landolt from which much in this chapter has been borrowed.

If we express the number of dioptres by *d.*, and the focal length by *F.*, then (i) To find the number of dioptres which correspond to the focal length of a lens we have the formula $d = \frac{1 \text{ m.}}{F}$, and (ii) For the focal length corresponding to any dioptre the formula $F = \frac{1 \text{ m.}}{d}$

In order to ascertain the corresponding numbers in the two systems for any lens, we must remember that 1 dioptre (or *metre*) = 37 Paris inches and (39·4 or nearly) 40 *English inches*, and that, therefore, the lens with 1 D. focal length corresponds to the lens in the old series whose focal length is 40 ins. ($\frac{1}{40}$); 2 D. to a lens with double this refracting power or $\frac{2}{40} = \frac{1}{20}$ of the old.

Where *d*, then, represents the number of dioptres, and *a* the number of inches, if we wish (i) to ascertain what lens in the old series corresponds to one of the new, we have the formula $\frac{d}{40} = \frac{1}{a}$. (ii) For the number of a lens in the new system corresponding to one in the old we have, $d = \frac{40}{a}$.

The old system of lenses in the trial cases, generally in use, have their focal lengths in inches, and do not correspond exactly with the measurements in dioptres. The following table gives the lens which, in an ordinary French or English case, will correspond *most* nearly with any dioptre.

For greater accuracy in any special case, the reader must calculate according to the formulæ given above.

TABLE.

D	Focus in English inches	Focus in Paris inches.	D	Focus in English inches.	Focus in Paris inches.
0·25	160	144	5·0	8	7
0·50	80	72	5·50	7½	6½
0·75	50	50	6·0	7	6
1·0	40	36	7·0	6	5
1·25	30	30	8·0	5	4½
1·50	24	24	9·0	4½	4
1·75	22	20	10·0	4	3¾
2·0	20	18	11·0	3½	3½
2·25	18	16	12·0	3¼	3
2·50	16	14	13·0	3	2¾
2·75	14	13	14·0	2¾	2½
3·0	12	12	15·0	2¾	2½
3·50	11	10	16·0	2½	2¼
4·0	10	9	18·0	2¼	2
4·50	9	8	20·0	2	1¾

CHAPTER IV.

Accommodation.

Def. 10. *By accommodation of the eye is meant the power which by muscular aid, that organ posesses in itself of bringing to a focus on its retina rays proceeding from objects situated at various distances.* These distances range between the "*far point,*" for rays from which the eye is adjusted when *not using any* of its accommodation, and the "*near point*" for rays from which the *whole* of the accommodative power is called into activity. The amount of accommodation thus exercised by an eye in passing from the former to the latter of these conditions is called the *Range* or *Amplitude* (Donders) of accommodation. This amplitude may be represented by the *convex* lens which, with *completely suspended accommodation,* would bring rays from the near point to a focus on the retina.

Now a lens whose *focal length equals the distance of the near point,* will, when placed close to an eye, render *parallel* the rays entering that organ from its near point. (*Vide* Chap. I. *b.*).

Since in *Emmetropia* (E.), when the eye is at rest, *parallel* rays come to a focus on the retina (Def. 3), such a lens represents in E., the amplitude of accommodation.

But in *Hypermetropia* (H.), when the eye is at rest, *parallel* rays do *not* come to a focus on the retina without the aid of a *convex* lens (Chap. II., Ded. 2). To get the amplitude of accommodation, the strength of the lens thus necessary to render the parallel rays sufficiently convergent, must therefore be *added* to that whose focal length equals the distance of the near point. Thus, if the H. = 3 D. ($\frac{1}{12}$), and the near point = 14 cm. (6 ins.) then, to the lens whose focal length = 14 cm., viz. 7 D. ($\frac{1}{6}$), we add that which brings parallel rays to a focus on the retina, viz. 3 D. ($\frac{1}{12}$). The amplitude therefore will be 7 D. + 3 D. = 10 D. ($\frac{1}{6} + \frac{1}{12} = \frac{1}{4}$).

From this it will be seen that, with the *same* amplitude of accommodation, the near point is *further* from the eye in H. than in E.

In *Myopia* (M.), since a *concave* lens is necessary for parallel rays (Chap. II., Ded. 1), it is evident that, for the amplitude of accommodation, the strength of the lens requisite to render parallel rays sufficiently *divergent* to come to a focus on the retina, must be *deducted* from that whose focal length equals the distance of the near point. Thus, if the M. = 3 D. ($\frac{1}{12}$), and the near point = 8 cm. (3 ins.), then, from the lens whose focal length = 8 cm., viz. 13 D., we *deduct* that which brings parallel rays to a focus on the retina, viz. 3 D. ($\frac{1}{12}$). The amplitude, therefore will be 13 D. — 3 D. = 10 D. ($\frac{1}{3} - \frac{1}{12} = \frac{1}{4}$). From this we see that, with the *same* amplitude of accommodation, the near point is *closer* to the eye in M. than in E.

It is further evident that, if the *near point* had been the *same* for each of the foregoing examples, the amplitude would have been greater in H., and less in M., than in E.

As age advances the near point recedes further from the eye, so that in *Presbyopia* there is *absolutely* less amplitude for any given age. If the near point recedes until it reaches the far point, the accommodation becomes *nil.*

CHAPTER V.

Perception of a Line.

The distinctness with which a line is visible depends upon the sharp and well-defined perception of its *margins;* if these are indistinct the line appears hazy. A line may be taken as made up of an infinite nnmber of elements or points, from *each* of which rays issue in *all* directions. To gain a distinct image of any line, it is necessary that the rays from these points, which emerge in planes at *right angles* to its long axis, should be brought to a focus at points on corresponding planes of the retina, otherwise circles of diffusion are formed in this *transverse* direction of the line, which overlap each other, and finally, by projecting beyond its *margins,* give to it an ill-defined and blurred outline, so that no distinct perception of it is obtained. If from these same points the rays, emerging in planes *parallel* to the long axis overlap each other, it is only at the two *extremities* of the line that, by projecting, they cause any blurring. The *margins* of the line, thus not being in any way affected, there is no interference with the outline, and a clear image is formed on the retina.

If then a patient with his accommodation suspended, and who is emmetropic in one meridian, and myopic or hypermetropic in the other, be placed at 6 m. (20 ft.) from radiating lines of equal definition, he will see most *distinctly* that line which runs at *right angles* to his *Emmetropic* meridian. Rays from points in the *transverse* planes of *this* line will, by passing through the emmetropic meridian, come to a focus on his retina giving a distinct, well-defined image of the *margins*, and hence a clear perception of the line. The line *parallel* to the emmetropic meridian will, at the same time, be the most *in*distinct. Rays from *its* transverse planes pass through the myopic or hypermetropic meridian. They thus come to a focus, in the former case, in front of, and in the latter behind, the retina producing circles of diffusion in these planes, and a consequent blurring of the *margins* of the line, so that no distinct image is obtained.

RULE I.—We have then the rule that in *simple* astigmatism, the patient, at 6m. (20 ft.) sees, *most distinctly*, the line *parallel* to the plane of his *error of refraction.*

It follows also, that a patient with either compound or mixed astigmatism, will not see *any* line distinctly at 6 m. with his accommodation suspended.

CHAPTER VI.

Description of Test-Types: Method of Employing Them.

Test-Types are divided into—*a*. Those for *near* vision, and *b*, those for *distant* vision. In using them we are obviously dependent on the answers given by the patient. For children, illiterate adults, and impostors, they are therefore inferior to the ophthalmoscope as a means of diagnosing and estimating refraction.

a. Test-Types for Near Vision.

Those generally in use for this purpose are Jaeger's or Snellen's. The latter are so graduated that each should be read *as far off* as the distance for which it is marked. The smallest should be seen as far off as 50 cm. ($1\frac{1}{2}$ ft.) and the largest at 4m. (12 ft.). These types are given into the patient's hand, and we then note the *smallest* he can read and the *nearest* and *farthest* points at which *it* is distinctly visible. The small types are chiefly useful in testing the accommodation, but they also afford an indication of the presence and amount of myopia *(vide* Chap. XII., Myopia).

b. Test-Types for Distant Vision.

Snellen's types for this purpose are so graduated that each should be distinctly legible *as far off* as the distance for which it is marked. The largest should be seen at 60 metres, and each succeeding line at 36, 24, 18, 12, 9, and 6 metres respectively (200 ft., 100, 70, 50, 40, 30, and 20).

In testing with these types, we so place the patient that rays issuing from them reach the eye as parallel rays. For *practical* purposes this is obtained at a distance of 6 m. (20 ft.) (*vide* Chap. I., *a.*) from which point the lowest line should be read by the normal eye without accommodation. For testing astigmatism, we have a fan of radiating lines, all of the same magnitude and definition. These should appear all equally distinct to the normal eye at 6 m. In noting the vision (= V.) we employ a fraction whose *numerator* denotes the *distance* at which the patient stands, and *whose denominator* indicates the *lowest* line which he *can* read. The number of the line is designated by the distance in metres or feet, at which it *should* be legible. Thus normal V. = $\frac{6}{6}$ ($\frac{20}{20}$) or 1; but if at 6 m. (20 ft.) the patient read only the line which *should* be read as far off as 12 m. (40 ft.) we say V. = $\frac{6}{12}$ ($\frac{20}{40}$) or $\frac{1}{2}$. Seeing that our object in testing refraction is always to have the accommodation suspended, we never place the patient nearer the types than 6 m. Should it be necessary, however, in defective V. *from other causes*, we may allow him to approach the types till he can read the largest; if this be at a distance of, say 2 m. (6 ft.), then V. = $\frac{2}{60}$ ($\frac{6}{200}$).

CHAPTER VII.

Indications afforded by use of Test-Types.

Note.—In the following section the patient is tested *without* glasses, then:—

Indication 1 If a patient read Jaeger 1 (= J. 1.) or Snellen 1= (Sn. 1.) with a good range, and read also $\frac{6}{6}$ ($\frac{20}{20}$) perfectly he is probably *Emmetropic.* He *cannot* be myopic though he *may* be hypermetropic: for a hypermetropic patient with active accommodation *could* do this.

Indication 2. If a patient *over* 40 *years of age* read only the larger J. or Sn. types (or *perhaps* even the smaller) but *only on condition that he holds them at a considerable distance;* while at the same time he can read $\frac{6}{6}$ ($\frac{20}{20}$) perfectly, he is simply Presbyopic.

Indication 3. If a patient must hold the types *close* to his eye but can then read even the *finest*, though he cannot see $\frac{6}{60}$ ($\frac{20}{200}$), he is *Myopic.*

Note.—A patient may read Sn. 1 as far as 50 cm. (No. 1 Sn. to 1½ ft.) or even Sn. 2 as far as 60 cm. (No. 2. Sn. to 2 ft.) together with some of the larger distance types such as $\frac{6}{36}$ ($\frac{20}{100}$). In this case he is *very slightly Myopic.* N.B. Since such a patient can read Sn. 1 *up to within a short distance from his eye* he is thus easily distinguished from the following.

Indication 4. If a patient read only the *larger* series of the small types, and the smaller series not at all, or only very imperfectly: while at the same time the distant vision is very defective, we suspect either some form of *Astigmatism* or *Hypermetropia without accommodation.*

In a patient *under* 40 *years of age* it is *probably* the *former*, but in one *over* that age it may be *either*, though it is frequently only the *latter* condition which exists.

Indication 5. If a patient *under* 40 or 45 can read only such large types as Sn. for 4 m. (J. 16) while he can read $\frac{6}{6}$ ($\frac{20}{20}$) he has *paralysis of accommodation.* This may be proved by giving him a strong convex lens, such as + 3 D. (+ 12 ins.), when he will read Sn. 1, or J. 1, at the focal distance of the lens. (*Vide* Accommodation, p. 12.)

Indication 6. If a patient, whose accommodation is suspended, see, quite distinctly, *one only* of the radiating lines at 6 m. he is *Emmetropic* only in the meridian at *right angles* to *this* line, and *either* Hypermetropic or Myopic in the other. (*Vide* Chap. V.)

CHAPTER VIII.

Indications afforded by means of Mirror alone. "Direct Method."

In order that the following indications of the refraction, afforded by this method, may be realised, the observer, if he be not emmetropic, must correct any error of his own refraction by means of spectacles or a lens behind the sight-hole of the mirror. He should then seat himself opposite, and 3 or 4 feet away from, the patient who is to gaze steadily at the *darkened* wall in front of him, looking towards the left side of observer's head when the left eye is under examination and *vice versa*. By this means the position of the optic disc is brought into the axis of vision of the observer. The latter must now throw the light from his mirror into the patient's eye, and, keeping the fundus illuminated, should move his head in various directions.

Indication 1. If he then get nothing more than the red reflex of the fundus or at most a *blurred* image of the disc, the eye is *Emmetropic* or *very slightly Myopic*. (*Vide* explanation, p. 22.)

Indication 2. If he see the image of the disc and its vessels moving in the *same* direction as, or *with*, his own head, the patient is *Hypermetropic*. (*Vide* p. 23.)

Indication 3. If the vessels in *one meridian only* are visible, and these move *with* the observer's head there is *Hypermet-*

ropia in *one meridian only*, viz., in that which is at *right angles to the one in which the vessels are visible.* (*Vide* explanation, p. 23, and compare with Chap. V.). = *Simple hypermetropic astigmatism.*

Indication 4. If the disc and vessels move in a direction *opposite* to, or *against*, that of the observer's head, the eye is *Myopic.* (*Vide* p. 24).

Indication 5. If the vessels are seen in *one meridian only* and moving *against* the observer, there is *Myopia* in the *meridian at right angles* to that in which the vessels are visible. (*Vide* p. 24, and Chap. V.). = *Simple myopic astigmatism.*

Indication 6. If the vessels are seen moving in one direction in one meridian, and in the opposite direction in the other meridian according to the accommodation of the observer, and his distance from the patient, there is *Mixed astigmatism.* This condition is, however, not easy of detection by the mirror alone.

Indication 7. If instead of the vessels of the disc moving evenly and regularly, they move slowly across the centre of of the pupil, but rapidly and irregularly towards the periphery, giving the appearance of rotating bent spokes of a wheel, the patient has *Irregular astigmatism.*

EXPLANATIONS,

For many points in the following explanations, and especially in those relating to the change in size of the disc, Chap. X., I am indebted to my friend Dr. G. A. Berry.

Of all the rays, (*vide* figs. 6 and 7), which diverge from any *single point*, *a* or *b*, of the fundus *one only*,

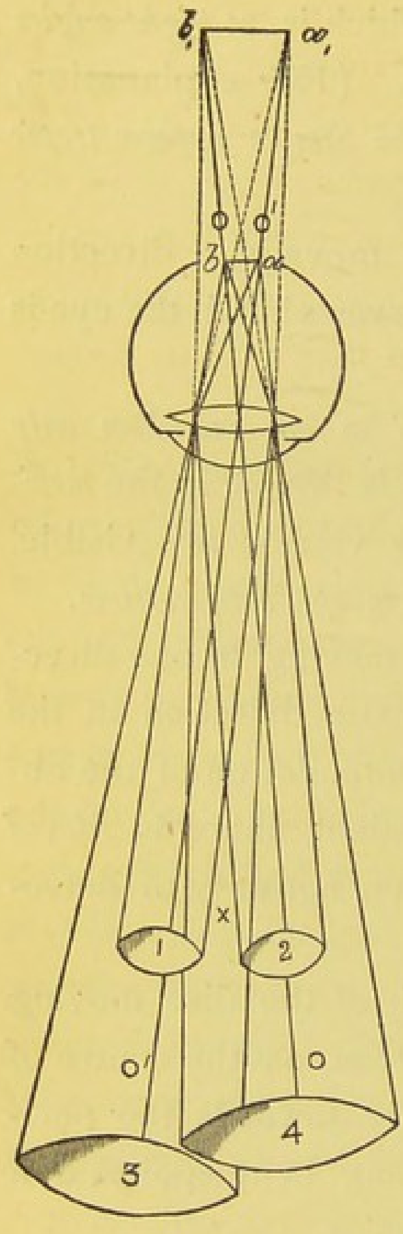


FIG. 6.

o' or o, passes *without deflection* through the *centre* of the crystalline lens. As many of the remainder as the size of the pupil will allow pass out in a cone of rays having a certain relation, according to the refraction, to the ray just mentioned. In order to get a view of any part of the fundus it is necessary that rays from *both* extremities of such portion should come to a focus on the observer's retina.

In *Emmetropia*, fig. 6, the rays which issue from the extremities *a* and *b* of the disc, emerge as two cylinders (1 and 2) of *parallel* rays taking the same direction respectively as those o' and o, which from the two extremities *a* and *b* pass through the centre of the lens. There are thus parallel rays in two cylinders, one from either extremity of the disc, emerging from the pupil and soon diverging from each other. They thus leave between them an area x in which there are no rays from these two points. If the observer's eye be situated in this space it is evident that he cannot get an image of the *whole* disc. He will however receive *parallel* rays from some luminous *point* of the disc: or even cylinders from *two very contiguous points* may run so closely together that on entering the observer's eye they might *theoretically* form an image of the space between them. *Practically*, however, such an image is rarely, if ever, obtained because the *absolute* suspension of accommodation necessary for its production is scarcely to be met with. We may therefore assume that for practical purposes no details of the fundus are visible with the mirror alone at some distance, and that therefore in *Emmetropia* the image of the disc is *blurred*.

In *Hypermetropia*, Fig. 6, the rays issuing from the extremities *a* and *b* of the disc emerge from the pupil as two cones (3 and 4) of rays which appear *as if* diverging from points $a_{\prime}$ $b_{\prime}$ situated behind the eye on prolongations backwards of the rays o′ and o, respectively which from *a* and *b* pass through the centre of the lens. By the union of the rays thus prolonged back we get an *erect* image $a_{\prime}$ $b_{\prime}$ of the disc *a b*. (For the *distance* of this image behind the eye, *vide* Chap. II., note to definition 6).

The cones 3 and 4 being formed of diverging rays, separate from each other only at a considerable distance from the eye. Some of the rays from each extremity of the disc, or at any rate those from two fairly distant portions of the same, will enter the observer's pupil, and, with the exercise of sufficient accommodation to overcome their divergence, will meet on his retina.

An object may be supposed as situated at the points whence *appear* to issue the rays entering the eye. The *object* therefore which the observer here appears to see is the *erect image* of the disc. Since the *object* thus apparently seen is *further* from the observer than the pupil, with which it is, though perhaps unconsciously, compared, it seems to move with the observer's head, (*vide* explanation, p. 24).

In *Myopia*, fig. 7, the rays issuing from the extremities, *a b* of the disc, emerge as two cones of rays which *converge* to points *a' b'* on their secondary axis, o' o, respectively, thus forming in front of the eye an *inverted* aerial image of the disc. If the observer be nearer the eye than where these rays unite, he will not get any image of the disc, since he receives only *convergent* rays which cannot come to a focus on his retina. If he, however, be far enough removed he will see the inverted image, *a' b'* of the disc. The rays, having *converged* to form this image, now cross and reach his eye, diverging (3 and 4) from the aerial image as if proceeding from an illuminated object placed at the same distance in front of the patient's eye.

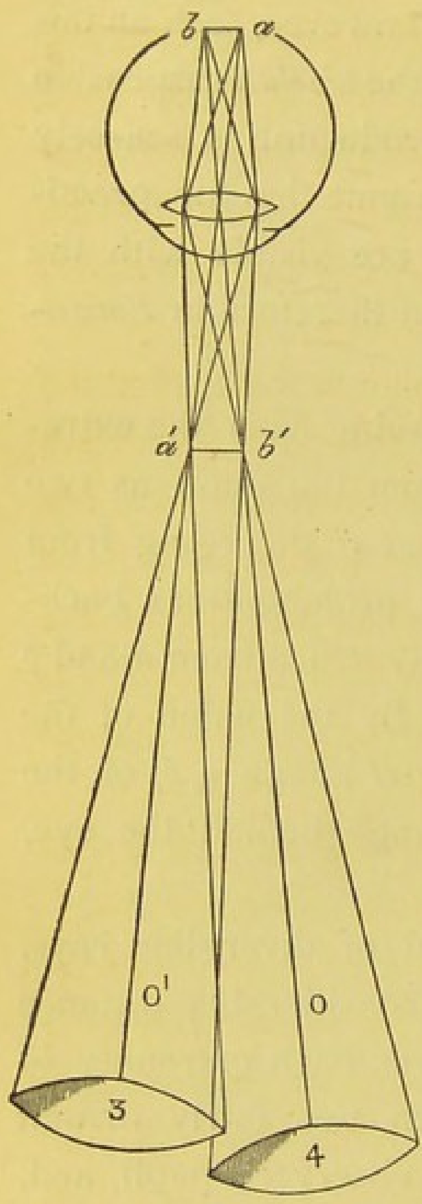


FIG. 7.

The aerial image thus seen, being *nearer* the observer than the patient's pupil, moves against the observer's head. (*Vide* following explanation).

The *apparent* movement of the image of the disc is easily explained when we remember that this image occupies a position further from the observer than the patient's pupil in H., and nearer to him than the pupil in M. This may be illustrated by holding two pencils vertically, one behind the other. If we suppose the *further* one to represent the image of the disc, and the near one the pupil, we have the respective positions of these objects in H. If, then, while moving the head laterally, we fix the eye on the *further* pencil, we find that this latter comes to be placed on the same side of the near one as that towards which we move. It *appears* therefore to travel *with* the observer.

If, however, we suppose the *near* one to represent the image of the disc, and the further one the pupil, we have their respective positions in M. On moving, then, the head laterally, while regarding the *near* pencil, it will be seen that this latter comes to be placed to the *left* of the further one when we move to the *right*, and *vice-versa*. It *appears* therefore to travel in a direction *opposite* to that of the observer.

The same explanation as that just given for the whole disc will apply also to vessels seen in different meridians.

In *Simple astigmatism*, we do not see vessels *at right angles* to the *emmetropic* meridian because rays from their *transverse* planes (*vide* Chap. V.) passing through the emmetropic meridian will (as was seen for simple emmetropia) not be visible. Whereas rays from the transverse planes of vessels at *right angles* to the myopic or hypermetropic meridian will, by passing through these meridians, produce in the former case an inverted, and in the latter an erect, image of the vessels. These follow the same rules of movement as in simple myopia and hypermetropia respectively.

In *Compound myopic astigmatism*, if the observer use his accommodation, vessels at *right angles* to the *most* myopic meridian will be distinctly seen much *closer* to the patient's eye than will those in the opposite meridian. Rays from the transverse planes of the former converge and form an inverted image much sooner than do those from the latter, just as in high degrees of simple myopia.

In *Compound hypermetropic astigmatism* we find that for the vessels at *right angles* to the *most* hypermetropic meridian more accommodation is required at a given distance from the eye, than for those in the opposite meridian. A greater extent of the former than of the latter vessels is, however, at the same time visible. Rays from the former are more divergent and the cones take longer to separate, *vide* Fig. 6.

In *Mixed astigmatism* images of the vessels *may* be seen sometimes inverted and at other times erect according to the meridian through which the rays emerge, and varying with the observer's accommodation. The details are more visible than in emmetropia, but are nevertheless very *indefinite.*

CHAPTER IX.

Keratoscopy (Retinoscopy.)

By means of what has been, unfortunately, called "Keratoscopy," we have a useful method of diagnosing errors of refraction with the ophthalmoscope mirror alone; and, what is perhaps equally important, we can correct them with ordinary trial lenses quite independently of aid from the patient. This plan is particularly valuable where it is impossible to obtain, either suspension of the accommodation, or complete steadiness of the eye under examination, as well as the *certainty* of relaxation of the observer's own accommodation. Without these conditions, the estimation of refraction by the ophthalmoscope, as described in Chap. XI., is quite impracticable. As long ago as 1864 (*vide* "Anomalies of Refraction and Accommodation of the Eye," Donders, p. 490) Mr. Bowman drew attention to "the discovery of regular astigmatism of the cornea, and the direction of the chief meridians, by using the mirror of the ophthalmoscope. . . . The area of the pupil then exhibits a somewhat linear shadow in some meridians rather than others."

Dr. Cuignet, of Lille, seems to have first systematised this method of examination, and, in 1874, published his conclusions in an article entitled "Keratoscopy."

Dr. Parent, of Paris, published an article on this method of examination, in the *Recueil d'Ophthalmologie* for Feb. and

July, 1880, and Dr. Forbes has drawn attention to the subject in the *Oph. Hosp. Reports*, vol. x. For valuable information concerning the theory of keratoscopy I would refer the reader to Dr. Charnley's article in the *Oph. Hosp. Reports*, vol. x., part iii.

The appearances, to be presently described, are due to the play of light and shade upon the *retina*, and are varied, in each case, by the refractive condition of the eye through which the rays of light reach, and issue from, the retina. Though the cornea, by means of its different curvatures, undoubtedly influences the appearances met with, yet, since it only acts as one of the refractive media, it would be preferable to drop the misleading word "Keratoscopy" and adopt, as suggested by Dr. Parent, the term Retinoscopy.

Rays of light from a distant lamp, falling on a *concave* mirror, issue from the latter convergingly, and crossing where they form an image of the lamp in front of the mirror, again diverge.

If, in front of a screen, we place a convex lens at such a distance that diverging rays from a concave mirror are brought to a focus exactly on the screen, there is formed the smallest and brightest possible image of the lamp, and the most sharply defined and densest surrounding shadow. If, then, we shift the lens, it is found that the further it is removed from the point just mentioned, either towards, or away from, the screen, the *larger* becomes the area of light and the *feebler* is the illumination.

The increasing circles of diffusion render indistinct the line of demarcation between light and shade, and cause the latter to appear fainter. If, with the lens at different distances from the screen, the mirror be variously rotated, the area of light and shade will be seen, in *every* position of the lens, to move, *on the screen*, in a direction *opposite* to, or *against*, that in which the mirror is rotated. If we replace the screen and lens by the retina and dioptric system of the eye (p. 5, DEF. 1) we have precisely similiar results. The area of illumination on the *retina*, in *all* states of refraction, really moves in a direction *opposite* to that in which the mirror is rotated. But since this illuminated portion is seen through the transparent media of the eye, the *apparent* direction of its movement will be influenced by the refraction of the eye under examination.

For making use of these facts in practice atropine, though not essential, certainly renders material assistance. The observer should be seated opposite to, and 1 m. 20 (48 ins.) away from the patient. The lamp is to be placed somewhat posterior to the patient's head, and to that side of it on which is the eye under examination. The latter is to be carefully shaded by a screen, while the rest of the room is rendered as dark as possible. The mirror used must be *concave*, and should have a focal length of about 22 cm. (9 ins.). If the observer be not emmetropic, he must correct his own error of refraction. The patient should regard the opposite wall, while the light from the mirror is thrown into his eye at an angle of 10° or 15° with his axis of vision; or, about in a line with the optic disc.

We then see, in the pupillary area, a bright image of the illuminated portion of the retina, bordered by a more or less linear shadow. If the mirror be now rotated around its various diameters, we shall see; *a*, that this *shadow* has its edge at *right angles* to that meridian of the eye parallel to which the mirror is rotated; *b*, that it travels along that meridian which is at *right angles* to the direction of its *edge;* and, *c*, that it indicates the refractive condition of this last named meridian.

If, for example, the mirror be rotated around its *vertical* meridian, from right to left or left to right, *i.e. parallel* to the *horizontal* meridian of the eye, the shadow will have its edge *vertical*; will travel in a *horizontal* direction across the area of the pupil; and will indicate the refraction of the *horizontal* meridian of the eye.

For any given meridian of the eye, the *direction* in which this shadow appears to move, *i.e.* whether *with* or *against* the mirror, depends upon, and furnishes the chief means of diagnosing the nature of, the refraction of that meridian.

If the rays issuing from the observed eye do not cross before reaching the observer, an *erect image* of the illuminated and shaded portion of the retina is obtained. This image is seen to move in the direction actually taken by the illuminated area upon the retina, viz., *opposite* to that in which the mirror is rotated. This is the case in H., E. and *low* M.

If, however, the issuing rays *cross* before reaching the observer, and form, between him and the patient, an inverted *aerial image* of the illuminated and shaded portion of the fundus, then, since the illuminated area on the *retina really* moves *against* the mirror, the *aerial image* of the same will appear to move in a contary sense, *i.e.*, in the *same* direction as, or *with*, the mirror. This appearance is met with in cases of M. of 1 D. ($\frac{1}{40}$) and upwards: for if the observer, with good power of accommodation, be seated as stated, at 1 m.20, from the patient, then, where the M. = 1 D. ($\frac{1}{40}$) the aerial image, being formed at 1 m. (40 ins.) from the patient, and 20 cm. (9 ins.) from the observer, will be easily perceived by the latter. Still more is this the case where, with increasing M., the image is formed nearer the patient. If, however, the M. be less than 1 D. ($\frac{1}{40}$), the convergent rays from the eye, either unite so close in front of the observer that no distinct image is received on his retina, or they meet behind him. In this latter case, the rays *not having crossed* before reaching the observer's eye, the image of the shadow is seen to move *against* the mirror. The way in which this condition is distinguished from H. or E., is explained further on (p. 33). If the eye under examination, be to such an extent myopic that its "far point" is situated at the position of the image of the lamp, say 25 cm. in front of the mirror, or 95 cm. from the eye, then the diverging rays from this image will come to a focus exactly on the patient's retina (DEF. 5 p. 5) and there form the smallest and brightest possible image of the lamp.

The further the departure from this degree, which we may call 1 D. ($\frac{1}{40}$) of M., the larger and feebler, as was seen on the screen, will be the illuminated portion of the retina.

The difference in degree of luminosity of this reflex can be easily appreciated, and furnishes a means whereby the amount of error may be approximately estimated : so that, speaking generally, we may say, the feebler the illumination the higher is the ametropia. An attempt has been made to use, for the same purpose, the difference in intensity of the shadow, but the appreciation of this is difficult and it therefore does not afford an altogether reliable source of information.

If, from some distance, say 1 m. 20, we examine an eye with the mirror alone, we find that, the higher the H. or M., the smaller is the image which we obtain of the disc: so that, in very high degrees, we see not only the whole disc, but also some of the surrounding fundus in the pupillary area. In E., on the other hand, so large is this image that only a small portion of it is visible at one time. With equally rapid rotations of the mirror then, the light would have to travel much faster over the large image of the latter, than the small image of the former, condition. This difference in the *rate* of movement in the various states of of refraction, was pointed out by my friend Dr. Charnley: it constitutes, especially when taken together with the *luminosity* of the image, probably the best of the means at our disposal for estimating, by this method, different *degrees* of ametropia.

In E. and the lower degrees of H. and M., so little is seen of the large image of the illuminated area and the surrounding shadow, that the small portion of the latter, visible at any one time in the pupillary area, appears approximately *linear;* while, although with the increasing degrees of H. and M., the nearly circular area of illumination on the retina also enlarges, yet, so much diminished is the image of the same, that more of the circumference of the surrounding shadow is visible at one time in the area of the pupil; it appears, therefore, more *crescentic,* while it becomes at the same time narrower.

Taking then the *direction* of the movement as denoting the *kind* of error; and the *rate* of movement, degree of luminosity, and curvature of the shadow, as indicating approximately the *amount* of the same, we may summarise as follows:—

1. If the image of the shadow move *with* the mirror: and, if the rapidity of movement, and curvature of the shadow, are the same in all meridians, we have a case of *simple* M.

2. If the image of the shadow move *against* the mirror: and, if the rapidity of movement, and curvature of the shadow, are the same for all meridians, we have to do with either H., E. or *low* M.

3. The *slower* the movements of the image, the *feebler* the illumination, and the more *crescentic*, and narrower, the shadow, the *higher* is the H. or M.

4. A *difference*, in two opposite meridians, either of the direction or rapidity of movement, or of the curvature, of the shadow, indicates *Astigmatism*. These two dissimilar shadows, moving at right angles to each other, either one vertically and the other horizontally, or both obliquely, denote the meridians of greatest and least refraction.

Since, however, as we have seen, with the shadow moving *against* the mirror there may be one of three conditions, we must distinguish between them in the following manner. Place in a spectacle frame, in front of the eye, a convex 1 D. ($\frac{1}{40}$). If the shadow *continue* to move *against* the mirror we know the eye to be Hypermetropic. But, if it now move *with* the mirror, it shews, either that the eye is Emmetropic and that we have produced artificial M. of 1 D. ($\frac{1}{40}$) or, that the eye is Myopic. We next replace the + 1 D. ($\frac{1}{40}$)

by + 0.75 D. ($\frac{1}{50}$) when, if the shadow move *against*, we know the eye to be Emmetropic; for, if M. of only 0·25 D. ($\frac{1}{160}$) were present we should produce M. of 1 D ($\frac{1}{40}$) and the shadow would move *with* the mirror.

The *amount* of error may be easily measured by ordinary trial lenses. If the shadow move *with* the mirror it proves that the eye is Myopic to the extent of, at least, 1 D. ($\frac{1}{40}$). We place therefore in the spectacle frame, *concave* lenses, gradually increasing in strength, until we find the *weakest* with which the shadow *ceases* to move *with* the mirror. As soon as this is the case, we know that the M., still remaining uncorrected, is less than one 1 D. ($\frac{1}{40}$). Suppose that with—4 D. ($\frac{1}{10}$) the movement is still *with* the mirror, it shews that there is 1 D. ($\frac{1}{40}$) left uncorrected and that the M. is at least 5 D. ($\frac{1}{8}$). If, on using—4·25 D. ($\frac{1}{9\frac{1}{2}}$), the movement *ceases* to be *with*, we know that there cannot be 1 D. ($\frac{1}{40}$) left uncorrected, and that the M. is not so much as 5·25 D. ($\frac{1}{7\frac{2}{3}}$). Seeing then, that the M. is between 5 D. and 5·25 D. we may order, as a correcting lens, — 5 D. ($\frac{1}{8}$) *i.e.* a glass 0·75 D. ($\frac{1}{50}$) *stronger* than the *weakest* lens with which the shadow *ceased* to move *with*. This would hold good for all cases if we were careful to ascertain the *very* weakest lens with which the latter result was obtained. Since, however, we must be careful not to give the glasses which are too strong (*vide* Chap. XII.), it will be better to say that, as a rule, in *Myopia* the glass ordered is to be 0·50 D. ($\frac{1}{80}$) *stronger* than the *weakest* lens with which the movement of the shadow *ceases* to be *with* the mirror.

When the shadow moves *against* the mirror, we proceed in the same manner with *convex* lenses until we find the weakest which reverses the movement. When this takes place, *i.e.* as soon as the shadow moves *with*, we know that we have produced artificial M. of 1 D. ($\frac{1}{40}$) : in other words that the H. is overcorrected by at least 1 D. Suppose that with + 4 D. ($\frac{1}{10}$) the shadow moves *against*, it shews that the H. is not *less* than 3 D. ($\frac{1}{12}$) for, if it were, the + 4 D. would have over-corrected it by 1 D. ($\frac{1}{40}$) and the movement would have been reversed. If, again, with + 4·50 D. ($\frac{1}{9}$) the shadow moves *with*, it shews that the H. cannot be *more* than 3·50 D. ($\frac{1}{11}$) for, if it were, the + 4.50 D. would not have over-corrected it 1 D. and the movement would not have been reversed. The H. is therefore between 3 D. ($\frac{1}{12}$) and 3·50 D. ($\frac{1}{11}$). It is evident then, that as a rule, in H. we may give a glass 1 D. *weaker* than the *weakest* lens which reverses the movement of the shadow.

If the *same* lens produces similar results for *all* meridians, we know that there is simple H. or M. But, if the weakest lens which reverses the movement in one meridian, leaves it unreversed in the other, we know that there is Astigmatism.

In *Simple Astigmatism*, (Def. 7, *a*) when we have found one meridian emmetropic, the other is corrected by a cylinder with its axis at *right angles* to the meridian along which the remaining shadow travels.

In *Compound Astigmatism*, (Def. 7) we may first reverse the movement in the least ametropic meridian by means of a spherical lens, and then reverse it in the other by a cylinder at right angles to the remaining meridian. This *latter* glass gives the degree of astigmatism and is therefore *actually* ordered. The *spherical*, however, as we have already seen, must be increased or diminished in strength according to whether it be concave or convex, respectively.

In *Mixed Astigmatism* (Def. 7, *c.*) the movement in one meridian is reversed by a spherical lens, and, that in the other, by an additional cylinder. If the former glass were convex, the latter would evidently be concave, and *vice versa* (*vide* Chap. XII. Astig.). In the correction ordered, we should give the *cylinder actually* reversing the movement, while the *spherical* lens would be increased or diminished in strength, according to whether it be concave or convex, as already explained. If each meridian be measured separately by means of a spherical lens, we have, in ordering the glasses, merely to give that spherical which corrects the ametropia in one meridian, and then, an additional cylinder, equal to the difference between the two sphericals, for the ametropia in the other meridian. The axis of the cylinder is of course at right angles to this latter meridian.

Care must be taken not to throw the light too obliquely on the eye, for, owing to the obliquity with which the rays traverse the media, the refraction of the horizontal meridian would be increased. It must also be carefully noted that the direction of movement of the *shadow,* as compared with the *mirror*, is the *reverse* of that of the *disc* or vessels, as compared with the *observer's head,* (*vide* Chap. VIII.).

In conclusion it may be as well to recapitulate some of the more important points mentioned in this chapter.

(i) The observer must always be seated at the *same* distance from the patient, viz. about 1 m. 20.

(ii) The mirror must be *concave* and preferably of 22. cm. focus.

(iii) The shadow travels along, and indicates the error of refraction in that meridian which is at *right angles* to the direction of its edge.

(iv) If the shadow move *with* the mirror, the refraction is myopic: and we order a lens 0·50 D. ($\frac{1}{80}$) *more concave* than the *weakest* with which its movement *ceases* to be *with* the mirror.

(v) If the shadow move *against* the mirror, we have a case of E., H. or *weak* M; and the glass ordered is 1 D. ($\frac{1}{40}$) *less convex* than that which reverses the movement.

(vi) The *feebler* the luminous reflex, and the *slower* the movement of the shadow across the area of the pupil, the *higher* is the ametropia.

CHAPTER X.

Indications afforded by Mirror and Object Lens. "Indirect Method."

This method of diagnosing Hypermetropia and Myopia was first pointed out by Mr. Hutchinson (*Ophth. Hosp. Rep.* vol. iv, p. 189) and Mr. Couper (*Med. Times and Gaz.* Jan. 30, 1869), has shewn how, by it Astigmatism may also be recognised. It is desirable that the patient should be under atropine, for otherwise an alteration in the pupil may easily lead to the supposition that the disc has changed in size. Upon seeing a change in the shape of the disc great care is requisite to say whether this is due to an elongation in one meridian or a diminution in the other.

In this mode of examination the observer must place the object lens *as close as possible* to the patient's eye; then, keeping the optic disc steadily in view, he must gradually withdraw the lens to the distance of a few inches: when—

Indication 1. If the disc remain the *same size* throughout, the patient is *Emmetropic* (*vide* expl. p. 39).

Indication 2. If the disc *diminish* in size on withdrawing the lens the patient is *Hypermetropic*, and the more so in proportion to the rapidity of diminution (*vide* expl. p. 40).

Indication 3. If the disc *decrease* in size *in one meridian only*, the patient is *Hypermetropic* in *that* meridian only = Simple hypermetropic astigmatism.

Indication 4. If the disc diminish in *every* direction, but *more* in *one* meridian than the others, there is *Hypermetropia all round*, but *most* in *that* meridian which decreases *most* = Compound hypermetropic astigmatism.

Indication 5. *Increase* in size on withdrawing the lens denotes *Myopia*, and more in proportion to rapidity of increase. (*Vide* expl. p. 41).

Indication 6. *Increase* in *one* meridian only, shows *Myopia* in that meridian alone = Simple myopic astigmatism.

Indication 7. *Increase* in *every* direction, but *more* in *one* meridian, indicates *Myopia* in *all* directions, but *more* in that meridian which *increases most* = Compound myopic astigmatism.

Indication 8. *Increase* in *one* meridian, and a *diminution* in the *opposite* meridian denotes *Myopia* in the former direction, and *Hypermetropia* in the latter = Mixed astigmatism.

Explanation of change in size of the disc.—These changes in size of the image of the disc will be evident on remembering that *the relative sizes of image and object are as their distances from the lens.* To find the distance of the image from the lens, we have the formula $\frac{1}{b} = \frac{1}{f} - \frac{1}{a}$ where b, = the distance of the image from the lens, f, = the focal length of the lens, and a, = the distance of the object. In each of the following examples the focal length of the lens is 4 cm.

In *Emmetropia* the rays issuing from the disc emerge from the eye *parallel* as if proceeding from an object situated at an *infinite* distance (Def. 3). It is of this supposed *object* that we get an *image* by means of a convex lens held in front of the patient's eye. It matters not, therefore, where this lens is held, the *parallel* rays from the object will *always* unite to form an image on the opposite side of the lens at its *principal focus* (Chap I, *b*). The relative distances of image and object from the lens remaining *constant*, the size of the image of the disc in Emmetropia does not vary with movements of the lens.

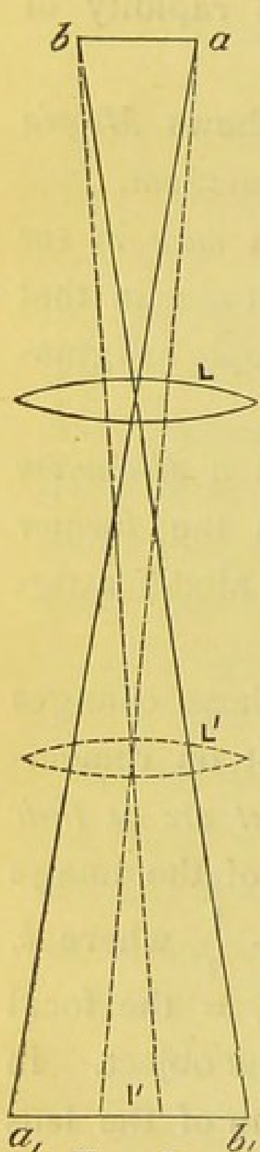


FIG. 8.

In *Hypermetropia*, fig. 8,* rays issuing from the disc emerge from the eye as if proceeding from an object, *b a*, at a certain distance behind it (Chap II, Def. 6.)

It is of this supposed object, *b a*, that we gain an *image*, $a_{,} b_{,}$ or I′, by means of a lens held in front of the patient's eye.

Suppose this lens, L, to be at 6 cm. from the *object*, we find by the formula that the distance of the image $a_{,} b_{,}$ is 12 cm. ($\frac{1}{b}=\frac{1}{4}-\frac{1}{6}=\frac{1}{12}$ or $b=12$.)

If we now withdraw the lens from the object (and also from the eye) till it is 12 cm. from the former as at L′, the distance of the image, I′ (between the dotted lines) will then be 6 cm. ($\frac{1}{b}=\frac{1}{4}-\frac{1}{12}=\frac{1}{6}$ or $b=6$.)

The ratio of the distance of the image from the lens as compared with that of the object from the lens being *greater* in the first case than in

* In Figs. 8 and 9, the distances of the lenses from the objects and images are drawn to scale ½ cm. = 1 cm.

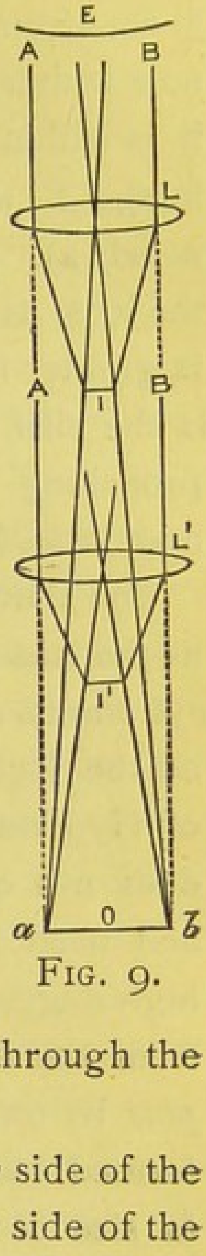


FIG. 9.

the second, so is the size of the image. In *Hypermetropia* on *withdrawing* the lens from the eye, the image of the disc *diminishes* in size.

In *Myopia*, fig. 9, rays from the disc emerge from the eye convergently and form, at a certain distance in front of it, an inverted aerial image, *a b*, of the disc. This latter we have now to regard as the *object*, O, whose image, I or I′, we obtain by means of a convex lens, L, or L′, interposed between it and the patient's eye, E. A lens, thus placed, intercepts the rays, B*b*, A*a*, (which, to avoid confusion, are the only ones shown of all those) which converge towards the points *b* and *a* respectively of this object, O. The rays being thus rendered more convergent, produce an image I or I′ whose extremities will be bounded by the lines passing from either end respectively of the object, O, through the centre of the lens, L or L′.

In this case, object and image are on the *same* side of the lens. The object here, being on the opposite side of the lens from the direction in which the rays proceed, it is customary, in order that the same formula may hold good in all cases, to regard $\frac{1}{a}$ as a *negative* quantity. For the distance of the the image from the lens then, we have the formula $\frac{1}{b} = \frac{1}{f} - \left(-\frac{1}{a}\right) = \frac{1}{f} + \frac{1}{a}$.

If we first place a lens, L, 12 cm. nearer the eye than where the object O would be formed, we have the image I at

3 cm. from the lens $\left(\frac{1}{b} = \frac{1}{4} + \frac{1}{12} = \frac{1}{3} \text{ or } b = 3\right)$. If we now withdraw the lens *from* the eye, *i.e.*, *towards* the *object* till it is within 6 cm. of the latter, as at L′, the distance of the image I′ will be nearly 2 cm. $\left(\frac{1}{b} = \frac{1}{4} + \frac{1}{6} = \frac{5}{12} \text{ or } b = \right.$ nearly 2). But as the ratio of the distance of the image from the lens, as compared with that of the object from the lens, is greater in the second than the first of these examples, so is the size of the image. In Myopia, therefore, on approaching the lens to the eye the image diminishes in size, and on *withdrawing* it *from* the eye the image *increases.*

The above explanation holds good for *Myopia* only so long as the lens is not withdrawn beyond the "far point" of the eye *plus* its own focal distance: for *Hypermetropia* only so long as the focal power of the lens is greater than the degree of Hypermetropia. The exception to this latter condition does not occur in practice if a lens of 3 ins. focus be used and need not therefore be considered. In the case of very high degrees of Myopia, however, if the lens be further from the eye than the aerial inverted image of the disc *plus* its own focal distance, an erect image of the disc is formed between the lens and the observer, the variations in size of which are subject to the same rules as those described for the inverted image in Hypermetropia.

CHAPTER XI.

Estimation of the Refraction by means of Lenses in the Ophthalmoscope.

In estimating refraction by this method the patient and observer must be seated side by side facing in opposite directions. Their heads and the lamp should be on the same level; the latter being placed on the same side of the patient as that under examination, a little out from, and slightly behind the position of, the patient's ear. If now the heads be inclined laterally towards each other, the eyes of the corresponding sides will come opposite one another while the noses and mouths will be left free for breathing. By this means the sight-hole of the mirror may generally be placed in the position which, when ordered, the glasses will occupy; the distance of these from the eye need therefore not be taken into consideration when prescribing from measurements thus obtained. Should it however be undesirable to approach thus close, the distance from the patient must be taken into account and the glasses ordered will have to be somewhat *weaker* in *myopia* and *stronger* in *hypermetropia* than the lens necessary to see the fundus would indicate. In estimating refraction by the ophthalmoscope it is absolutely essential that the accommodation of both patient and observer be *completely* suspended. In order to secure the former we must place the patient opposite a *dark* wall or curtain, or employ atropine.

For the observer voluntarily to relax his own accommodation while looking at an object so near to him as the patient's eye, requires much practice. The best way of overcoming the difficulty is to regard the fundus as situated some hundreds of yards distant. This habit may be acquired by looking alternately at a spot on the window pane and then at some remote object: or by gazing vacantly at the page of a book until the type disappears; then, having noticed the sensation produced on thus relaxing the accommodation, endeavour to induce the same condition while observing a fundus.

In the following indications it is of course necessary that the observer be fully cognisant of the state of his own refraction, and in the following cases he is supposed to be emmetropic, (if not, *vide* note, p. 46). With accommodation then entirely suspended, the eye of the emmetropic observer is adjusted for *parallel* rays.

Indication 1. If therefore he can see distinctly the details of any fundus, the rays issuing thence must be *parallel* and the eye *emmetropic*.

NOTE. Though this *appears* to contradict what has been said concerning seeing the disc in emmetropia, (Chap. VIII, p. 22), yet we must remember that when *close* up to the patient's pupil, the observer *does* receive rays from the two extremities of the disc. Moreover if the observer endeavour to accommodate for the patient's eye, he will find it impossible to do so, since, if he is as close as he should be, the latter, as explained by Mr. Power, is nearer to him than his "near point". The effort is therefore not maintained, and as when the accommodation is *partially* suspended the disc *begins* to appear, it is unconsciously *altogether* relaxed and a *distinct* view is obtained.

Indication 2. If, however, the details of the fundus cannot be seen except by the intervention of a *concave* lens, this proves the patient to be *Myopic*. The converging rays from such an eye, (Def. 5. p. 5.), require a *concave* lens to render them *parallel* for perception by the emmetrope. The strength of the lens which effects this change of direction indicates the *degree* of M., for it is evident that the same lens which renders parallel the converging rays issuing from the retina, will bring parallel rays to a focus on the retina of the same eye.

Indication 3. If again, with suspended accommodation, the details of the fundus are not visible without the aid of a *convex* lens, this indicates the patient to have *Hypermetropia*. The diverging rays from a hypermetropic eye require a convex lens to render them parallel. The strength of the lens necessary for this purpose denotes the amount of H., for the lens which renders parallel, rays proceeding from a retina, will also bring parallel rays to a focus on the same retina.

Indication 5. If the vessels in one meridian are seen without any lens while a convex or concave lens is required for those in the other meridian, it is a case of *Simple astigmatism*. The emmetropic meridian is the one at *right angles* to the vessels seen without any lens, (*vide* Chap. V, p. 14).

Indication 6. If, for the two opposite meridians, we require *either* two convex *or* two concave lenses of *unequal* power, we have to deal with a case of *Compound* astigmatism: hypermetropic or myopic respectively. The *greatest* error of refraction in each case is at *right angles* to the vessels for which the *strongest* lens is necessary.

Indication 7. If, for vessels in one meridian we require a *convex* lens, while for those in the other a *concave* is necessary, it indicates *Mixed* astigmatism. The *hypermetropic* meridian is at *right angles* to the vessels seen best with a *convex* lens: and the myopic to that for which a concave lens is necessary.

In all these forms of astigmatism then, we see that the lens which, with *absolutely* suspended accommodation, gives the best view of vessels in *one* meridian, measures the *amount of* error which exists in the *opposite* meridian.

NOTE. Should the observer not be emmetropic, yet, if he correct his own error with spectacles, he is in the same position as an emmetropic observer. If he however prefer to estimate refraction without his glasses he must make an allowance for his defect by means of the lenses behind the sight-hole of the mirror. To see the details of an *emmetropic* fundus, a hypermetropic or myopic observer *starts* with a lens corresponding to the amount of his own error. For any particular fundus, therefore, the glass required by him must be, to the extent of his H. or M., *more* convex or concave respectively than would be necessary for an emmetrope to see the same fundus. Consequently the *patient* will always have that amount *less* H. or M. respectively than the same lens would indicate if the observer were emmetropic; we have then the

RULE II. That the observer must *deduct* the amount of his own H. or M. from the lens which enables him to see distinctly any particular fundus.

Tabular view of the State of Refraction as indicated by the various methods.

TEST TYPES.			OPHTHALMOSCOPE.				
			MIRROR ALONE.				
DISTANT VISION.	NEAR VISION.	RAYS IN FAN.	Movement of *Image of O. D. and vessels* compared with *Head.*	Movement of *Image of Shadow* compared with *mirror.*	INDIRECT METHOD. Image of O. D. on *withdrawing* lens.	Lens necessary in Ophthalmoscope *without accom.*	REFRACTION.
$\frac{6}{6}$ $\left(\frac{20}{20}\right)$	Sn. 1. 5 in. to 20 in.	All clear.	Red reflex only.	*Against*; same rate in all meridians.	Constant in Size.	None.	E.
By accom. may be $\frac{6}{6}$ but is often less.	Sn. 1, or larger, but *not close up.*	All clear *by accom.*	Erect; moves *with.*	*Against*; same rate in all meridians.	Decreases.	Convex.	H.
Not $\frac{6}{6}$	Sn. 1, (or 2) but not so far off as distance marked.	None.	Inverted; moves *against.*	*With*: (except low M) same rate in all meridians.	Increases.	Concave.	M.
Not $\frac{6}{6}$	Larger series (or smaller with difficulty).	*One* clear at *rt. ang.* to *Em.* meridian.	Vess. parallel to *Em.* merid. move *with.*	In two opp. merids. Both *against* at diff. rates.	Decreases in *one* meridian only	Vess. Parl. to Em. merid. = + Vess. Parl. to Hc. merid. = O.	H. As.
			Vess. parallel to *Em.* merid. move *against.*	In two opp. merids. one *against*, one *with.*	Increases in *one* meridian only.	Vess. Parl. to Em. merid. = — Vess. Parl. to Mc merid. = O.	M. As.
Variable.	Larger only.	Varying with accom.	Vess. at diff. distances, *all* move *with.*	In two opp. merids. Both *against* at diff. rates.	Decreases all round, but *more* so in *one* meridian.	Two diff. *convex.*	C H.As.
		None.	Vess. at diff. distances, *all* move *against.*	In two opp. merids. Both *with* at diff. rates.	Increases all round but *more* so in *one* meridian.	Two different *concave.*	C.M.As.
		One at *rt. ang.* to Hc. merid. *by accom.*	Some vess. *with* and others *against.*	In two opp. merids. one *against*, one *with.*	Decreases in *one* but Increases in *opp.* meridian.	One merid. + Opp. merid. —	M . As.

Abbreviations:—E. Emmetropia; M. Myopia; H. Hypermetropia;
H. As Simple Hypermetropic Astigmatism: C. H. As. Compound Hypermetropic Astigmatism.
M. As. " Myopic " C. M. As. " Myopic "
Md. As. Mixed Astigmatism; Vess. Vessels; Parl. Parallel; Diff. Different; O. D. Optic Disc.

CHAPTER XII.

Test Glasses and Types as applied to the Estimation of Refraction.

When ascertaining with the distance types the state of the patient's refraction, we must be absolutely certain that his accommodation is completely relaxed. In myopes, it generally is so, but in hypermetropic and astigmatic patients it is frequently a troublesome and misleading factor. If, from the varying and inconsistent statements of the patient, it is suspected that he does not relax his accommodation, he may do so more easily if he close his eyes between each change of glasses, not opening them until the fresh ones are *in situ*. Another method of assisting the patient is to let him put on a pair of + 4 D. (10 ins.) for ten or fifteen minutes, and then, without removing, gradually neutralise them by stronger and stronger concave lenses placed in front, until those are found with which the patient can see in the distance as well as without any glass. The *difference*, then, between the concave lens thus required and + 4 D. ($\frac{1}{10}$), gives the manifest hypermetropia.

One caution must be especially borne in mind, viz, : *never*, in any doubtful case, to commence testing vision with *concave* glasses, for to see with such lenses it is necessary for all, except those whose myopia is equal to or less than the glasses being used, to employ their accommodation, and when once called into activity, this is not easily suspended.

Let the patient be placed at 6 cm. (20 ft.) from the types. We have already seen what, with test types, are the indications of emmetropia and simple presbyopia, (p. 18).

Hypermetropia.

If the patient read $\frac{6}{6}$ ($\frac{20}{20}$) perfectly without glasses, still *this fact does not exclude Hypermetropia*, the presence of which is *proved* if he can read the distance types as well with, as without, *convex* lenses. The *strongest* which are thus tolerated indicate the degree of *manifest* hypermetropia, and they *at least* must be ordered for close work. In young adults, and in the higher degrees of H., we must for this purpose even give glasses 1 D. or 1·50 D. ($\frac{1}{40}$ or $\frac{1}{24}$) stronger. In order to rest the ciliary muscle, it is advisable for distant V. to prescribe at any rate the glasses which correct the *manifest* hypermetropia. If the H. be measured under atropine, the glasses ordered must be 1 D. (or possibly even 1·50 D.) *weaker* than the total amount thus found (*vide* Chap. XII.) These should be suitable for all purposes, though, for distant V., weaker ones are sometimes necessary.

Myopia.

As we have already stated, (Chap. VII. Ind. 3) if the patient *can* read the *finest* type to within 4 ins. or 5 ins. of his eye, while at the same time his distant V. does not exceed $\frac{6}{24}$ ($\frac{20}{70}$) and is probably not $\frac{6}{60}$ ($\frac{20}{200}$), he is *myopic.* An indication of the *degree* may be obtained by observing the *furthest* point at which either of the smallest types can be read. Provided it be nearer than that for which it is marked, the *distance* of this point gives the *focal length* of the lens required to neutralise the M.

e.g.—If Sn. 1 be legible only as far off as 12 cm. (5 ins.) the M. is measured by the concave lens having this focal length, viz., 8 D. $\left(\frac{1\ D.}{12\ cm.}\right)$ or ($\frac{1}{5}$). Or again, if No. 4 Sn. marked for 1 D. (40 ins.), can be read only at 50 cm. (20 ins.), the M. = 2 D. $\left(\frac{1\ D.}{50\ cm.}\right)$ ($\frac{1}{20}$).

In testing the distant V. we commence with the *weaker* concave glasses, and work up to the stronger. In doing this, we cannot be too careful in ascertaining which is the *weakest* glass that neutralises the M. and gives the best V., whether this be $\frac{6}{6}$ ($\frac{20}{20}$) or less. The glass thus found gives the measure of the M. and may in *all* cases be ordered for *distant* V. Such glasses may also be given for *close* work when, *with good accommodation,* the M. does not exceed about 6 D. or 8 D. ($\frac{1}{6}$ or $\frac{1}{5}$). In *most* cases where the M. is higher, and in *all* where the accommodation is feeble, we must order *weaker* glasses for *close* work. These, according to Donders, may be found in the following manner, viz: From the neutralising lens *deduct* the strength of the glass whose focal length equals the distance at which we wish the patient to work.

e.g.—With M. = 10 D. ($\frac{1}{4}$) we wish the patient to do work at 40 cm. (16 ins.) From 10 D. ($\frac{1}{4}$) we deduct therefore the lens whose focal length is 40 cm. (16 ins.), viz. : 2·50 D. ($\frac{1}{16}$), and the glasses ordered will be (10 D.— 2·50 D.=) − 7·50 D. ($\frac{1}{4} - \frac{1}{16} = \frac{1}{5\frac{1}{3}}$)

For the various exceptions to these, only very general indications of glasses to be ordered, as well as for the numerous complications of myopia, the reader must be referred to the larger works on this subject.

Astigmatism.

If the V. cannot be brought up to $\frac{6}{6}$ ($\frac{20}{20}$) with any *spherical* glasses, we probably have to do with a case of *Astigmatism.* In dealing with this error *each* eye is to be tested *separately.*

If, from the previous examination with the ophthalmoscope, we have, diagnosed,—

(1.) *Simple* astigmatism, we can proceed to test with the fan of rays. If our surmise has been correct, the patient should now see *quite distinctly*, *only* the line at *right angles* to his emmetropic meridian, (Chap. V.) If this line were *vertical,* it would therefore denote that the meridian *parallel* to it was either hypermetropic or myopic; we should then ascertain what cylinder, with its axis at *right angles* to this latter meridian is required to correct it: *i.e.* to render clear the horizontal line. If the correction thus found gives V. = $\frac{6}{6}$ ($\frac{20}{20}$), it may be ordered for constant use; but if it do not, then, as where none of the rays are distinct, and more particularly if first one then another is most clearly seen, we must not hesitate to employ atropine.

It matters not now, whether we have to deal with—

(2.) Compound or mixed astigmatism. We have merely to ascertain what *spherical* lens clears *one* of the rays, and then, leaving this glass *in situ*, try what cylinder, with its axis at *right angles* to the line thus cleared, renders equally distinct the ray in the opposite meridian. This sphericocylindrical correction, *after due allowance for atropine* (Chap. XIII.), is ordered for constant use.

(3.) Another less scientific, though practically useful plan, is to substitute the test-type for the lines, and having found the spherical lens which gives the best V., try what additional cylinder is required.

(4.) If *each* meridian has been measured *separately* with spherical glasses, either for the fan, or in the ophthalmoscope for the fundus, we shall have to calculate what spherico-cylinder is required. (*a.*) For *compound* astigmatism we generally give the *spherical* lens, which corrects the meridian of least error, and then add the cylinder (concave for myopic, and convex for hypermetropic astigmatism), whose strength equals the difference between the two meridians. (*b.*) In *mixed* astigmatism the *difference* between the *sphericals* also gives the degree of astigmatism and the strength of the cylinder required. If, therefore, we correct the myopic meridian with a *concave spherical* lens, we shall require in addition a *convex* cylinder and *vice-versa*.

e.g.—With vertical meridian myopic 2 D. ($\frac{1}{20}$) and the horizontal meridian hypermetropic to the same extent, the *difference* between them = 4 D. ($\frac{1}{10}$). If, therefore, we give *minus* 2 D. sph. ($\frac{1}{20}$), we must add *plus* 4 D. cyl. ($\frac{1}{10}$) with its axis *vertical*, (*i.e.*, at *rt. angles* to the hypermetropic meridian, Chap. I., p. 4.) But if we give *plus* 2 D. sph. ($\frac{1}{20}$), we shall require in addition *minus* 4 D. cyl. ($\frac{1}{10}$) axis horizontal. The action of atropine (Chap. XIII.), must of course be taken into account.

5. Another method of testing astigmatism is by means of Tweedy's optometer, of which, with the exception that the later instruments are marked in dioptres and inches instead of only in inches, he has published a description in the *Lancet*, for Oct. 28, 1876. The patient under atropine, is made artificially myopic by a convex lens, a card with fine radiating lines is gradually approached to his eye, until *one* line becomes quite distinct. The meridian at *right angles* to this line is then known to be the *least* refractive. The *concave* cylinder is found, which, with its axis at *right angles* to the line first seen, makes the line in the opposite meridian equally distinct. This shews that the latter meridian is now made as little refracting as the former. The distance at which the first line is seen indicates the kind and degree of the error for the *least* refracting meridian. A *spherical* lens correcting this is then ordered, and, in combination with it, the *concave* cylinder of the strength, and in the axis, which were found necessary to equalise the two meridians.

Presbyopia.

Though the patient does not require glasses for distant V., he may, as age advances, find it more and more difficult to *read* without them. This defect is called *Presbyopia* and is caused chiefly by failure in the power of accommodation, but is also accompanied by a flattening of the crystalline lens. It is *indicated* by a *recession of the near point*, and it is said by Donders to have commenced when this is further from the eye than 22 cm. (9 ins.), *i.e.*, than the focal length of a lens whose refracting power is 4·50 D. ($\frac{1}{9}$). As we have already seen, (Chap. IV.) such a lens would, in *Emmetropia*, bring rays from the "*near point*" to a focus on the retina in the absence of *all* accommodation.

The *difference*, then, between this lens and one whose focal length equals the distance of any given *receded* near point, denotes for *Emmetropia* the amount of accommodation which is deficient, and the lens necessary to enable the patient again to read at 22 cm.

e.g.—With near point receded to 40 cm. (16 ins.) we must deduct from 4·50 D. ($\frac{1}{9}$), the lens, whose focal length is 40 cm. (16 ins.) viz., 2·50 D. ($\frac{1}{16}$) and have, as the necessary lens, + 2 D. ($\frac{1}{20}$).

When *all* accommodation is lost, even an eye which was *originally emmetropic* may require a convex lens for parallel rays (Donders). The strength of this lens must, of course, then be *added to* 4·50 D. ($\frac{1}{9}$) in order that such a patient may read at 22 cm. (9 ins.)

The following table gives, according to Donders, the glasses necessary for Presbyopia in *Emmetropia* at different ages.

AGE.	GLASS.	
	D.	ENGLISH INCHES.
45	1	$\frac{1}{40}$
50	2	$\frac{1}{20}$
55	3	$\frac{1}{12}$
60	4	$\frac{1}{10}$
65	4·50	$\frac{1}{9}$
70	5·50	$\frac{1}{7\frac{1}{2}}$
75	6	$\frac{1}{7}$
80	7	$\frac{1}{6}$

Since these are the glasses which enable the *emmetropic* eye to see at 22 cm. (9 ins.) it is evident that, if either M. or H. be present, the amount of the former must be *deducted from*, and that of the latter *added to*, the lens here specified for any particular age. Though these are *theoretically* the glasses required, we must test practically each individual case, for the various patients prefer different distances, at which to read or work.

APHAKIA

or "*absence of lens*," as after cataract operations, involves loss of accommodation. If we replace the crystalline lens by a glass in front of the eye which focusses parallel rays on the retina, we render the eye *practically emmetropic*. To enable such a patient to read at any specified distance, it is necessary merely to add to that glass, the lens whose focal length equals the distance in question.

e.g.—If a patient requires + 13 D. ($\frac{1}{3}$) for parallel rays and we wish him to read at a distance of 33 cm. (12 ins.), we add together 13 D. ($\frac{1}{3}$) and the lens whose focal length is 33 cm. (12 ins.), viz.: 3 D. ($\frac{1}{12}$), thus getting + 16 D. ($\frac{1}{2\frac{1}{2}}$) as the necessary glass.

For cataract patients we order two pairs of spectacles. One for distant V., generally + 10 D. to + 13 D. ($\frac{1}{4}$ to $\frac{1}{3}$), and the other for reading, from + 15 D. to + 20 D. ($\frac{1}{2\frac{3}{4}}$ to $\frac{1}{2}$) according to the previous state of the refraction.

To ascertain whether the glasses given, accord with our prescription, it must be remembered that if, while moving a *convex* lens to and fro in front of our eye, we regard some distant object, this latter appears to move in the *opposite* direction. A contrary effect is produced with a concave lens. A concave and a convex lens of equal strength *neutralise* each other, and there is no movement of the object.

If this latter result is obtained with a lens of the *same* strength as that ordered (though of an *opposite sign*), the glasses are correct. If the lens, thus necessary, is *not* of the same strength, we ascertain the amount of error by noting the number of the glass required for neutralisation.

CHAPTER XIII.

ATROPINE:—ALTERATIONS NECESSARY IN MEASUREMENTS MADE UNDER ITS INFLUENCE.

ACCORDING to DEF. 3, parallel rays *should* come to a focus on the retina of an emmetropic eye when the accommodation is completely paralysed by atropine. Emmetropia, however, as thus defined, is rarely met with. An eye may have V. = $\frac{6}{6}$ ($\frac{20}{20}$) and its distant V. made indistinct by even the *weakest* convex lens, yet, when fully under atropine, it will generally be found that a certain amount of accommodation *was* being exercised, for a *convex* lens is *now* necessary to see $\frac{6}{6}$ ($\frac{20}{20}$), *i.e.*, to bring practically parallel rays to a focus. That portion of the accommodation which can be overcome only by atropine is due to the "*tone*" of the ciliary muscle, and must always be taken into the calculation when ordering glasses from the measurement of the refraction as determined under atropine. For *practical* purposes, we may consider that eye emmetropic, which, when fully under atropine, does not require a convex lens stronger than 1 D. ($\frac{1}{40}$) for parallel rays.

In *Hypermetropia* the convex lens which brings parallel rays to a focus, when the eye is fully under atropine, should *theoretically* convert it into an emmetropic eye. It is found, however, *practically* that, owing to hypertrophy of the ciliary muscle, patients with this error of refraction find great difficulty in relaxing their accommodation to anything like its fullest extent. The result of this is, that the lens which brings parallel rays to a focus under atropine, cannot be ordered for the same eye with its accommodation active. The increased convexity of the crystalline lens (produced by accommodation) added to the correcting lens just mentioned, renders parallel rays too convergent, and brings them to a focus in front of the retina. In Hypermetropia, then, it becomes necessary to *deduct* from the measurement made under atropine at least 1 D. ($\frac{1}{40}$), and, in children and young adults, sometimes as much as 1·50 D. ($\frac{1}{24}$) for the tone of the ciliary muscle.

In *Myopia* the concave lens which brings parallel rays to a focus on the retina of an eye under atropine will be found *too weak* for the same eye when *not* under atropine. The effect of the accommodation is to bring to a focus in front of the retina, the rays which, under atropine, were focussed upon it; in other words, the myopia is still uncorrected, and requires a concave lens 0·50 D. ($\frac{1}{80}$) or 0·75 D. ($\frac{1}{50}$) stronger. We have, therefore, the

Rule III.—That glasses ordered for permanent use must when *convex*, be 1 D. ($\frac{1}{40}$) or occasionally 1·50 ($\frac{1}{24}$) *weaker*, and when *concave*, 0·50 D. ($\frac{1}{80}$) to 0·75 ($\frac{1}{50}$) *stronger*, than is indicated by the measurements made under atropine.

The application of this rule need be exemplified only in a case of mixed astigmatism. If, under atropine, one meridian be hypermetropic, 2 D. ($\frac{1}{20}$) and the other myopic, 2 D. ($\frac{1}{20}$), the fully correcting glass would be *either* + 2 D. sph. ◯* — 4 D. cyl. (+ $\frac{1}{20}$ sph. ◯ — $\frac{1}{10}$ cyl.) *or* — 2 D.

* The sign ◯ means "combined with."

sph. $\bigcirc$ + 4 D. cyl. (— $\frac{1}{20}$ sph. $\bigcirc$ + $\frac{1}{10}$ cyl.). The glasses ordered for permanent use would be, in the first case, + 1 D. sph. $\bigcirc$ — 4 D. cyl. (+ $\frac{1}{40}$ sph. $\bigcirc$ — $\frac{1}{10}$ cyl.) and in the second — 3 D. sph. $\bigcirc$ + 4 D. cyl. (— $\frac{1}{12}$ sph. $\bigcirc$ + $\frac{1}{10}$ cyl.). In the former example, by *deducting* 1 D. ($\frac{1}{40}$) from the *convex spherical* we at the same time *practically add* 1 D. ($\frac{1}{40}$) to the strength of the *concave* cylinder (for it has thus *less* neutralisation to perform). While in the second example, by *adding* 1 D. ($\frac{1}{40}$) to the *concave spherical* we *lessen* the strength of the *convex* cylinder, since it now has more to neutralise.

In *Mixed* astigmatism, then, by *deducting* from the strength of the spherical, we *increase* that of the cylinder: and, by adding to the strength of the spherical, we *diminish* that of the cylinder.

In *Compound* astigmatism, if we add to, or deduct from the strength of the spherical, we at the same time increase or diminish respectively the correction for each meridian.

The calculations necessary for the action of atropine may thus be made for both meridians simultaneously, by means of the *spherical* lens alone.

In simple astigmatism, as we have seen (p. 51) atropine is not necessary.

Conclusion.

It need scarcely be mentioned in conclusion that there are many cases in which, though the error of refraction has been duly diagnosed, estimated and corrected, yet there is no consequent improvement in vision. Such results may be found in old standing cases of strabismus or in diseased eyes. Others again, without any error of refraction, may have defective vision owing to disease; with such, however, we have not here to deal. These pages have been intended merely to indicate the various modes of estimating and correcting errors of refraction; the reason why, after such correction, the vision is not improved must be ascertained by other means. Some patients, in whom we cannot find either disease or error of refraction, may simulate total or partial blindness. The latter may often be detected by holding in front of their eyes different pairs of convex, neutralised by their corresponding concave lenses. With these, thinking they are being aided, such patients may frequently be persuaded to read perfectly. Another method of detecting simulation, especially of *one* eye, is to hold in front of the *blind* (?) eye, a prism with its base out or in, when if there be an attempt (seen by movement of the eye) to fuse the *double* images, it proves sight present in the eye in question.

If some such order of procedure, as indicated in these pages, were adopted, one would not, as is now frequently the case, see a beginner fall into the error of supposing a patient myopic because he can read $\frac{6}{6}$ ($\frac{20}{20}$) as well with, as without, a *concave* lens; or that hypermetropia is present because the patient can read Sn. 1 with *convex* glasses.

Some of the statements may have appeared somewhat too general but it has been thought advisable not to confuse the beginner by enumerating all the possible and minor exceptions to the general rules.