ON

# DEFECTS OF VISION

WHICH ARE

## REMEDIABLE BY OPTICAL APPLIANCES.

### A Course of Lectures

DELIVERED AT

THE ROYAL COLLEGE OF SURGEONS OF ENGLAND,

BY

ROBERT BRUDENELL CARTER, F.R.C.S.,

LATE HUNTERIAN PROFESSOR OF PATHOLOGY AND SURGERY TO THE COLLEGE;
OPHTHALMIC SURGEON TO ST. GEORGE'S HOSPITAL;
SURGEON TO THE ROYAL SOUTH LONDON OPHTHALMIC HOSPITAL;
CORRESPONDING MEMBER OF THE ROYAL MEDICO-CHIRURGICAL SOCIETY OF EDINBURGH.

With Numerous Illustrations.

LONDON:
MACMILLAN AND CO.
1877.

GLOUCESTER:
PRINTED BY JOHN BELLOWS,
STEAM PRESS.

# PREFACE.

THE following Lectures were delivered at the Royal College of Surgeons during the present year, and were immediately afterwards published in the *Medical Times and Gazette*. They are now reprinted with only a few verbal alterations.

My object in composing them was to place in the hands of the profession a simple account of conditions which are often sources of great trouble and annoyance to patients, which generally admit of being relieved, and concerning which there have been recent changes both as regards nomenclature and practice.

*69 WIMPOLE STREET, W.*
*October, 1877.*

# CONTENTS.

# LECTURE I.

# REFRACTION.

MR. PRESIDENT,

THE fact that certain defects of vision can be corrected by optical appliances is one which has been known to the human race from very remote antiquity. In England, spectacles did not come into common use until the reign of Richard II.; but in China, and probably in other Oriental countries, they have been employed from time immemorial. The limits within which these lectures are confined afford me no opportunity of entering into historical questions; but this is scarcely to be regretted, inasmuch as spectacles appear to have been used empirically, and with very little knowledge either of their precise mode of operation or of the conditions which called for them, until the invention of the ophthalmoscope furnished the starting-point for researches in physiological optics which have richly rewarded many of those who have taken part in them. Prior to the time mentioned there had, indeed, been illustrious Englishmen, notably Porterfield and Thomas Young, who had devoted much attention to similar problems. Unfortunately, however, even Young, who alone among these enquirers must be credited with the possession of the necessary combination of physical, physiological, and geometrical knowledge, scarcely appears to have occupied himself with the clinical requirements of mankind; or to have had any extensive or accurate acquaintance with the actual optical wants of the many sufferers from defective vision. Thus, when he had analysed his own astigmatism, and had discovered the form of the lens by which it could be corrected, it does not seem to have occurred to him that the defect was a common one, by which many persons were practically debarred from the full use of their eyes; and neither he, nor in more recent time Airy, made any attempt to arrive at formulæ for dealing with astigmatism which should be of easy and universal application. Many of those who concerned themselves with the phenomena of vision were content to assume the existence of conditions which were optically sufficient to explain the facts; and did not trouble themselves to ascertain whether these assumed conditions had any real existence. Thus, in my own youth, there were elementary treatises on optics in the hands of boys; and these treatises, I believe without exception, set forth that short sight was due to unnatural convexity of the cornea, and that presbyopia was due to a progressive flattening of the cornea, which occurred during the decline of life. It is manifest that unnatural convexity of an otherwise symmetrical cornea might produce some of the symptoms of short sight, and also that progressive flattening of the cornea might to some extent imitate presbyopia; but, as a matter of fact, neither of these conditions is met with. The cornea of a myopic eye is, as a rule, somewhat less convex than the normal standard; and there is no flattening of the cornea as life advances. It is hardly necessary to say that, while questions of this kind were disposed of by ingenious guesses, and without appeal to facts, no scientific progress or precision of knowledge could even be expected. Of late years, however, since the investigation of all the optical causes of defective sight has been recognised as forming one of the most important branches of ophthalmic surgery, we have been arriving by degrees at more accurate information; and, although there is still much to be learned, the growth of knowledge within a comparatively short period of time has been sufficient to afford good ground for congratulation, and also sufficient to relieve a very large amount of discomfort or even suffering. It may now be laid down, as a general principle, that almost every eye which has good vision under any limitations of time or distance can be so assisted as to be made comparatively independent of these limitations, and able to accomplish its proper share of work in the world; while some eyes, which when unaided have not good vision under any circumstances, may have their defects remedied by lenses of various kinds.

The vision of the natural eye ranges from infinity to a so-called near-point, which gradually becomes more remote from the cornea as life advances, but which should not be farther away than eight inches. A pair of such eyes possess clear vision of all objects over the specified range of distance, that is, from eight inches to the horizon or the fixed stars; and they can continue the act of seeing, at any point over the whole of this range, for any reasonable time without interruption. The vision of the myopic eye is conditioned by space, and so also is that of the presbyopic eye; the former not being able to see clearly any objects which lie beyond a definite distance, and the latter not being able to see clearly any objects which lie within a definite distance. The presbyopic eye has its near-point farther away than eight inches, or than is natural; and the myopic eye has its far-point nearer than infinite distance. In the asthenopic eye, there may be similar limitations of vision within given distances; but the limitation chiefly complained of is one of time. The patient can see, if not perfectly, yet sufficiently well for many purposes, for a given period only; and, when this period is overpast, the sight becomes blurred, or the eyes become painful, and further use of them, in either case, becomes difficult or impossible. In all the foregoing conditions, whenever there is useful sight within any range, however limited, or for any time, however short, we may be satisfied that we have to deal with a defect which can be remedied, always in some degree, and often completely, by optical means; or, in other words, that the fault is in the curvatures of the refracting surfaces of the eye, or in its shape, or in its muscular organs of adjustment or of direction, and neither in the transparency of its media nor in the nervous apparatus of vision, either central or peripheral. The distinction thus made, as we shall see hereafter, is often one of the greatest possible importance to the patient.

There are, indeed, a few cases, chiefly those of high degrees of astigmatism, in which the unaided vision, within all limits of space or time, is always very defective, and in which the defect is nevertheless entirely optical. To these it will be necessary to return hereafter; and they are only mentioned now because they furnish apparent exceptions to the general rule that it is only the eyes which possess good vision under some circumstances to which the surgeon may afford relief by optical means alone.

In order to make clear the nature of limited or conditioned vision, it is necessary to glance at the chief functions upon which vision depends; and in doing this I shall trust to be pardoned if I deal, for a short time, with very elementary matter. There are certain facts so universally known that it would not be proper to dwell upon them at any length; and yet so important, that it would not be proper to omit all mention of them.

The factors of normal vision, then, assuming that the media are transparent, and that the nervous structures are healthy and receptive, are three in number—namely, Refraction, Accommodation, and Convergence. By Refraction, is meant the optical state of the eye when at absolute rest; by Accommodation, the power of adjusting it to see with equal clearness at varying distances within its far-point; and by Convergence, the power of directing the visual axes of the two eyes to some point nearer than infinity.

Dismissing from consideration, for the sake of simplicity, the actual complexities of its structure, we may regard the eye merely as a *camera obscura*, designed to form inverted images of outward objects upon the percipient layer of the retina. In like manner, we may regard the several refracting surfaces as forming only a single convex lens of definite focal length; and it is obvious that this focal length may either be equal to, or somewhat different from, the length of the antero-posterior axis of the eyeball. If the length of the antero-posterior axis of the eyeball is precisely equal to the principal focal length of the refracting media, it follows that parallel rays of light, such as proceed from infinitely distant objects, will be united in a focus upon the retina, and the eye is then said to be *in measure*, or *Emmetropic*, as in Fig. 1. If, on the other hand, the eye is longer than the focal length of the media, the focus of parallel rays will be in front of the retina, as in Fig. 2; and, if the eye is shorter than the focal length of the media, the focus of parallel rays would be behind the retina if they could pass through it, as in Fig. 3. These two conditions, in which, taking the focal length of the media as a standard, the eye is too long and too short respectively, are both expressed by the common term *Ametropia*, the eye being *out of measure*; but it is manifest that the conditions themselves have very little else in common, and that they must require to be separately discussed and differently treated. It is also manifest that a veritably emmetropic eye can only be formed by a correspondence of measurement so exact that it cannot often be expected to occur; and that a certain amount of ametropia, on one side or the other, must be the rule rather than the exception. Unless this ametropia attains a degree capable of easy recognition and measurement, it does not become disturbing to vision, and does not in any way declare its presence; and we therefore call many eyes emmetropic, which, if strictly examined, would be found not to fall within the terms of the definition.

FIG. 1.

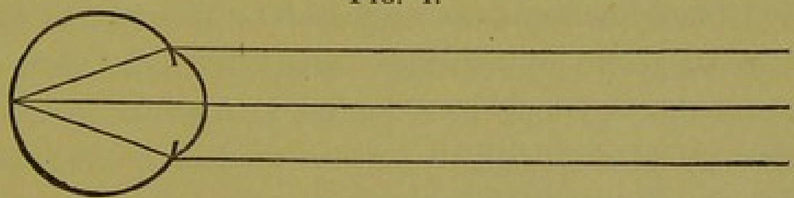


FIG. 2.

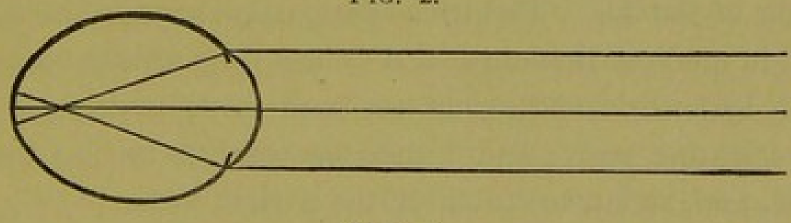
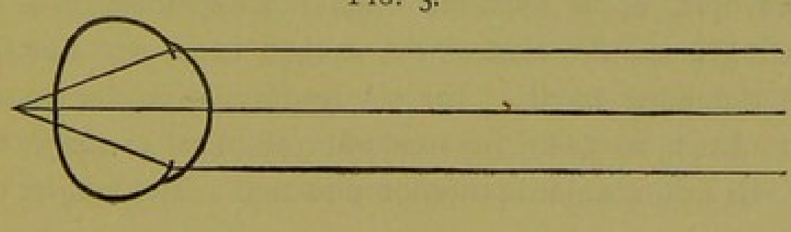


FIG. 3.

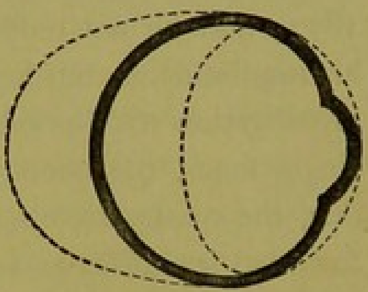


The form of ametropia in which the eyeball is shorter than the focal length of the media, was called hypermetropia by Donders. who discovered and first described it; and this word is now universally accepted. It would seem to imply, etymologically, that the focal length is too great; but, as a matter of fact, the focal length is generally much the same as in a normal eye, and the fault is that the axis of the eyeball is too short. The eye is compressed, or flattened from before backwards, as has been shown by innumerable dissections; and as may often be seen in the living subject when the eye is adducted to the full extent. The ordinary length of the emmetropic axis is about 24·5 millimetres; while the shortest axis recorded from actual measurement, in a hypermetropic eye, was only 16 millimetres. In the high degrees of hypermetropia the eye is usually small in all its dimensions, and must then be looked upon as being in a state of imperfect or arrested development. In such cases, the acuteness of vision is often low, seemingly from structural imperfection of the retina; and the orbits sometimes share in the general undergrowth.

The opposite condition, in which the focal length of the media is less than the length of the axis of the eyeball, might properly be called brachymetropia, as suggested by Donders, or hypometropia, as suggested by Scheffler. But it produces short or near sight; and this has long been known as myopia, on account of the tendency of short-sighted persons to diminish the circles of light-diffusion from distant objects by partial closure or nipping together of the lids. This trivial designation has become so firmly rooted in medical literature, and is also so generally understood, that no systematic endeavour has been made to displace it by a more scientific term; and I therefore purpose to use the word myopia, and, so far, to remain in the ancient ways.

In myopia, as in hypermetropia, the departure from correct proportion is on the side of the eyeball itself, and not on that of the refracting media. Every myopic eye is elongated from front to back, so as to be somewhat elliptical in shape, with its major axis in the antero-posterior direction. The longest myopic axis which has been actually measured was no less than thirty-four millimetres; being more than double the length of the shortest hypermetropic axis, and nine and a half millimetres longer than the average of the normal eye. The annexed diagram (Fig. 4) represents the proportions of a normal eye, showing the relation of its anterior portion to a spherical outline; and the interrupted lines within and without the circle represent the proportion, to this normal eye, of the two extreme instances of ametropia which have been mentioned.

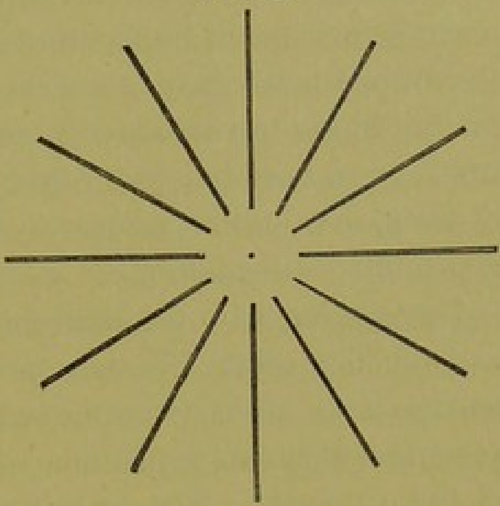
FIG. 4.



In the majority of instances, the two eyes of the same person will be alike in their refraction, or nearly so, the difference being too small to require to be taken into consideration in practice; but cases arise in which there is a difference of a decided kind. One eye may be emmetropic, and the other ametropic; or one myopic, and the other hypermetropic; or they may both present the same form of ametropia, but in different degrees. As eyes of like refraction might be called isometropic, it was an obvious suggestion that eyes of unlike refraction might be called anisometropic; and this word, and its substantive, anisometropia, were introduced in 1867, by Kaiser, and have ever since been commonly employed in ophthalmic literature. The fact is not important; but I mention it because a recent writer in the *British and Foreign Medico-Chirurgical Review*, in a composition which he would probably call a critical notice of a book of mine, said that the word anisometropia was of my invention, and condemned it in forcible language. It must always be interesting to an author to find that his professed critic is so ignorant of the subject on which he writes, so ignorant even of the headings of the pages of standard books, as to be capable of making such a blunder as this. The word in question is often convenient, as a means of avoiding circumlocution; but last year Dr. Noyes, of New York, proposed to limit its employment to cases in which the refraction of the two eyes is alike in kind, although different in degree, and to use the term *antimetropia* for those in which the refraction in the two eyes is of opposite or dissimilar qualities.

The differences between the two eyes, although often sources of difficulty in practice, are less important than those which may exist between different meridians of the same eye. Young, in 1793, discovered that his vision was not the same for vertical and for horizontal lines; and, having calculated the difference, he caused a glass to be ground for its correction. Sir George Airy, the present Astronomer-Royal, repeated Young's discovery in 1827; and he not only calculated the curves of a glass to meet his requirements, but he also communicated the particulars of his investigation to Whewell, who suggested that, as the eye had no single focus, the condition might be called astigmatism. After this, the matter slumbered until 1862, when Professor Donders, to whom we are so greatly indebted for his labours in investigating all the anomalies of refraction and of accommodation, announced that astigmatism, so far from being an unusual condition, was almost the normal state of the human eye; and that in about 2 per cent. of all the cases of defective sight it was present in such a degree as to be disturbing to vision. The treatise which he soon after published on the subject left little to be done by subsequent inquirers, except to verify the conclusions at which he had arrived, and, in some small degree, to simplify and improve his first methods of investigation. In this introductory paragraph, it is sufficient to say that the surface of the human cornea, instead of being spherical in its outline, is somewhat differently curved in two opposite directions or meridians, which often correspond with the vertical and horizontal corneal diameters, and are called the two chief meridians, or the meridians of least and of greatest curvature. These chief meridians, even when they are not approximately vertical and horizontal, are always at right angles to each other; and when the difference between them exceeds a certain small degree, there is a conspicuous difference in the distinctness with which lines drawn in different directions are seen from the same point of view and with the same adjustment of the

FIG. 5.



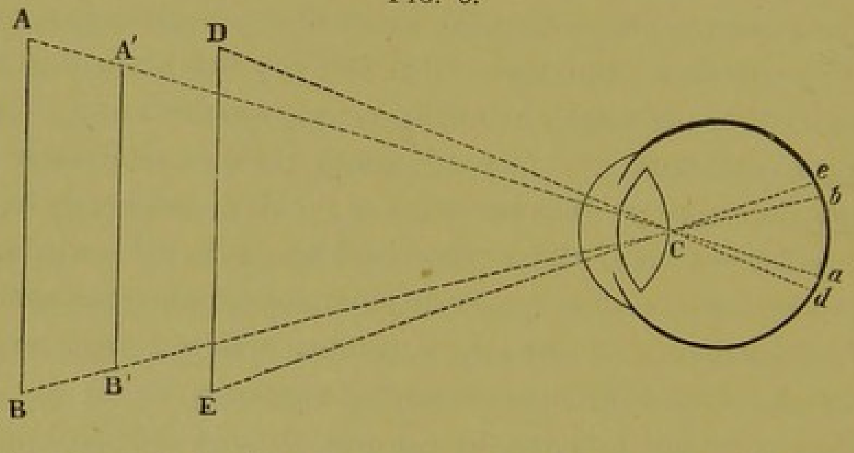
eye. The lines in this star-like figure (Fig. 5), or those in any analogous test-object, are as precisely alike as they can be made; but there are many people who would see them with different degrees of distinctness; and there are some to whom one particular line would appear confused and blurred, although that at right-angles to the former might be perfectly well defined. I may mention, as a curious illustration of how easy it sometimes is to mistake a surmise for a fact, that a gentleman once consulted me on account of what he called a "periodical obscuration of vision." I found that he sat in an office which commanded a view of a large clock-dial on the other side of a quadrangle. When the hands of the clock were approximately vertical, he could see them plainly; but when they were approximately horizontal, he could scarcely see them at all. This, which was the fact, he confounded with his own conjecture that he saw differently at different hours of the day; and hence he had been induced to read all he could find about "vital periodicity," and to regard himself as a curious physiological phenomenon. A pair of spectacles, selected in a manner which I must explain hereafter, restored his vision to normal regularity.

The differences between the two meridians in astigmatism may be of every possible kind. An eye may be emmetropic in one meridian and ametropic in the other; or it may be ametropic in both; and in the latter case we may find either different degrees of the same form in the two meridians, or one form in one meridian, and the other form in the other. All these are matters of detail which will have to be considered when the special characteristics of astigmatism are described; and at present it is sufficient to recapitulate that an eye is normal or emmetropic when the length of its axis is the same as its principal focal length;

that it is ametropic when this correspondence does not exist; that ametropia occurs in two contrasted forms, according as the axis of the eyeball is too long or too short; that these two forms may be present in the two eyes of the same person, constituting anisometropia or antimetropia; and that they, or different degrees of one of them, may also be present in two meridians of the same eye, constituting astigmatism.

Disregarding, for the moment, the effect of accommodation, and thinking of the eye as a passive organ, it may be said that ametropia, in all its forms, occasions a diminution of the natural acuteness of vision, a function which is measurable by means of the visual angle. The magnitude of the visual angle depends upon two factors—the size of the object seen, and its distance. The visual angle is that which is formed between two lines drawn from the extremities of an object to the nodal point of the eye, that is, to a point lying close behind the crystalline lens. In Fig. 6,

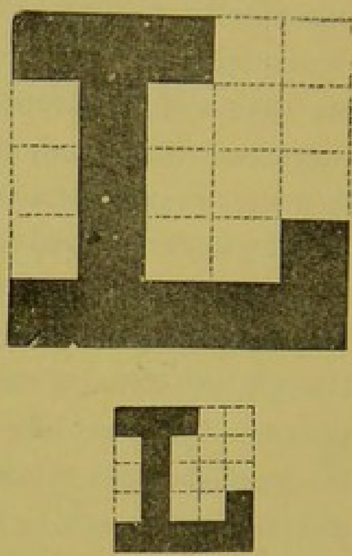
FIG. 6.




C being the nodal point of the eye, and A B an object, A C B is the visual angle of that object, and *a b* is the magnitude of its image on the retina. But the smaller object A′ B′, which is nearer to the eye, is seen under the same visual angle and forms an image of the same magnitude; while the object D E, which is equal in size to A B, but nearer, is seen under the larger visual angle D C E, and forms the larger retinal image *d e*. In order that the retinal image may excite visual perception, it must be of a certain size, and therefore the object forming it must be seen under a certain visual angle; and it has been experimentally determined that square letters, which have limbs and subdivisions equal in breadth to one-fifth of the height of the letters, and which are so placed that this height is seen under a visual angle of 5′, are distinctly legible to the normal eye. Dr. Snellen applied this principle to the construction of test-types which give a means of determining the acuteness of vision with exactness. His letters are drawn of the proportions mentioned, and of various magnitudes, each distinguished by a number which indicates the distance, in metres or parts of a metre, at which the height of the letter will be seen under a visual angle of 5′, the breadth of its limbs under an angle of 1′, and at which the letter as a whole should be legible. The acuteness of vision, usually written V in English, or sometimes S (the initial of the German *Sehschärfe*), is expressed by the distance of the test letters from the eye, divided by the number of the smallest letter which can be recognised with certainty at that distance; the resulting fraction being reduced to its lowest terms. If the distance be six metres, the person who can read letters of the corresponding number at that distance has V equal to 6-6ths, or equal to 1; and this is taken as the normal standard. One who can only read No. 9 has V equal 6-9ths, or 2-3rds of the normal. One who can only read No. 60 has V equal 6-60ths, or 1-10th of the normal, and so on. In order to use this method in practice, a sheet of test-letters of various sizes should be hung up in a good light, care being taken that the number of the smallest size is a little less than the number of metres in the available distance. In my own consulting-room, for example, the letters hang at three metres from the patient's chair, and the sizes range from 2·5 to 60, so that I can recognise variations of acuteness ranging from 6-5ths, or more than the normal, to 3-60ths, or 1-20th of the normal, and the examination is completed in a moment. For my own use, I have a set of test-types which were designed by Dr. John Green, of St. Louis, U.S.A., and which are constructed on the same principle as those of Snellen, but are superior to them in certain points of detail. The letters are so selected as to be of more uniform legibility, and the number of gradations is greater. Green's types, however, are not easily procurable in this country; while those of Snellen, which fulfil every purpose, may be obtained from any bookseller.

Fig. 7 displays two examples of Snellen's letters, which should be legible at twenty-four and at nine metres respectively.

FIG. 7.



In every case of ametropia, of whatever kind, it is manifest that the retina must receive a patch of light, technically called a diffusion circle, from objects which would be represented by a defined image upon the retina of an emmetropic eye. A glance at Figs. 2 and 3 will show that, in the case of myopia, the diffusion circle is formed by rays which have united within the eye and have overcrossed; while in the case of hypermetropia it is formed by rays which have not yet come together; but both these conditions are alike in impairing the distinctness of vision. Now, it is one of the properties of convex lenses that they render convergent the parallel rays of light which pass through them; and it is one of the properties of concave lenses that they render parallel rays of light divergent. It follows, therefore, if we place a convex lens before a hypermetropic eye, that the convergence caused by the lens will enable the eye to bring the rays of light to an earlier focus than by its unaided refraction; and, if we place a concave lens before a myopic eye, the concave lens will bring the rays of light to a more distant focus, as shown by the dotted lines in Figs. 8 and 9. In every case of ametropia, therefore, there is a lens which will postpone or promote the union of parallel rays in the precise degree which is necessary in order to cause them to form their focus upon the retina, instead of either in front of it or behind it; and this lens not only corrects the ametropia, and restores vision, if not otherwise impaired, to its natural standard, but it also measures the ametropia, which is most conveniently expressed in terms of the lens which will neutralise or correct it. Hence it is necessary, for the sake of definiteness and clearness of

FIG. 8.

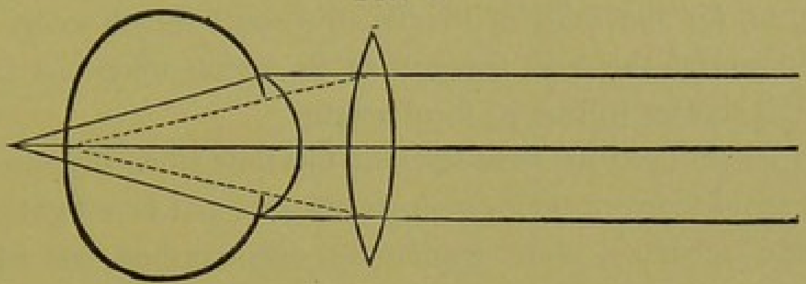
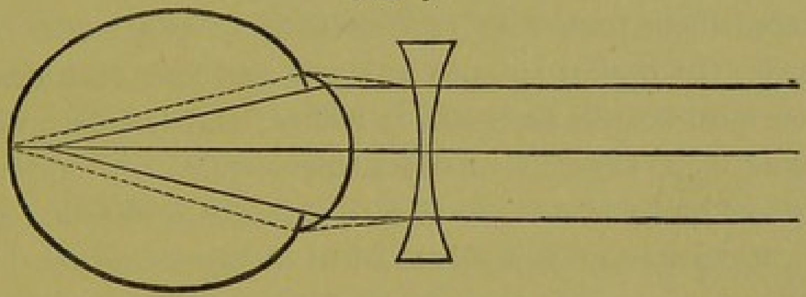


FIG. 9.



expression, to possess lenses of known and constant value; and this value is expressed by the distance from the optical centre of the lens to the point F, Fig. 10, at which, if convex, it will unite parallel rays in a focus, or by the distance of the point F, Fig. 11, from

FIG. 10.

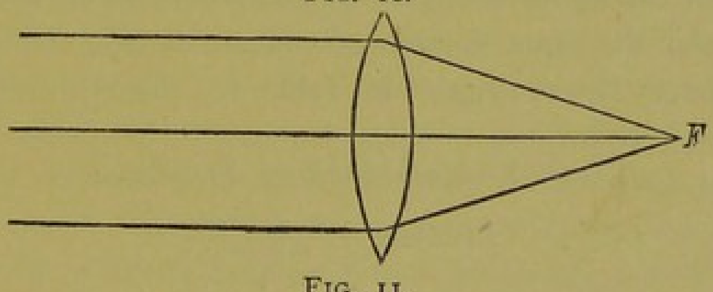
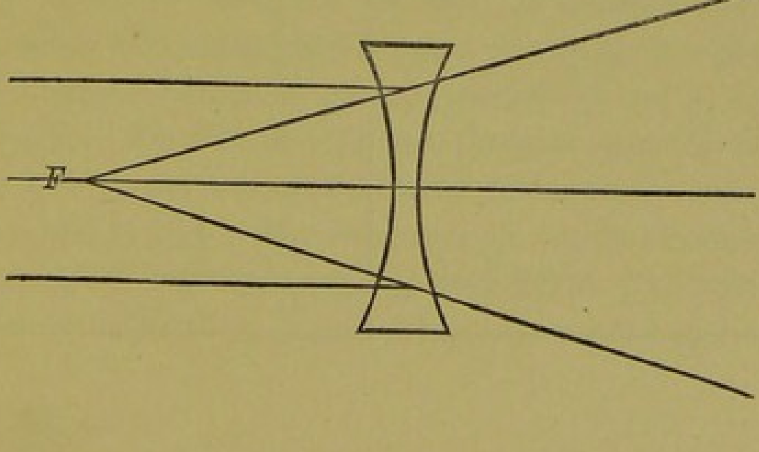



FIG. 11.



which, if the lens be concave, parallel rays appear to diverge after they have passed through it. This point is called the principal focus of the lens; and its distance is called the principal focal length, or, for the sake of brevity, the focal length only. The more powerful the lens, the greater its action upon the rays of light, the shorter will be its focal length.

The lenses used for spectacles, at the time when the principles which should govern their employment were first investigated with scientific accuracy, were commonly distinguished by arbitrary numbers. A manufacturer made twelve different powers, and he numbered them from 1 to 12 consecutively, as a matter of convenience. In optical researches, lenses had long been described by their focal lengths expressed in inches; and Donders, when he first published, adhered to this nomenclature, and employed a scale which had a lens of one inch focal length as its unit. Putting aside a few very rare exceptions, a lens of two inches focal length is the strongest that is ever required in ophthalmic practice, and this is only one-half of the inch unit. Hence, Donders launched us at once upon a system of fractional expression. According to his original nomenclature, a lens of two inches focal length was $\frac{1}{2}$, a lens of twenty-four inches focal length was $\frac{1}{24}$, and so on throughout the whole series, which comprised twenty-five pairs of convex, and the same number of concave lenses, of the powers shown under "focal length" in Table I.

TABLE I.—*Inch Scale of Test-Lenses.*

| Focal length in inches. | Intervals. | Focal length in inches. | Intervals. |
|---|---|---|---|
| 2 | | 6 | |
| | $\frac{1}{10}$ | | |
| $2\frac{1}{2}$ | | 7 | |
| 3 | | 8 | |
| $3\frac{1}{2}$ | | 9 | |
| 4 | | 10 | |
| $4\frac{1}{2}$ | | 11 | |
| | $\frac{1}{45}$ | | $\frac{1}{132}$ |
| 5 | | 12 | |
| | $\frac{1}{30}$ | | $\frac{1}{84}$ |

TABLE I. (continued.)—*Inch Scale of Test-Lenses.*

| Focal length in inches. | Intervals. | Focal length in inches. | Intervals. |
| --- | --- | --- | --- |
| 14 | | 30 | |
| | | | $\frac{1}{180}$ |
| 16 | | 36 | |
| | | | $\frac{1}{360}$ |
| 18 | | 40 | |
| | $\frac{1}{180}$ | | $\frac{1}{200}$ |
| 20 | | 50 | |
| | $\frac{1}{120}$ | | $\frac{1}{300}$ |
| 24 | | 60 | |
| | $\frac{1}{120}$ | | $\frac{1}{240}$ |
| | | 80 | |

It was found before long that the use of this series was attended by the gravest practical inconveniences. In the first place, it is often necessary, in estimating degrees of astigmatism, or in determining the power which should be given for working at some specified distance, to add or to subtract one lens to or from another. This necessarily involves the addition or subtraction of fractions—an operation which many people cannot perform correctly without (and some not even with) the aid of pencil and paper, and which, in the consulting-room or the out-patient department, is very troublesome and inconvenient, always occupying time which might be better employed. So much was this the case that Dr. Schobbens actually worked out, and published in the *Annales d'Oculistique* for 1867, a table of reciprocals, by which such calculations were to be facilitated. A second objection was that the steps of the series were irregular, no two of them being separated by the same interval, and many of the intervals being widely different. The right-hand columns of Table I. show some of the optical intervals between lenses which stand next to one another in the series; and you will see, for example, that while the first half-inch interval (that between $\frac{1}{2}$ and $\frac{1}{2\frac{1}{2}}$) is equal to a lens of $\frac{1}{10}$, the last half-inch interval (between $\frac{1}{4\frac{1}{2}}$ and $\frac{1}{5}$) is equal to a lens of $\frac{1}{45}$. The first inch interval (between $\frac{1}{5}$ and $\frac{1}{6}$) is equal to a lens of $\frac{1}{30}$; the last inch interval (between $\frac{1}{11}$ and $\frac{1}{12}$) is equal to a lens of $\frac{1}{132}$. The first two-inch interval (between $\frac{1}{12}$ and $\frac{1}{14}$) is $\frac{1}{84}$; the last (between $\frac{1}{18}$ and $\frac{1}{20}$) is $\frac{1}{180}$. The first four-inch interval (between $\frac{1}{20}$ and $\frac{1}{24}$) is $\frac{1}{120}$; the last (between $\frac{1}{36}$

and $\frac{1}{40}$) is $\frac{1}{200}$. The interval between the two strongest lenses has already been stated to be $\frac{1}{10}$; that between the two weakest is $\frac{1}{240}$. There is no attempt at any kind of optical regularity; and the intervals are nothing but a succession of anomalies. The last, and perhaps the most important, objection rested upon the want of uniformity among the inches themselves. Lenses are made and measured in three countries—England, France, and Germany; and the inches of these three countries are not coincident. The Paris inch exceeds the English by one-sixteenth; and this difference, in some of the higher powers, is too considerable to be disregarded. A lens of four Paris inches is equal to an English four and a quarter, and a lens of eight Paris inches to an English eight and a half. If a surgeon prescribes in Paris inches, and the patient receives a lens measured in English inches, the intentions of the prescriber are not precisely carried out; and the difference, especially with very sensitive eyes, or in the correction of astigmatism, is sometimes important. Moved by these considerations, the International Congress of Ophthalmology decided, in 1867, to appoint a committee to report upon the question; and in 1872, having received the report, the Congress resolved to adopt a metrical scale; but there were many obstacles to be overcome before this decision could be carried into effect. In the first place, the manufacturers of lenses rebelled against the proposal as a matter of commerce, and objected so strongly to having their inch grinding tools rendered obsolete, that at one time metrical lenses could not be procured. I obtained a set myself, nine years ago, from Paetz and Flohr, of Berlin; but both they and the Paris makers, so lately as in 1874, refused to supply another set, or even to make good some breakages in that which I possessed; and, in consequence of this refusal, I still described inch lenses in the treatise on Diseases of the Eye which I published in the following year. Ever since 1868 I have had the great practical convenience of working with metrical lenses; but I was obliged to translate them into inches in prescribing. A second difficulty arose from the fact that there was not complete agreement as to the nature and the divisions of the metrical scale which would be most convenient in practice; but both these difficulties were at length removed by Professor Donders, who announced last year that Dr. Snellen and himself had agreed upon a convenient scale, and that they had persuaded a Paris optician—Roulot, of 3, Rue des Vieilles - Haudriettes — to manufacture and supply the lenses. Professor Donders came to this country and delivered a lecture explanatory of the new system at Moorfields. To this lecture the leading London opticians were invited; and since it was delivered, the practice of prescribing in the metrical scale has become common.

TABLE II.—*Metrical Scale of Test-Lenses: Number of Dioptrics.*

| | | |
|---|---|---|
| 20·0 | 8·0 | 2·50 |
| 18·0 | 7·0 | 2·25 |
| 16·0 | 6·0 | 2·0 |
| 15·0 | 5·50 | 1·75 |
| 14·0 | 5·0 | 1·50 |
| 13·0 | 4·50 | 1·25 |
| 12·0 | 4·0 | 1·0 |
| 11·0 | 3·50 | 0·75 |
| 10·0 | 3·0 | 0·50 |
| 9·0 | 2·75 | 0·25 |

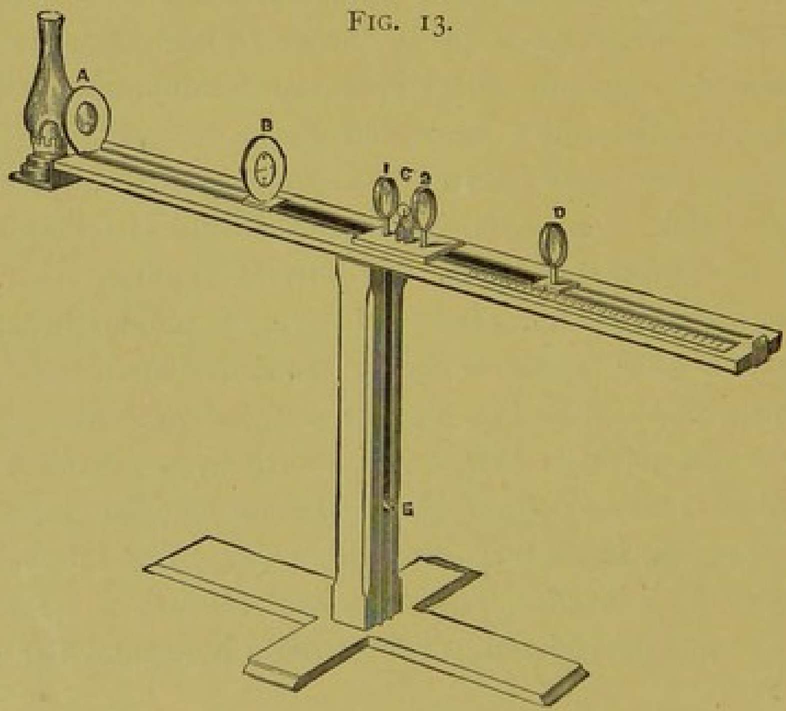
In this scale, the lenses of which, thirty in number, are enumerated in the above table, the unit is a lens of one metre focal length; and this unit is called a *Dioptric.* We take as our unit, you will observe, a weak lens instead of a strong one; and the first result of this arrangement is that our other lenses are multiples of the unit instead of being parts of it. The lens of one metre focal length, or the one dioptric, being No. 1 of the series, No. 2 is a lens equal to two of the former—that is, it is of double the power of the dioptric, or of half the focal length. It is two dioptrics, and its focal length is half a metre. No. 3 is equal to three dioptrics—that is, its focal length is one-third of a metre. Throughout the series every whole number expresses the number of dioptrics to which the lens so numbered is equal; and hence, from whole number to whole number all the intervals are the same. There is a difference of one dioptric between No. 6 and No. 7; and there is equally a difference of one dioptric between No. 1 and No. 2. This difference, however, is sometimes too great for practical purposes; and hence a few quarter and half dioptrics have been added to the lower powers of the scale. These introduce the simple decimal fractions 0·25, 0·50, and 0·75; but these fractions are so easily manipulated that they cause no inconvenience. A quarter dioptric is a lens having a focal length of four metres; a half dioptric has a focal length of two metres; and three-quarters of a dioptric has a focal length of one metre and one-third. A glance at the table will show that the quarter dioptrics of the series go up to No. 3, and the half dioptrics to No. 6. For higher powers, such fine divisions are not needed; but if they were needed, the uniformity of the scale would afford a ready means of supplying them. If I want a lens of six and a half dioptrics, or of eight and a half dioptrics, I have only to place 0·50 as an addition to 6 or 8, and my requirement is at once fulfilled. In describing these lenses, as with those of the old scale, it is customary to indicate convexity by the *plus* sign, and concavity by the *minus* sign. Thus, + 2·0 is a convex of two dioptrics; — 3·0 is a concave of three dioptrics. In the cases supplied by M. Roulot, the lenses have their numbers very legibly marked upon them with a diamond, and they are strongly mounted in metal settings, which are gilt for the convex and silver plated for the concave lenses. These settings are furnished with convenient handles, and they also spring into the clips of the two spectacle frames which are supplied with the case, one of which is specially constructed and graduated to receive cylindrical lenses. Besides convex and concave lenses, thirty pairs of each, the case contains eighteen plano-concave and eighteen plano-convex cylindrical lenses, ranging from 0·25 to 6·0 dioptrics; ten prisms, ranging from 2 degrees to 20; four slips of coloured glass, and four diaphragms in settings like those of the lenses. The whole collection, in a handsome rosewood box, is sold in Paris for 220 francs.

We have been so much accustomed to think of the degrees of ametropia in inches, that a little practice is required before we are quite at home with the new nomenclature; and, in hearing of a myopia of five dioptrics, one is tempted at first to ask how much that means on the old scale. It will greatly facilitate the necessary translation of the thoughts, if we consider that a metre is equal to 39·337 English inches; that is, for all practical purposes, it is equal to forty inches. This means, using English instead of Paris inches, that the dioptric is the old $\frac{1}{40}$; the No. 2 is the old $\frac{1}{20}$; the No. 4 is the old $\frac{1}{10}$. At the extreme end of the scale we have the lens of a quarter dioptric, equal to one of 160 inches, and only half the strength of the weakest of the inch series. Next, we have the half dioptric, equal to a lens of 80 inches. Next, we have the three-quarters of a dioptric, equal to a lens of 53 inches. Coming to the higher powers, we find many coincidences, the chief of which are indicated in Fig. 12, where the horizontal line represents a metre. One dioptric coincides with 40 inches; 2 dioptrics coincide with 20 inches; 3 dioptrics

FIG. 12.


coincide, nearly, with 13 inches; 4, with 10 inches; 5, with 8 inches; 8, with 5 inches; 10, with 4 inches; and so on throughout. If we wish to translate dioptrics into Paris inches, we must consider the metre equal to 36 inches instead of to 40. The coincidences obtained by either method are important, and show that the difficulties raised by manufacturers were almost entirely imaginary; since every glass which is ground on the old tools has its proper value in the dioptric scale, and all that is necessary is to define and register this value. In order to facilitate such determinations, Dr. Snellen has invented a very ingenious instrument, to which he gave the name of "phakometer," or lens-measurer, and which is shown in Fig. 13. It is based upon the principle that, when an object and its image formed by a convex lens are of equal size, the object and the image are equidistant from the lens, and are separated from it on either side, by an interval equal to twice its focal length. The instrument consists of a foot, supporting an upright pedestal, which carries a horizontal bar eighty-six centimetres in length. At one end of this bar is a small shelf, which supports a lamp; and the flame of this lamp is in the principal focus of a lens (A), which, therefore, transmits parallel rays. The luminous object is a black metal screen (B), pierced with several holes and covered with ground glass. The holes are arranged in the form of a cross, and are illuminated by the parallel rays already mentioned. The screen (D) on which the image is received consists of ground glass, and is marked by black dots, which correspond accurately with the little openings on the screen, but are reversed in position. The luminous object and the screen are moved by the same mechanism, so that they can be made to approach or to recede from a lens placed between them, at the centre of the bar, at an equal rate. Each is affixed to one extremity of a thin, very flexible, steel ribbon, which runs along the track on which object and screen move, and which descends into the upright on which this track is supported. The centre of the ribbon is secured to a movable button (E), so that pushing the button upwards causes the distal extremities of the steel band to pass in opposite directions along the track; while pulling it down brings them nearly together in the centre, followed, of course, in both movements, by the object and by the screen.

FIG. 13.



The lens to be examined is held in a clip (C), consisting of two metallic rings placed in the centre of the apparatus, midway between the luminous object and the screen. One of these rings has an upright spur, designed to point out the true centre of the lens under examination. Two auxiliary convex lenses, each of 2·75 dioptrics (1 and 2), are placed one on either side of the clip, fifty millimetres apart, in order to shorten the focal distances equally on both sides, and thus to diminish the length of the instrument. The luminous object and the screen can be separated from each other 777·94 millimetres, at which distance a sharp image of the luminous points is formed upon the screen, and the zero of the scale is situated. This scale is engraved on a strip of metal which runs parallel to the track on which the screen moves; and its divisions correspond with the metric lenses from 0·25 up to 20. A small pointer projects from the screen, for the purpose of denoting the division of the scale opposite to which it stops.

The lens which is to be tested is placed in the central clip, and the object and screen are moved from or brought towards each other until a sharp image of the luminous points is formed upon the screen. The division of the scale opposite the point of arrest of the screen shows the value of the lens in dioptrics. If the luminous points do not coincide with the dots on the screen already described, the lens is improperly centred, and must be moved until correspondence is secured. The true centre of the lens is then indicated by the pointer attached to the clip.

The use of this phakometer requires only a few seconds, and it enables the optician to determine the value in dioptrics of every lens in his possession. It is not less valuable to the surgeon, who can accurately test the lenses supplied to his patient, and can discover whether they are properly centred in their settings. It is the custom of manufacturers to assume that all lenses ground upon the same tool are of the same focal length, and to number them accordingly; although it is manifest that differences in the refracting power of different pieces of glass may occasion corresponding differences in the results.

It is therefore desirable that every lens should be separately tested before it is taken into stock, as in no other way can occasional errors be prevented. The phakometer is being made by Mr. Browning, of 63, Strand, from whom it will shortly be procurable.

Having thus secured a series of testing lenses arranged upon a sound principle, they are used as measures for the degrees of ametropia. The accommodation being paralysed, if necessary, by atropia, and the patient placed opposite to a scale of test-types, at a convenient distance, we find, if he is ametropic, that his vision is below the normal standard of acuteness, and that it is improved by a lens of some description. Assuming that we are unacquainted with the form of his ametropia, we take a concave and a convex lens, each of one dioptric, and place them alternately before the eye under examination, the other eye being closed or covered. If the concave lens improves vision, there is myopia; if the convex lens improves vision, or does not impair it, there is hypermetropia. The existence and the form of ametropia being thus ascertained, the next point is to arrive, by successive trials, at the lens which gives the best vision, which raises it to the natural standard or nearly so, or, at all events, which does better than any other. This lens at the same time corrects and measures the ocular defect. If it is a convex of five dioptrics, we say that the hypermetropia is equal to five dioptrics, or more shortly, to 5. If is a concave of three dioptrics, we say that there is a myopia equal to 3. Excepting in moderate degrees of ametropia, we must not expect to obtain, by any lens, vision fully of the normal standard; for in the hypermetropic eye there is something which approaches very nearly to arrest of development, often with corresponding defect of functional activity; and in the myopic eye there are often morbid changes in the deeper tissues of the organ. We may expect, however, to obtain from the patient a decided preference for one glass over all others; and, if we do not find this decided preference—if the patient sees little difference between the effects of two or three adjacent members of the series,—we must suspect the existence of astigmatism. To such matters of detail I must return on a future occasion, my object in this preliminary lecture being to define the general principles by which the varieties and degrees of ametropia are recognised and expressed.

In the foregoing method of examination with lenses and test-types we have to deal only with subjective phenomena; and, except for the check afforded by repeating the examination at a different distance, we are almost entirely dependent upon the statements made to us by the patient. It follows, of course, that we are also dependent upon his good faith and accuracy of observation; and there are many conditions in which these cannot command our implicit trust. In young children, or in persons of defective intelligence, we may be deceived by the patient without intention; and in other cases, as by soldiers seeking to be discharged, or perhaps sometimes by railway plaintiffs, we may be deceived with full intention. It is therefore important to be able to test ametropia objectively, and independently of the statements which are made to us; and this can to some extent be accomplished by the aid of the ophthalmoscope. The course of the rays which enter an eye, to form or not to form a picture upon the retina, and the course of the rays which leave it, are strictly correlated phenomena; and, when a glass is required to afford the patient a clear view of outward objects, a similar glass is also needed in order to afford a clear view of the retina of such a patient to the surgeon. The glass used with the ophthalmoscope may therefore be a measure of ametropia. But a more complete account of this method of examination, and of the limitations of its usefulness, will be most suitably entered upon in a future lecture, after the influence of accommodation and the varieties of ametropia have been more fully described.

Another contrivance which promises to be useful in the measurement of refraction, and which at the same time affords a certain amount of control over the statements of the patient, is an optometer which has recently been suggested by Dr. Hirschberg, of Berlin. This instrument, which is now being made at my request by Mr. Browning, superficially resembles a binocular opera-glass. The distance apart of its two tubes can be regulated to suit different distances between the pupils; and one of the tubes can be closed by a metal cap when only one eye is under examination. Each tube contains two biconvex lenses of rather high power; an ocular of say two and a half, and an object-lens of four centimetres of focal length. The precise power is not material, but the two must be different. When the patient looks through this optometer at test-types placed at their full legible distance, the object-lens receives rays which are approximately parallel; and, when the two lenses are separated precisely by the sum of their focal lengths, the rays which leave the ocular lens are also approximately parallel, so that they afford a perfect image to a passive emmetropic eye. The image is, of course, inverted; but this disadvantage may be overcome by inverting the test-types to begin with. If the lenses are brought nearer together, the rays which leave the ocular will be divergent, so that they will afford a clear image to a myopic eye; and, if the lenses are separated by a longer interval than the sum of their focal lengths, the rays which leave the ocular will be convergent, so that they will afford a clear image to a hypermetropic eye. In either case, the degree of divergence or of convergence of the rays depends upon the amount of approximation or of separation of the lenses; and one of the tubes is marked with two scales, each having its zero at the point where the lenses are separated by the sum of their focal lengths, and where the issuing rays are parallel. One of these scales shows the distance between the object-lens and the ocular in millimetres, the other indicates dioptrics of ametropia for each distance of separation. We have only to desire the patient to look through the instrument, and to adjust it so as to obtain the best view of the distant test-types, in order to read off the degree of his myopia or hypermetropia, as the case my be. In order to test his accuracy, we next reverse the instrument, telling him to look through the object-lenses instead of through the oculars, and to adjust it again. If the scale is at the zero point, no other difference than a diminution of the size of the image will be produced by the reversal; but for any other distance between the lenses a change in the amount of divergence or of convergence of the issuing rays will be produced, and a corresponding change of adjustment will be required. This amount of change is a known quantity in every degree of ametropia, and may be marked upon a third scale, which will then show whether the patient has made the amount of readjustment which his former statement would require. Should he have done so, it may fairly be inferred that he was accurate on both occasions. A full account of Hirschberg's optometer, with the necessary formulæ for calculating the degrees of divergence or convergence of the issuing rays, will be found in the second part of the inventor's "Beiträge zur Praktischen Augenheilkunde." Of the employment of this optometre in the determination of astigmatism I shall have to speak further in a subsequent lecture.

## LECTURE II.

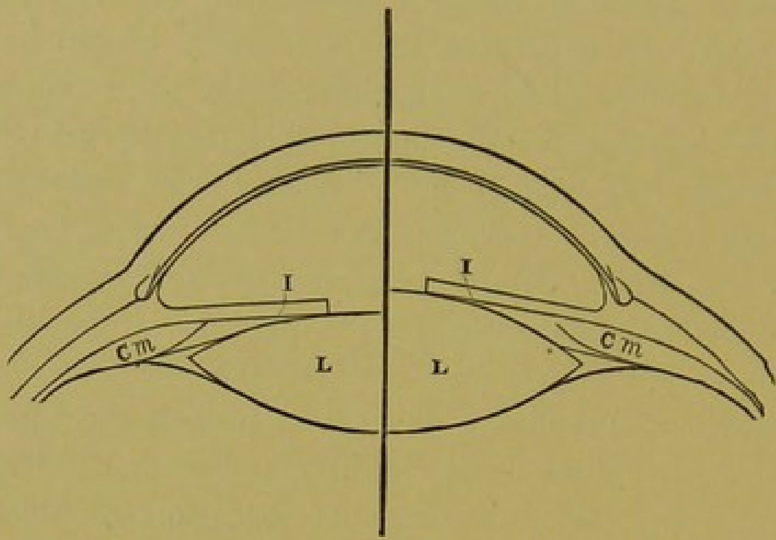
# ACCOMMODATION AND CONVERGENCE.

Mr. President,

THE two remaining factors of sustained clear vision, the accommodation and the convergence, require to be considered not only separately, but also in their relations to one another. The first of these two factors, the accomodation, was defined in my former lecture to be the power of adjusting the eye to see with equal clearness at varying distances within its far-point; and Mr. Hulke, when he held office as Arris and Gale Lecturer, fully described in this theatre the mechanism by which the function is performed. There is therefore no occasion for me to occupy ground which has already been so well covered; and I need only point out the necessity which there is for accomodation, and the nature of the change which produces it. Taking the emmetropic eye as a starting-point, with its capacity for uniting parallel rays upon its retina, it is obvious that rays coming from comparatively near objects will no longer be parallel, but divergent; and that the degree of their divergence will constantly increase as the object from which they proceed comes nearer and nearer. In order to overcome this constantly increasing divergence of the rays, and still to obtain clear images from near or from steadily approaching objects, the eye must possess the power of increasing its own action upon the rays of light. That it does possess such a power may be shown in many ways, among which that proposed by Donders is perhaps the most convenient. If we take a piece of net, and hold it between the eyes and a printed page, we may at pleasure see distinctly the fibres of the net, or the printed letters on the page through the interstices of the net ; but we cannot clearly see both at once. When we are looking at the letters, we are only conscious of the net as a sort of intervening film of uncertain character ; and when we are looking at the net, we are only conscious of the page as a greyish background. In order to see first one and then the other, we are quite conscious of a change which takes place in the adjustment of the eyes ; and if the net is very near, and we look at it for any length of time, the maintenance of the effort of adjustment becomes fatiguing.

It has been thoroughly established, by the observations of Cramer, Helmholtz, Donders, and others, that the crystalline lens undergoes a change of shape in the act of accomodation ; and there is abundant proof that this change of shape is brought about by contraction of the ciliary muscle. It appears, however, that the muscle does not act upon the lens directly, or alter its shape by virtue of any pressure or tension which it exercises, but that its action is to relax the capsule of the lens and the zonule of Zinn, and thus to allow the proper lens-tissue to undergo the necessary change by virtue of its own elasticity. When all parts are at rest, the capsule is believed to compress the lens, and to retain it in its state of greatest flatness ; but when the ciliary muscle comes into play, it draws forward the ciliary body and makes tense the choroid, and so allows the lens to expand to the degree which the relaxation of its capsule will permit. The change of shape occurs chiefly in the anterior portion of the lens, although the posterior surface participates in a slight degree. Besides the principal alteration, that in the shape of the lens itself, there are other changes which accompany the act of accommodation, but which are not essential to its performance. The pupil contracts, and the iris-tissue is rendered more tense. The whole of these changes are diagrammatically represented in Fig. 14, in which L represents

FIG. 14.

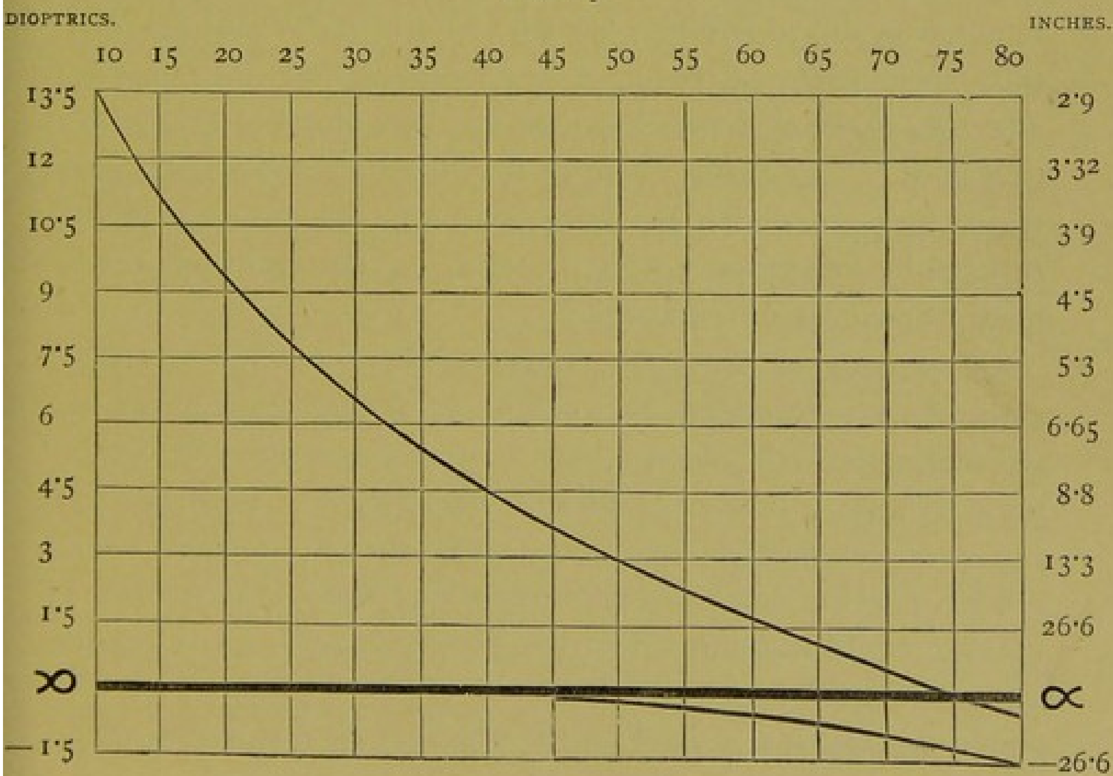



the lens, I the iris, and *Cm* the ciliary muscle. The left-hand half shows the parts at rest, and the right-hand half shows the changes which occur when accommodation is being exerted.

Putting aside the mechanism of accommodation, it may be broadly said that the effect of the effort is precisely that of placing an additional convex lens within the eye; and the amount of refracting power which can thus be added is very definite, and admits of easy and precise measurement. For every eye there is a point within which clear vision is no longer possible without optical assistance; and this, which is called the near-point, marks the limit of the power of accommodation. Still assuming the eye to be emmetropic, with its far-point at infinite distance, let us suppose that it can see small objects clearly at twenty centimetres, or one-fifth of a metre, but not at any shorter distance. The effort of accommodation, which is exercised in seeing at this near-point, produces precisely the same optical result which would be attained by placing within the eye a convex lens of the same focal length as the distance from the eye to the near-point. In the case supposed, therefore, the accommodation is equal to a lens of five dioptrics; and in the improved nomenclature it is expressed as being equal to five, and not, as would have been the case two years ago, by the focal length in inches, reduced to a fraction by placing unity as its numerator. The fifth of a metre being eight inches, the fraction would have been one-eighth; and in this instance, as in many others, the usefulness of the metric system in simplifying calculations becomes at once apparent.

As life advances, probably on account of the regularly diminishing elasticity of the crystalline lens, the power of accommodation constantly diminishes, and the near-point consequently recedes farther and farther from the eye. The diagram in Fig. 15 is taken from Donders, and is only so far altered as to adapt it to the metric system, by expressing the accommodation in dioptrics, and the successive distances of the near-point in English instead of in Paris inches. It represents the ordinary course of the accommodation in an emmetropic eye from the age of ten years to the age of eighty. The figures at the top of the diagram show the years of life, and those at the sides the amount of accommodation, expressed to the left in dioptrics, and to the right in English inches. The larger curved line shows the course of the accom-

Fig. 15.

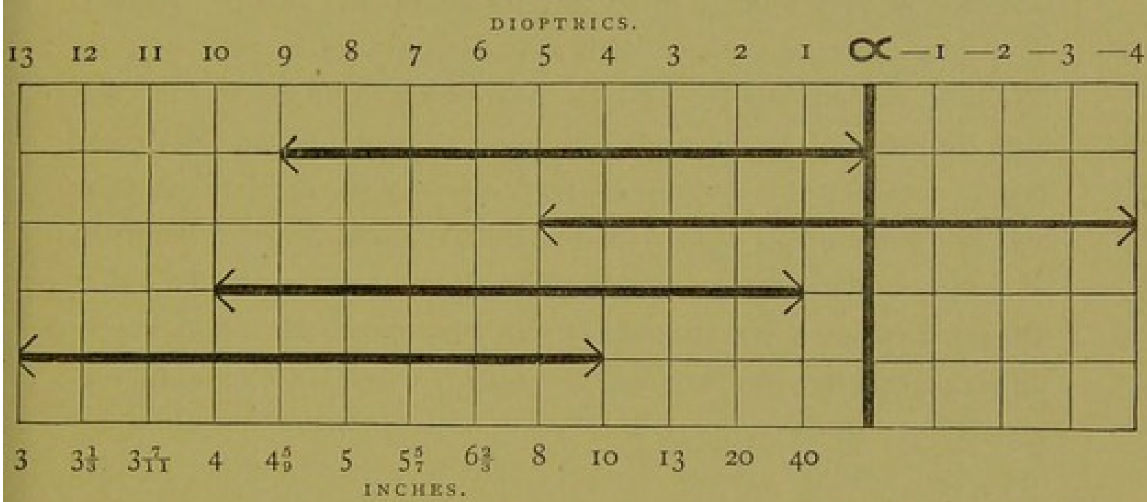


modation; and it is drawn as the mean of a great number of observations. We see that the emmetropic eye, at the age of 10, has a power of accommodation equal to 13½ dioptrics; or, in other words, its near-point is a little nearer than the thirteenth part of a metre—a distance equal to 2·9 English inches. At 13—that is, before we reach the line marking the fifteenth year—the power of accommodation is reduced to 12 dioptrics, and the near-point has receded to 3·32 inches; at 17, the accommodation is 10·5 dioptrics, and the near-point is at 3·9 inches; at 21, the accommodation is at 9 dioptrics, and the near-point is at 4·5 inches; at 26, the accommodation is 7·5 dioptrics, and the near-point at 5·3 inches; at 32, the accommodation is 6 dioptrics, and the near-point at 6.65 inches; at 40, the accommodation is 4·5 dioptrics, and the near-point at 8·8 inches; at 50, a great change has taken place—the accommodation is only 3 dioptrics, and the near-point has receded to 13·3 inches; at 60, the accommodation is only 1·5, and the near-point is at 26·6 inches; at 75, accommodation is wholly lost, and the near-point is at infinite distance; at 80, we have what Donders described as acquired hypermetropia, and, in the total absence of accommodation, a weak convex lens is required even for infinitely distant objects. It is probable that this phenomenon of acquired hypermetropia will be found to admit a somewhat different explanation from that which Donders gave of it. The smaller curve on the diagram exhibits the course of the far-point during the same succession of years, and shows that the hypermetropia which is said to be acquired is first traceable at about the forty-fifth year.

In speaking of the accommodation, there are two technical expressions in common use, which are somewhat liable to be misinterpreted, and about which it is very important to obtain perfectly clear notions. These are, respectively, the *range* and the *region* of accommodation. The range should be used as a synonym for the power of accommodation; that is, to express the number of dioptrics to which the power is equal. The region should be used to express the limits of space within which the power is exercised. In Fig. 16, which is also modified from

Donders, the distinction is shown in a diagrammatic form. The horizontal lines, marked successively 1, 2, 3, and 4, exhibit, by their darker portions, the differences of region which will exist, with the same range of accommodation, in an emmetropic eye, an eye hypermetropic to four dioptrics, an eye myopic to one dioptric, and an eye myopic to four dioptrics. Each square is equivalent to one dioptric of added refraction—that is, of accommodation; and the squares are numbered both on the positive and on the negative side of infinite distance.

FIG. 16.



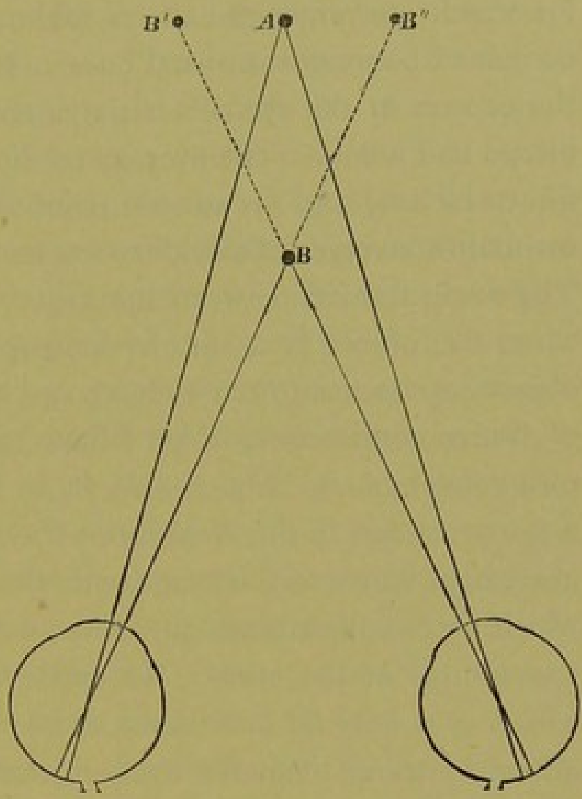

The figures above indicate the dioptrics, and those below the position of the near-point, in English inches, for each dioptric of accommodation. In Fig. 15, the emmetropic eye at twenty-one years of age was shown to have a power or range of accommodation equal to nine dioptrics, and a region of accommodation extending from infinite distance to a point 4·5 inches from the eye. The same condition is exhibited by line 1 of Fig. 16. The far-point is at infinite distance; the near-point, determined by nine dioptrics of accommodation, is at 4·5 inches. On line No. 2 we have the same range of accommodation, but combined with four dioptrics of hypermetropia. Hence, the first four dioptrics of accommodation are required for parallel rays, or, in other words, to bring the far-point up to infinite distance; and only five dioptrics of accommodation remain for use in the ordinary way. The eye is in the position of an emmetropic eye which has only five dioptrics of accommodation; and the exercise of these five dioptrics places its near-point at eight inches. Moreover, as it is not generally practicable to employ more than half the accommodation continuously, the working near-point would be that given, at most, by five dioptrics of accommodation, and would therefore be forty inches away. On the third line, a myopia of one dioptric places the far-point at forty inches, and the nine dioptrics of accommodation must all be exercised within the limits thus imposed, that is, between a distance of forty inches and a distance of four inches, to which the near-point can be brought. The last example, an eye with four dioptrics of myopia, has its far-point at ten inches, and its near-point at three inches, the nine dioptrics of accommodation being all exercised on the nearer side of ten inches. As regards their near-points, the last two eyes are like emmetropic eyes which possess ten and thirteen dioptrics of accommodation respectively; and the four examples show that the same *range* of accommodation may be exercised in four widely different *regions*: In the first, the region extends from infinity to 4·5 inches; in the second, it is partly a mathematical negation, on the other side of infinite distance, and is partly between infinity and eight inches; in the third, it is between forty inches and four; in the fourth, it is between ten inches and three. The words "range" and "region" are not, I think, the best which could have been chosen for the purpose of expressing the ideas which they are intended to convey; and on this account it seemed desirable to explain them in some detail, and to endeavour to remove all ambiguity from their respective meanings.

We shall see hereafter that the power of accommodation is very much influenced by the convergence; and from this relation we derive other expressions, which hardly carry with them the senses in which they are used. The *absolute* accommodation is the whole amount which one eye can exert singly, the other being excluded from vision; the *binocular* accommodation, somewhat greater than the absolute, is the whole amount which can be exerted when both eyes are used, their convergence increasing as the accommodative effort approaches its maximum; and the *relative* accommodation is the extent to which the accommodation can be made to vary, while both eyes remain immovable, either at parallelism, or at some definite degree of convergence. Variations in the range, and in the region, of *relative* accommodation will be found to exercise a most important influence upon the power of sustained visual effort; but the consideration of this influence must be postponed until after the convergence function itself has been briefly described.

The convergence, the third factor of clear vision, is a term used to express the whole of that range of mobility by which the axes of vision are moved from parallelism, or even from a certain degree of divergence, to be directed towards some near-point in space. The eyes may, of course, be directed convergently towards some lateral part of the field of vision; but such a direction is infrequent, and can scarcely ever require to be sustained. Practically, therefore, we mean by convergence the direction of the eyes to some point in a median plane between them, so that the muscles on the two sides are called into equal action for the maintenance of the effort. The conditions of human occupation, moreover, generally require a downward direction of the gaze, so that the inferior recti muscles are to some extent brought into play; but convergence is mainly dependent upon the internal recti, and upon the state of equilibrium between these and their antagonists, the external recti. In a state of rest the optic axes, or rather the lines of visual direction, which do not necessarily coincide with the optic axes, are at least approximately parallel, usually with a slight tendency towards convergence; and this position must be taken to represent the state of equilibrium between the antagonistic muscles. The antagonism of these muscles, however, is of such a kind that it is constantly becoming co-operation; for, while each internal rectus, in convergence to the median plane, acts together with its fellow, and opposes, and is opposed by, its antagonist, yet in lateral vision, or in convergence towards any lateral portion of the field, each internal rectus acts in unison with the external rectus of the other eye. Dr. Broadbent has pointed out that the motor ganglia of any two or more muscles which are constantly called upon to act in unison have generally an intimate connexion; and we must assume, I think, that the stimulus to median and to lateral fixation must be derived from distinct centres. The actions themselves, although performed by the same muscles, are yet the results of combinations so entirely dissimilar in their character that no other hypothesis seems to meet the facts of the case.

As the perfection of accommodation for any object is shown by the clearness and sharpness of vision, so the perfection of convergence for any object is shown by the singleness of vision, assuming it first to be ascertained that the person who is the subject of inquiry can see binocularly. If any object is in such a position as to be seen, and if both the visual lines are not directed towards it, the images formed in the two eyes will not fall upon corresponding points of the retinæ, and double vision will be the result. A simple test of the possession of binocular vision is afforded by placing before one eye a prism with its base directed either upwards or downwards—an arrangement which, when both eyes are directed towards some moderately distinct object, will produce diplopia if binocular vision exists. Another simple test is furnished by holding any slender object, such as a pencil or a knitting-needle, between the eyes and a printed page, nearly in the middle line. The observer should then read the print; and, if he has binocular vision, he will see two images of the intervening object, neither of which will shut out any letter from his view. He will be able to read as distinctly and as uninterruptedly as if the two images were not there. If he has not binocular vision, or if he closes one eye experimentally, the intervening object will be seen single, and then it will shut out some portion of the page from his view. The reason of this is apparent from Fig. 17, in which A represents the point on the page which is the object of vision, and B the intervening object. The rays from A fall upon the yellow spot of each eye; but those from B fall upon the retinæ at points external to the yellow spot of each eye, so that to the right eye B seems to be situated at B′, while to the left eye it seems to be at B″. An examination of the diagram will also

FIG. 17.




render it obvious that, whether there be a printed page as background or not, the slender object will be seen double, with crossed images, if the eyes are directed to a point beyond it, and double, with direct or homonymous images, if the eyes are directed to a point nearer the observer. The purpose of convergence, it must be borne in mind, is the avoidance of double images, or the fusion of the images which are formed upon the two retinæ; and this can only be accomplished when the eyes are both directed to the same point. In estimating convergence, the apparent direction of the eyes is not always a perfectly safe guide, because this apparent direction may be governed by that of the axes of the eyeballs, and not by that of the axes of vision, which, as I have already said, do not always coincide with the former. The impulse to fusion, by which the convergence is governed or directed, can only be referred to the centres of visual sensation; and the urgency of the instinctive demand is shown by the giddiness and general disturbance of co-ordination which double images frequently produce. When single vision is maintained, and when it can be disturbed by means of a prism used in the manner already indicated, we have the best possible assurance that the demand for fusion exists in the nervous centres, and that the machinery for fulfilling the demand is of natural strength and in full operation.

Having thus a test of the accuracy of the convergence for a given point, the power or range of the function may be estimated by two standards. The first of these is the distance of the nearest point for which convergence can be maintained, and the angle then contained between the visual lines. The average distance apart of the centres of the eyeballs is sixty-four millimetres, or nearly two inches and a half. The average reading distance may be stated at fifteen inches; and the nearest point at which I find it possible to maintain convergence, even for a few moments, is twelve centimetres. The angle formed between the visual lines amounts only to 10° when the object is at fifteen inches, increases to 14° when the object approaches to ten inches; and becomes 28° at the distance of twelve centimetres, which I have mentioned as the limit of my own convergence. Mannhardt, in an interesting paper published a few years ago in the *Archiv für Ophthalmologie*, sought to attach great importance to this angle, and also to the increase of the angle which necessarily attends any increase of the normal width between the centres of the eyes. He endeavoured to show that people whose eyes were far apart must of necessity be more fatigued than others in using them for near objects; but he appears to have overlooked the obvious consideration that all such differences of original formation are likely to receive compensation from muscular attachments in harmony with them; and, as a matter of fact, I am not aware that Mannhardt's view has been confirmed by practical experience even in a single instance.

The other method of measuring the convergence-power, and certainly the most generally applicable, is by determining the capacity of the internal and external recti muscles for fusing together the double images produced by prisms. On a simple optical principle, which it is only necessary to mention, the rays of light which pass through a prism are deflected towards its base, so that any object seen through a prism is changed in apparent position, and seems to be displaced in the direction of the refracting angle. If the object is in the median line, and we look at it with one eye through a prism with its base turned towards the nose, the object appears to be displaced outwards towards the temple of the spectator; and if the base of the prism is turned towards the temple, the apparent displacement is in the opposite direction, or towards the median line.

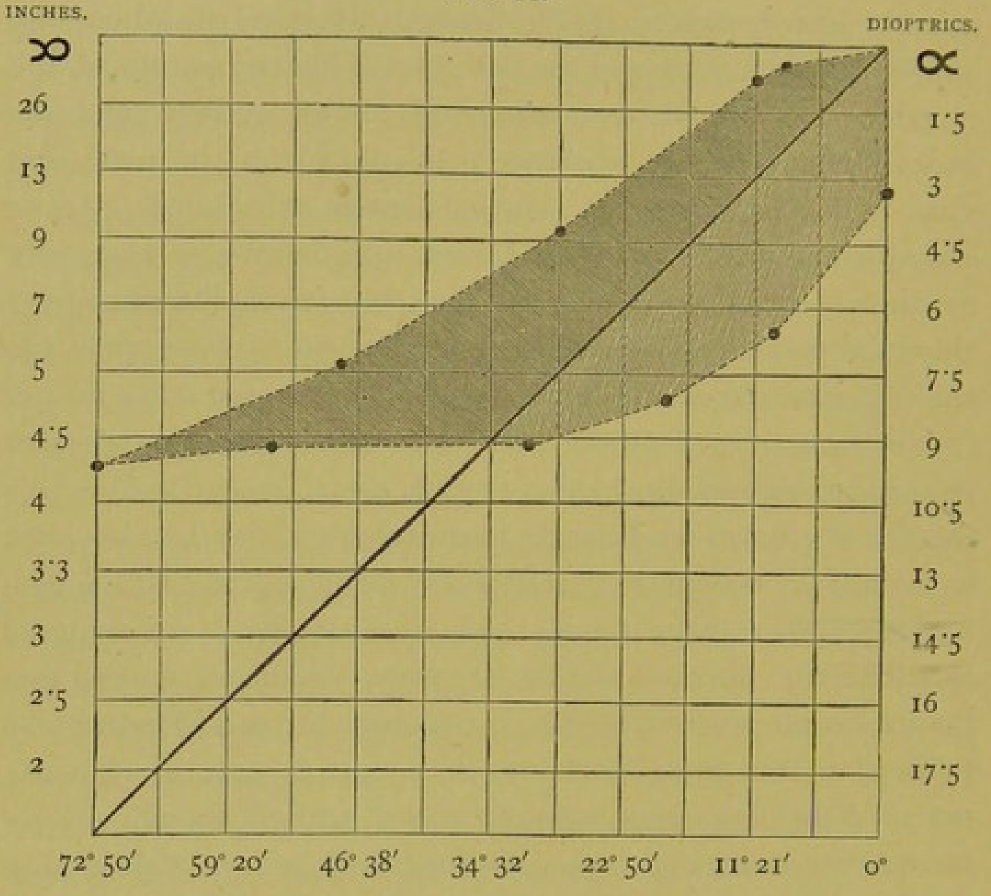
It follows, if we hold before each eye a prism with its base inwards, and look at an object in the middle line, we shall have to render our optic axes more divergent than the true position of the object requires, in order to see it singly; and the strength of the prisms which we can thus overcome by voluntary muscular effort is the measure of our power of voluntary divergence or abduction. In like manner, if we place the prisms with their bases outwards, we shall have to exert our converging power in order to see singly; and the strength of the prisms which we can overcome is in the same way the measure of the converging faculty. Taking as an object a flame at twelve feet distance, I find that I can overcome, for a short time at least, prisms of 22°—that is, two each of 11°, with their bases outwards, and two each of 6°, with their bases inwards. This is with fully relaxed accommodation, wearing convex spectacles of 0·75 to neutralise my hypermetropia. Great variations of power will be found in different persons, and I lately tested a gentleman who had no abduction or divergence power at all, so that he could not overcome two prisms each of 2° with their bases inwards, but who overcame all I could give him, amounting to an aggregate of 34°, when the bases were turned outwards, and his internal recti muscles came into play.

TABLE III.

| | Overcame by adduction (bases outwards). | Overcame by abduction (bases inwards). |
|---|---|---|
| Case 1 . . | 17° + 17° = 34° | 3° + 4° = 7° |
| 2 . . | 17° + 17° = 34° | 5° + 5° = 10° |
| 3 . . | 16° + 16° = 32° | 5° + 4° = 9° |
| 4 . . | 15° + 15° = 30° | 8° + 8° = 16° |
| 5 . . | 12° + 12° = 24° | 4° + 4° = 8° |
| 6 . . | 10° + 10° = 20° | 3° + 4° = 7° |
| 7 . . | 9° + 9° = 18° | 3° + 4° = 7° |

Table 3 shows the adduction and abduction powers of seven students at St. George's Hospital, taken at random. It will be seen that their adduction power ranged from a minimum of 18° to a maximum of 34°; and their abduction from a minimum of 7° to a maximum of 16°. The object looked at was a flame eight feet away, and five of the students were presumably emmetropic. No. 3 was the subject of hypermetropia equal to 2·75 dioptrics; No. 7 of hypermetropia equal to 1·75 dioptrics. Although the purpose of convergence is entirely different from the purpose of accommodation—the former function being subservient to singleness of vision, or fusion; the latter to clearness or distinctness only,—yet it will be seen on brief consideration that the two functions must, in emmetropic eyes at least, almost always be called into action simultaneously. Accommodation is required only for near objects, and the nearer the object the more accommodation is necessary. The same is strictly true with regard to convergence; and hence, but only in emmetropic eyes, the two functions necessarily stand to each other in close and constant relationship, and, at least during the first forty years of life, are performed simultaneously and in strictly corresponding degrees. Convergence for a given point implies accommodation for the distance of that point, and the internal recti muscles and the ciliary muscles contract and relax together, as if by a common impulse communicated to the two. This harmony of action reminds us of Dr. Broadbent's doctrine, already mentioned, of the close connexion of the motor ganglia in such cases; and suggests the idea of a natural and complete co-ordination, common to the human race, and dependent upon the structure of the nervous system. If this be so, it is plain that such a co-ordination will not easily be overcome by changes in external organs—changes which, in their essential nature, are of an acquired or accidental character; and, although both myopia and hypermetropia derange the ordinary correlation between accommodation and convergence, yet the former of these errors of refraction is an acquired condition, while the latter, in its higher grades, is apparently an arrest of development, and neither of them can be expected to modify a ganglionic co-ordination equally in all cases; or even at all, except as the result of time, and of the gradual training of the muscles to adapt themselves to a disruption of their natural harmony. It was held by Porterfield, who published his treatise on the Eye in 1759, that "to every degree of convergence there is a fixed and absolute amount of accommodation;" but this view of the case is maintained by Donders not to be absolutely correct. In the first place, he argues, the two functions may be absolutely dissociated from each other, either by artificial means or by disease. Complete paralysis of the accommodation by atropia has no influence upon the convergence; and, although general paralysis of the third nerve would abolish both functions, there have been many cases of partial paralysis in which one of them has suffered alone. I have recently had a patient in St. George's Hospital in whom the levator palpebræ muscle of the left eye was entirely paralysed, the superior and inferior recti paralysed almost entirely, and the internal rectus greatly weakened; but in whom the pupil was small and active, and the accommodation unimpaired. Quite lately also, in private practice, I have seen the precisely opposite condition—the ciliary muscle and the sphincter pupillæ of one eye greatly weakened, apparently from intracranial syphilis, while the recti muscles were unaffected. Von Graefe has recorded a case of complete paralysis of all the external muscles without impairment of the accommodation; so that there is some reason for believing that the two functions, however intimately they may be associated in the healthy state, are physiologically distinct; and that the connexion between them is mainly of the character of an acquired co-ordination. Even in the healthy state, Volkmann showed that the interdependence of the two is not absolute; and Donders, who followed in the same direction, says—"It is easy to convince one's self that both eyes together, as well without as with slightly concave or convex glasses, can accurately see an object at a definite distance, and that, consequently, without change of convergence, the accommodation may be modified. With equal ease, we observe that, in holding a weak prism before the eye, whether with the refracting angle turned inwards or outwards, an object can be accurately seen with both eyes at the same distance, and that, consequently, the convergence may be altered without modifying the accommodation. When, therefore, it is required for the sake of distinct vision with both eyes, the connexion between convergence and accommodation can be, at least partially, overcome." Fig. 18 shows the diagram by which Donders illustrated these changes, as he found them occurring in the eyes of an emmetropic subject fifteen years of age. The diagram is altered by the conversion of the figures into dioptrics and English inches, and by different shading of the positive and the negative parts of the relative accommodation; but in all essential respects it is the same. The diagonal line represents successive degrees of

FIG. 18.




convergence; and the two irregular lines represent respectively the near-point and the far-point for each degree of convergence. An examination of the diagram shows that for all moderately distant points there was a play of accommodation on either side of that to which the visual lines were directed; but that the convergence power was in excess of the accommodative, so that the subject was able to converge to a point which the accommodation could not reach. The whole range of accommodation for each convergence is called the relative accommodation for that point; and the diagram shows that not only the range, but also the region, of this relative accommodation differs according to the degree of the convergence. Thus, it appears that the eyes of this subject, whilst their axes were parallel, could accommodate from infinite distance up to a point which was only twelve inches away; and, when their convergence angle was 22° 50′, they could accommodate from thirteen inches up to about four inches and three-quarters. With a convergence angle of 46° 38′, by which the visual axes were directed to a point only 3·3 inches distant, the accommodation had almost attained its maximum, and was also entirely on the other side of the diagonal; so that it actually did not reach to the convergence point. With a convergence of 72° 50′—that is, to a near-point of only two inches' distance, the absolute near-point of accommodation was attained; but at this degree of convergence there was no longer any space for accommodation, and the lines of the far-point and of the near-point cut one another.

With reference to this diagram, Donders continues—"It is of importance further to observe, that the relative range of accommodation consists of two parts—a *positive* part and a *negative*. The diagonal represents the convergence of the visual lines, and for each point of convergence the portion of the range of accommodation on the nearer side of this line (the lightly shaded portion) is the positive, that on the farther side (the darkly shaded portion) is the negative. The first represents what, reckoning from the point of convergence, we can accommodate still nearer; the second, what we can accommodate still farther off. For example, the emmetropic eye, at a distance of thirteen inches, is normally accommodated for this distance; but the accommodation may, with the same convergence, be made more tense—for a distance, namely, of six inches; and it may also be relaxed to distinct vision at a distance of seventy-two inches. The first is evident, since with negative, the second, since with positive glasses of definite strength, at the same distance of thirteen inches, with both eyes at once, accurate vision can be maintained. The figure also shows that in the emmetropic eye, with parallel visual lines, the relative accommodation is wholly positive; that, with increasing convergence, the negative part rapidly increases, soon, also, at the expense of the positive; and that at a convergence of 36° the relative accommodation has become entirely negative. The distinction here made acquires importance from the fact that the accommodation can only be maintained for distances at which, as compared with the negative, the positive part of the relative range of accommodation is still tolerably great."

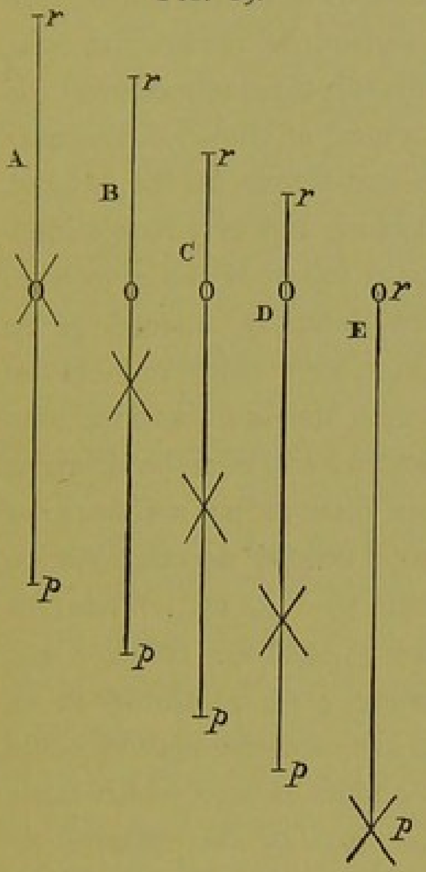
This subject of relative accommodation is one that underlies the useful employment of spectacles in almost all the cases which present any difficulty; and therefore, as at first sight it seems a little intricate, I may perhaps be excused if I dwell upon it with some minuteness. In the observations from which Fig. 18 was taken, Donders found that his patient, when the eyes were directed to a point thirteen inches away, and when by the maintenance of single vision it was certain that the convergence remained unchanged, was still able to overcome—that is, to see clearly through —convex glasses of 2·50 dioptrics, and concave glasses of 4·0 dioptrics. He found, also, by further observations, that work could only be maintained at distances at which the concave glass which could be overcome was greater than the convex glass; or, in other words, while the power of increasing the accommodative effort was greater than the power of relaxing it. Inquiries of this kind are more difficult than would at first sight appear, because they require a young subject, in whom the full vigour of accommodation has not begun to undergo curtailment from age, and who, nevertheless, is trustworthy as an observer. Moreover, they require the use of a very elaborate optometer, such that for every degree of convergence the lenses used may be placed at right angles to the visual lines, and also with their centres exactly opposite to the centres of the pupils. If the latter condition were not fulfilled, and if the patient were suffered to look through the lateral parts of the lenses, these would at once exert a prismatic action, which would vitiate the experiment by producing a displacement of the apparent position of the object, and, therefore, a corresponding alteration in the direction of the visual lines. For a description of the optometer, I can only refer to the great work of Donders; and, concerning the trustworthiness of the subject who was employed, we have no other ground of judgment than such as is supplied by the fact that Donders himself appears to have been satisfied upon the point.

The next inquiries in the same direction were made by Dr. Loring, of New York; and it is impossible even to refer to them without a passing tribute to the extraordinary care and diligence with which American practitioners have entered upon investigations of this kind, and to the success which has crowned their efforts. Dr. Loring was not satisfied with the then accepted view of a sort of fast and loose relation between accommodation and convergence —a relation which was intimate but not essential, which was to be explained no one exactly knew how, and which could be relaxed within the wide limits which are shown by Donders' diagram. He thought it more consonant with physiology to believe that there must be a close relation or none; and he tested the phenomena of relative accommodation from this point of view. He first showed, by an ingenious experiment which I will describe almost in his own words, that the tension of the internal recti muscles is modified by every change in the accommodation, and that the reason why such increased tension of the interni does not modify the position of the visual lines is to be found in the opposition of the external recti, which also become more tense, and which act as inhibitory structures against convergence in order to maintain the fusion of the two images which is necessary to singleness of vision. The experiment was conducted by placing letters of Snellen's test-types, No. 6, at a distance of six metres from the observer, while a lighted taper was so arranged as to be at the same level with the letters, and as nearly as possible in the same plane. The eyes being then fixed upon the letters, the visual lines were practically parallel, and the tension both of the interni and of the ciliary muscles was at the minimum. Binocular vision having been proved to exist by means of prisms, concave glasses of gradually increasing strength were successively tried, until the power was found which the accommodation, with parallel visual lines, could no longer overcome, and with which, therefore, vision began to be indistinct. Concaves of 2·25 dioptrics were the strongest glasses through which vision was distinct for both eyes. With these glasses binocular vision was also apparently perfect, as there was not a particle of diplopia or spreading of the rays of light. The glasses represented, therefore, the amount of relative accommodation which could be called forth independently of convergence, for, as the visual lines were parallel, the tension of the interni was apparently at its minimum. If every increased tension of the ciliary muscle were to be attended by increased tension of the interni, it would at first sight appear that this increased tension would show itself by increased convergence, which would then be expressed by diplopia. There was no diplopia; did the assumption of an increased tension of the interni therefore fall to the ground? By no means; for if, under the foregoing conditions, a coloured glass was placed before one eye, diplopia followed immediately, with homonymous images separated to the extent of twenty-three inches. If the two images were then allowed to coalesce, by lessening the tension of the interni, so that binocular vision was restored, the letters and light became indistinct, showing that by lessening the tension of the interni the observer lessened at the same time the tension of the ciliary muscles, so that the concave glasses could no longer be overcome. The same result followed when weaker glasses were employed, only the separation between the images was not so great. With — 2·25, as already said, the images were separated 23 inches; with — 1·75, 12 inches; with — 1·25, 3 inches; with — 1·0, the images overlapped each other. With any weaker glass, actual diplopia was not produced; but with — 0·75, if a point of light was used instead of the flame, there was a perceptible widening of the point. The fact that the distance between the images corresponded with the strength of the glasses is very significant, and lends support to the belief that for every degree of tension of the ciliary muscle there is a corresponding degree of tension of the interni; while the reason why there was no diplopia with very weak glasses was evidently because the tension of the ciliary muscle in overcoming them, and consequently the corresponding tension of the interni, were so slight as not to be appreciable with the coarse test employed.

The explanation of the above-described phenomena is very simple. In order to overcome the concave glasses a certain amount of increased tension was required of the ciliary muscle. This latter contracted under nervous influence, and vision became distinct. If it be true that all nervous action imparted to the ciliary muscle is extended to the interni, then the impulse which called the ciliary muscle, into contraction would be so extended, and an increased tension of the interni would be the result. The equilibrium between interni and externi (which was perfect before this increase took place) would necessarily be destroyed, and there would be a preponderance in favour of the interni proportionate to the increase of tension in the ciliary muscle. If such preponderance were produced, it ought to declare itself under the well-known test of the coloured glass and prism. We place the coloured glass before one eye (both eyes being, of course, still armed with the concave glasses), and homonymous double images are the result—proving, beyond doubt, the existing want of equilibrium.

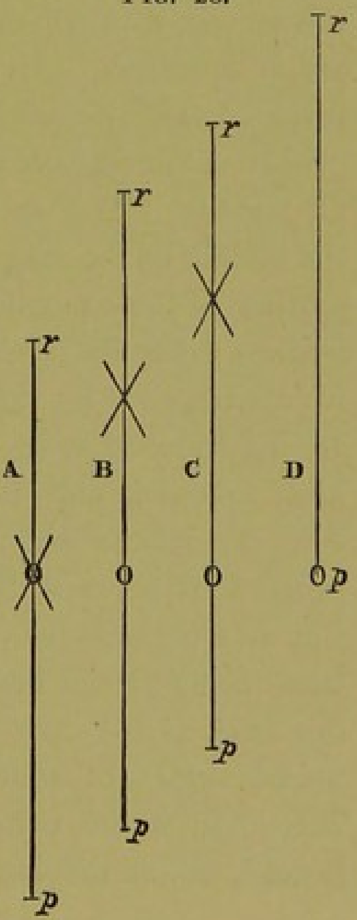
It may be objected to the above reasoning that, when the eyes simply look through the concave glasses, the tension on the ciliary muscle, in order to overcome them—and, consequently, the tension extended to the interni—is just as great without the coloured glass as with it; and that the eye would have the same tendency to turn inwards whether the coloured glass were employed or not. This is true; the tension on the ciliary muscle, and that communicated to the interni, are just as great, and the tendency for the eye to turn in is also just as great, in the one case as in the other; but this tendency is resisted and overcome by a factor which is in full force when the eyes are looking through the concave glasses alone, but which ceases to exist as soon as the coloured glass is added. This new factor is the intuitive desire for single vision with the two eyes. So long as the images on both retinæ are equal in intensity, the desire for each eye to perform its share in the common act of vision is so great that every attempt to destroy this by a change in the direction of the optic axes is at once vigorously opposed. As soon as the increased tension of the ciliary muscle (called forth in order to overcome the glasses) is extended to the interni, the change in the direction of the visual lines, which would be the natural result, is counterbalanced by the desire for single vision, which, in this case, can only be retained by the agency of the external recti, the antagonists of the interni. Thus the equilibrium of the muscles, which would be destroyed by the increased action of the interni, is reinstated and maintained by a correspondingly increased action of the externi. As soon, however, as the image on one retina is reduced and altered, by placing the coloured glass before one eye, the instigation towards single vision is removed; and as soon as the desire ceases, the necessity for the muscular effort, by means of which the desire was fulfilled, ceases also; or, more plainly, the externi cease to act. Their relaxation destroys the equilibrium between the opposing muscles in favour of the interni, and homonymous images are the result. We have only to remove the coloured glass, or, in other words, to restore the power of, and with the power the desire for, single vision, and the homonymous images immediately become united; thus proving that when the eyes look through the concave glasses alone there is the same tension of the interni, and the same tendency for the eyes to become convergent, as when the coloured glass is added, but that this tendency is counteracted by the desire for single vision. Dr. Loring next turned his attention to the influence of increased convergence-effort upon the ciliary muscles. Making his own eyes the subject of experiment, he found, on directing them to a point eighteen inches distant, that he was able to maintain distinct and single vision through either concave or convex glasses. He took as his object a word printed in the smallest type which he could read at the specified distance, so that any imperfection in the image would immediately make itself felt, and he found that the strongest convex glass which he could overcome was one of 1·75 dioptrics, and the strongest concave was one of 2·50 dioptrics. This gave a total of 4·25 dioptrics of relative accommodation—that is to say, of power to vary the accommodation

Fig. 19.




while the convergence position remained unchanged. The convex of 1·75 dioptrics showed the extent to which the accommodation could be relaxed, or the negative part of the relative range; and the concave of 2·50 dioptrics showed the extent to which the accommodation could be increased, or the positive part of the relative range. The conditions are shown in diagrammatic form at A, Fig. 19, where O represents the object of vision and the point to which the visual lines are directed, O *p* the positive part, and O *r* the negative part, of the relative accommodation. So far, as in the earlier portion of the former experiment, the results appeared to bear out the view expressed by Donders. But Dr. Loring found, when he placed a prism of $5^\circ$ with its base outwards before each eye, by which the convergence was increased, that, although the object still remained distinct, it could not be said that the accommodation remained unchanged. The strongest glass for which the accommodation could be relaxed was then 1·50 dioptrics, but it could be strengthened to overcome 3·0 dioptrics. The whole amount of relative accommodation was therefore increased from 4·25 to 4·50 dioptrics, and at the same time the proportion between its two parts was

Fig. 20.



wholly changed. The object, instead of lying at the intersection of the optic axes, and at the line of division of the positive from the negative accommodation, was beyond the intersection, and wholly within the negative part of the range, as shown in Diagram B, Fig. 19. These changes in the conditions of the relative accommodation are exactly similar in kind, and very nearly identical in degree, with those which would follow if the eyes were rendered convergent to twelve inches naturally, instead of by means of prisms. When stronger prisms were employed—say of 10°—the changes which took place were the same in kind, but greater in degree. A convex of 1·25 dioptrics was then the strongest glass through which the object remained distinct, but a concave of 3·50 could be overcome, making the total relative accommodation again equal to 4·25. This is shown in C, Fig. 19. When the prisms were 12·5 the convex glass was 0·75, and the concave 4·0, the entire relative accommodation being 4·75, as shown in D, Fig. 19. When the prisms were 15, the accommodation could not be relaxed at all, even for so weak a glass as 0·50, which made vision indistinct. Hence the positive part of the relative accommodation became constantly smaller as the strength of the prisms was increased; until (in E, Fig. 19) the accommodation is all negative. And whereas, in the first diagram, the object was in the middle of the range, or at the very beginning of the negative portion of the accommodation, it ultimately came to lie at the farthest extremity of this portion. If now, instead of increasing his convergence by turning the bases of the prisms outward, Dr. Loring lessened it by turning them inward, a result identical in kind followed, only the optic axes intersected farther from the eyes, the relative accommodation was likewise removed, and the proportions between its positive and negative portions modified. Fig. 20 represents the various changes produced by the prisms, the bases being placed inwards. Weaker prisms were employed in this case, as the optic axes are rendered parallel by prisms the united angles of which amount to 15°. Consequently, those were used whose united angles amounted to 5°, 10°, and 15°; instead, as in the former case, of 10°, 20°, and 30°. It will be seen that just as O was in the former arrangement always within the negative portion of the relative accommodation, so in the second series of experiments it was always within the positive portion; and just as *r* with increased convergence gradually descends to O, so *p* under diminished convergence ascends to O. It is very true that the object was distinctly seen at the same distance with all these different degrees of convergence; but this does not prove that the accommodation had not been modified, for with every alteration in the convergence there was a manifest and calculable modification of the accommodation, equalling in the aggregate a convex glass of 4·75 dioptrics. The reason why the object remains distinct while the convergence is changed by prisms is not because the accommodation has not been modified, but because the object remains within the limits of the modification; or, in other words, within the *region* of the relative accommodation, notwithstanding the alteration in convergence. From Fig. 19 it is evident that the convergence may be increased at pleasure, and yet the object will be distinctly seen as long as it remains in the region represented by the negative portion of the relative accommodation—that is, till *r* descends to O; while, on the other hand, Fig. 20 shows that the convergence may be diminished until *p* ascends to O. When, however, in either case, O passes outside the limits of the relative accommodation, the object at once becomes indistinct.

By the results of these experiments, Dr. Loring may, I think, be taken to have proved that the earlier notion of an essential dependence between the ciliary muscle and the interni represents, at least, the physiological condition, and that the independence observed by Donders and others is more apparent than real; depending, in the case of the interni, upon the inhibitory action of the externi, and, in the case of the ciliary muscles, upon the varying degree of latitude given by the extent of the range of relative accommodation. Muscular action, however, when regarded as a source of exhaustion or fatigue, must not be measured by the effect which is produced, but by the force which is exerted; and, when looked at from this point of view, I think we shall find, in the intimate and essential harmony between accommodation and convergence, and in the occasional disturbance of this harmony by the variations of either function, a full and sufficient explanation of many of the states which are productive of painful limitations of vision, and a key to their successful treatment. To these states, under the general name of asthenopia, I shall have to direct attention in the concluding lecture.

# LECTURE III.

# PRESBYOPIA.

MR. PRESIDENT,

HAVING in the former lectures briefly sketched the chief features of the three great factors of sustained vision—the refraction, the accommodation, and the convergence,—and having described the manner in which these may severally be estimated and measured, I may now pass on to the consideration of the principal forms of what I have already termed "conditioned vision," that is to say, a state in which the patient, although able to use his eyes at certain distances, or for limited periods of time, is not able to use them at all distances or for all periods; and is constantly reminded of their existence by the very fact of the bounds which are set to his power to employ them. The form of conditioned vision to which I shall first refer is the least important of any as regards the structural states on which it depends; but it may be considered the most important on the ground that it is common to the whole human race, and that it befalls the eyes of all persons who reach middle age, whether those eyes are normal or abnormal, emmetropic or ametropic. I refer, I need hardly say, to the condition of presbyopia, or aged sight.

I have already mentioned that the faculty of accommodation, the power to adjust the eyes for clear vision at distances nearer than their far-point, is gradually curtailed as life advances, and I have already shown you (see Fig. 15) the diagram in which

Donders has traced out the natural progress of the change. The cause of this change is probably diminished elasticity of the crystalline lens, which obviously undergoes progressive molecular changes of a marked character. In infancy and childhood it is brilliantly transparent, so that even its presence can scarcely be recognised by any kind of direct examination. After a few years, if we dilate the pupil and throw a fine pencil of rays into the eye, we shall observe more or less fluorescence in the lens-tissue, the light breaking up against its inequalities, and the blue waves being returned to the spectator. Later still, if we examine our own eyes by looking at diffused light through a very fine perforation, we shall see, besides floating fibres or bodies in the vitreous, stationary granules in the lenticular substance—granules which, being opaque by comparison with the parts around them, cast shadows upon the retina and appear as dark spots in the illuminated field. Later still, the fluorescence passes into what appears to be a very manifest cloudiness by reflected light, although to transmitted light the lens may yet be perfectly transparent; and this cloudiness is often traversed by brighter lines which mark the divisions between the sectors of which the structure is built up. Later still, the lens becomes more or less of a yellow or an amber tint, even though it may never undergo the changes which constitute cataract. Assuming, as already stated, that the increased convexity of accommodation is the result of a change of shape which occurs spontaneously as soon as the lens is released, by the action of the ciliary muscle, from the restraint exercised upon it by its capsule, it is easy to understand how alterations in its molecular structure may involve a progressive loss of its elasticity; so that, although the capsule may be relaxed, the change in the curvature of the lens may become less and less, and ultimately may altogether cease. Hence, at the same time, the refractive power which the changed curvature was wont to add, becomes diminished in a corresponding ratio; and the near-point of distinct vision recedes slowly but steadily from the eye. During many years, although this change is occurring, it is not felt to be a source of inconvenience; but by-and-by a time comes when very small objects, in order that they may be clearly seen, must be held so far away that they either subtend a visual angle which is too small to allow them to be recognised with facility, or else sufficient light for the requirements of vision is no longer reflected from their surfaces. The amount of light reflected from any point, and falling upon a given area, such as the pupil of the eye, varies, it need hardly be said, as the square of the distance between the two; so that an object which is only twelve inches distant gives the pupil four times as much light as it would do if it were removed to a position twenty-four inches away. Hence, those who are becoming presbyopic in an inconvenient degree first feel the effect of the change by twilight, or by artificial light of any kind, which, however good it may be, and however dazzling when near the eyes, never approaches in its general illuminating effect to that of even a feeble degree of diffuse daylight. By the age of forty-five, or thereabouts, it is generally necessary for the possesser of emmetropic eyes to hold very small print so far away (especially in the evening) that it becomes difficult to decipher. It will help us to realise the improvements which have been made, during the present century, in the means of artificial lighting, if I remind you of Dr. Kitchener's well-known saying, that people who were fifty years old began to "bless the man who invented snuffers." At the same period, or somewhat later, we often see an artificial light held between the reader and his page, so as to increase the illumination of the latter to the utmost, without unduly taxing the accommodation.

The term presbyopia, in former times, has been used with a good deal of latitude, or, rather, with a complete absence of anything like scientific precision; but now, in accordance with the teaching of Donders, it is used only to signify the alteration of vision which is produced by the recession of the near-point, or the gradual curtailment of the power of accommodation, which is incidental to advancing life. It is evident, therefore, that the term, used in this sense, cannot be defined, except in an arbitrary manner; for the degree of presbyopia which is felt as an inconvenience will be mainly determined by the nature of individual pursuits or employments, or even by such an accidental circumstance as the character of the illumination of the room which is chiefly inhabited. In order to meet this difficulty, Donders suggested that presbyopia should be looked upon as established when the binocular near-point has receded to eight inches; that is, when it was no longer possible, by any effort of voluntary adjustment, to read the smallest type at a nearer distance than eight inches. This limit is probably as good a one as can be fixed, and it has the advantage of attaching a definite meaning to the word.

By the time that the binocular near-point has receded to a distance of eight inches, the convenient near-point at which any visual effort can be sustained will have gone a good deal farther away. It is seldom possible to use more than half of the actual range of accommodation for more than a short period of time; and hence, if an emmetropic person has only five dioptrics of accommodation—the amount which would bring his near-point to eight inches,—he will only have two and a half dioptrics, or say a near-point at sixteen inches, really available for continuous efforts at his occupation. For some occupations this may be sufficient, but for others it will clearly not be sufficient; and in cases of the latter kind, remembering that accommodation is practically the addition of a convex lens to a passive eye, we supply by art the deficiency of nature, and give such lenses as may be enough to bring back the near-point, without effort to the user, to the place or distance at which it is wanted. We say that the patient requires spectacles; and in a vast majority of instances we see that he can be effectually supplied with them by a sort of rule of thumb of an extremely simple character. Those who deal in spectacles sell what they call glasses of first or of second sight; and they recommend one or the other of these accordingly as the patient has or has not worn spectacles before. In many instances the necessary relief is at once obtained; and the patient feels no further inconvenience for perhaps two or three years. After some such period of time his former difficulties return, and he again obtains relief from them by using glasses somewhat stronger than those which he procured in the first instance.

It has long been a tradition among opticians, that people who were advancing in life should be very chary of employing spectacles of too great magnifying power—partly because it was believed that such spectacles were likely to be injurious to the eyes, and partly lest the desire of the eyes for more power should grow with indulgence, until it might at last outstrip the resources of the spectacle-grinder. These opinions were much confirmed, and were widely diffused among the public, by an elaborate essay on spectacles which was published in the *Quarterly Review* some sixty years since, and which was commonly attributed to the late Sir David Brewster. The writer, whoever he may have been, was not in advance of his time concerning the subject on which he wrote, and had little or no knowledge of the changes which occur in the eye, or of the altered conditions of vision which they entail. He approached the question from a standpoint of pure optics, and did little more than give a new lease to some prevalent errors and misconceptions. Convex spectacles, of whatever power, cannot do more than place the far-point at the distance of their own focal length; and, in an emmetropic eye, with restricted accommodation, the near-point would not be very much within the far-point. The only harm that could be done by spectacles which were too strong, or stronger than was needful, would be so to approximate the visual distance as to call upon the internal recti for a fatiguing effort of convergence in order to maintain binocular vision; and this effort would in any case be relinquished, because it would be fatiguing, long before it could by any possibility become injurious to the eyes of a person of mature age. The excessive convergence which, as we shall see hereafter, is incidental to the higher degrees of myopia, is often injurious in youth, when the ocular tunics are yielding and extensible; but seldom or never becomes so at an advanced period of life, if no harm has previously been occasioned by it. Apart from forced convergence, the use of high magnifying powers is absolutely harmless. I have often had occasion to remark to students how rarely it happens that we see at the hospital any persons who follow the trades, such as watch-making, wood engraving, and the like, which require the constant use of a single magnifying-glass; and I believe the tradition about the ill-effect of powerful convex spectacles is mainly due to the fact that a premature and rapidly increasing presbyopia, such as to call for constantly stronger and stronger glasses, is one of the early symptoms of approaching glaucoma. The demand for strong spectacles has itself, in these cases, been merely a sign of the impending destructive disease; and, before the symptoms of the disease were understood, the resulting blindness, although perfectly independent of the spectacles, may often have been erroneously attributed to their influence.

We may therefore, as far as the safety of the eyes is concerned, give to the presbyopic person spectacles which are strong enough completely to supply his deficiency; so that, without any strain upon his accommodation, his work may be brought near enough to be seen under sufficient illumination. The annexed table, taken from Professor Donders, but translated into dioptrics, gives approximately the strength of the lenses which will be necessary for an emmetropic person at each age of life, and also the strength which will be required for those whom the author regards as having been originally emmetropic, but ultimately the subjects of acquired hypermetropia; a doctrine upon which I shall have more to say in the sequel. A third column states the distances at which the specified glasses should give clear vision.

TABLE IV.

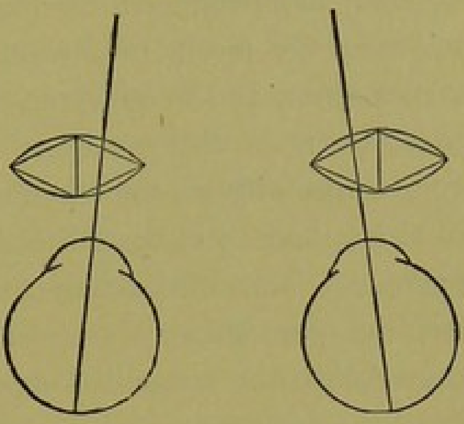
| Years of age. | In present emmetropia. (Dioptrics.) | In original emmetropia. (Dioptrics.) | Distance of distinct vision in inches. |
|---|---|---|---|
| 48 . . | 0·75 | 0·75 | 14 |
| 50 . . | 1·0 | 1·0 | 14 |
| 55 . . | 1·25 | 1·50 | 14 |
| 58 . . | 1·75 | 2·0 | 13 |
| 60 . . | 2·0 | 2·25 | 13 |
| 62 . . | 2·50 | 3·0 | 13 |
| 65 . . | 2·75 | 3·50 | 12 |
| 70 . . | 3·50 | 5·0 | 10 |
| 75 . . | 4·0 | 5·50 | 9 |
| 78 . . | 4·50 | 7·0 | 8 |
| 80 . . | 5·0 | 8·0 | 7 |

I have never myself found it necessary or useful to prescribe glasses so strong as those here suggested for emmetropic persons of seventy years old and upwards; and it must, of course be rememebered that age does not by any means furnish a certain criterion of the power of accommodation. Before prescribing, it is always necessary to test the state of the patient, and to be guided by the distance to which his near-point has actually receded.

It will often happen, however, that the lenses which a presbyopic patient would himself choose by reason of their immediate effect, and which may afford him the best and most comfortable vision for a time, will yet become sources of strain or inconvenience if their use is continued; and this result is usually traceable to the way in which the glasses disturb the previously existing relation between accommodation and convergence. As presbyopia becomes declared, its inevitable tendency is to call for a stronger effort of accommodation than before, in order that the eyes may be adjusted for any given distance; and, in this way, as the measure of the accommodation exerted must be the amount of effort, and not the amount of result, it is manifest that the patient will be called upon to exert a greater amount of accommodation than before, for any given amount of convergence. In other words, for any given convergence, say to eighteen inches, he will have to strain the positive part of his relative accommodation; and the effort to do this, although in itself more or less irksome, would within certain limits become more easy by practice. Let us now suppose that he puts on a moderately strong pair of spectacles, which enable him, at the same distance of eighteen inches, to read almost without exercising his accommodation at all. The relation between the two muscular functions is suddenly reversed; and, having for some time been gradually accustoming himself to use accommodation in excess of his convergence, he is all at once compelled to maintain a degree of convergence which is in excess of his accommodation. In other words, his work falls almost wholly within the negative part of his relative accommodation; and this, especially whilst it is a new condition, is apt to be a very irksome one. I may somewhat vary the illustration by pointing out that, when presbyopia first becomes an inconvenience, the book or newspaper, held at eighteen inches distance, requires as much accommodation effort as would have sufficed a short time before for a distance of thirteen inches, but it still requires, of course, only the old convergence effort for the actual distance of eighteen inches. The eyes, therefore, may be regarded as accommodating for thirteen inches, while they are only converging to eighteen. Convex lenses outside the eyes rest their accommodation by rendering an equivalent quantity of increased convexity of the internal lenses unnecessary. Convex lenses of three-quarters of a dioptric almost precisely represent the difference between accommodation for thirteen inches and for eighteen, and such lenses, therefore, restore the equilibrium which has been disturbed, and render the accommodation effort and the convergence effort the same in quantity. Anything weaker than these would fail to remedy the inconvenience; and anything stronger—lenses of a dioptric and a half, for example—would afford over-compensation, so as to require an accommodation effort less than that of the convergence, and to produce strain by this new disparity. If presbyopia were a fixed instead of a progressive affection, the lenses of 0·75 would cure it once for all. In actual fact, they only correct the accomplished portion of a progressive change, and they leave the eyes still on the threshold of presbyopia, compelled to use a considerable accommodation effort. After a short time, this again creeps so far ahead of the convergence effort that the disparity once more becomes painful, and then stronger spectacles are required in order to redress the balance.

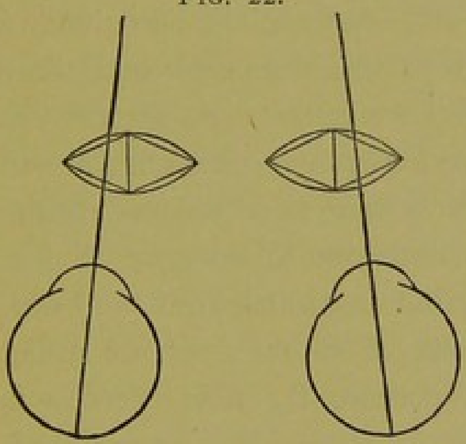
It has long been known to opticians, as a matter of empirical observation, that the dicomfort arising to the presbyopic from glasses of too high a power is much increased if these are mounted in frames a little too wide for the patient, so that the eyes look through the inner sides of the lenses instead of through their centres; and also that the discomfort is diminished, or is less likely to arise, if the frames are somewhat narrow. When the relation between accommodation and convergence became known, the action of misfitting frames was rendered easily intelligible. A convex lens, within its curved surfaces, may be regarded as being made up of an infinite number of prisms with their bases meeting at the centre; and a concave lens is in like manner made up of an infinite number of prisms with their bases outwards or at the periphery. Hence, as shown by Fig. 21, a person who looks through the inner sides of convex lenses, as he must do whose frame is too wide for the distance

FIG. 21.



between his eyes, is looking not only through convex lenses, but also through prisms with their bases outwards; and he who looks through the outer sides of the lenses, as happens when the frame is too narrow, and as shown by Fig. 22, looks through prisms with their bases inwards. The former arrangement, it will at once be manifest, calls upon the convergence muscles for still greater efforts, notwithstanding that the accommodation is almost entirely relaxed; and the latter rests the convergence together with the accommodation. Dr.

FIG. 22.



Giraud-Teulon was, I believe, the first to suggest that this action of eccentrically placed lenses should be systematically utilised in the manufacture of spectacles; and after him the same subject was carefully considered by Dr. Hermann Scheffler, of Brunswick, whose treatise on ocular defects I translated nine or ten years ago. Dr. Scheffler approached the subject almost entirely from a geometrical point of view, and I gather from his various writings that he is not even a practitioner. He expresses the opinion that "the accommodation and the convergence are two primitive independent visual faculties, directed to the attainment of two wholly distinct and definite purposes, through efforts after wholly distinct and definite sensory impressions. By reason of the original independence of these faculties, every pair of eyes possesses the power to accommodate more or less with the same convergence, and to converge more or less with the same accommodation; as also to exert accommodation and convergence voluntarily, without the stimulus of light or of an external object of vision, and to increase the degree of this voluntary exertion by practice. Notwithstanding this original independence, the two faculties pass into a secondary dependence upon one another, caused either by congenital organisation, or in consequence of their usually coincident exercise, or as the result of an induction framed by the sensorium, as a higher central apparatus dominating over all the visual processes. From this secondary dependence, it follows that, in voluntary convergence, even when the eyes do not fix any object, the accommodation, if unstrained, involuntarily keeps pace with the convergence; and inversely, that in voluntary accommodation without the stimulus of light, the eyes involuntarily assume a corresponding degree of convergence. So long as this secondary proportionate dependence between accommodation and convergence, in regarding an object, is such as corresponds to the normal relative proportion of the functions in the pair of eyes concerned, the visual process is carried on without strain and with entire completeness. So soon, however, as the eyes are called upon for an abnormal relative proportion, the visual process is attended by strain."

In order to bring this view of the matter to a practical bearing, Dr. Scheffler suggested that every spectacle-lens should be used eccentrically, and should be looked upon as a combination of a convex or concave lens, destined to influence the refraction or the accommodation, with a prism destined to influence the convergence, and that each of these two elements should be studied and calculated, in every case, with an equal degree of care. He described, as a standard combination, spectacles which he called "orthoscopic," and which require a moment's consideration. It is manifest that every prism, say with its base inwards, will produce a certain definite degree of divergence, or at least of alteration from convergence, of the visual lines, just as every convex lens will place the far-point at some definite distance. Orthoscopic lenses are pairs in which the two elements are so combined that they are precisely coincident in their action—that is, that the prisms produce convergence of the visual lines precisely to the distance of the principal focus of the lenses. An instance of such a combination is furnished by two convex lenses, each of 1·25 dioptrics, ground upon prisms of four degrees and a half of angular measurement, and combined in a spectacle-frame with their bases inwards. A person wearing these spectacles, and looking at an object eighty centimetres distant, would have absolute repose both of the convergence and of the accommodation. The prisms would render the axial rays of the two pencils of light which reached the two eyes from an object at that distance precisely parallel, so that the visual lines must also be parallel in order that single vision might be maintained; and the lenses would render the component rays of each pencil also parallel, so that an emmetropic eye would not be called upon for any effort of accommodation. The eyes would be perfectly passive, directed to the horizon and accommodated for infinite distance; and yet clear and single vision of an object thirty inches distant would be obtained. Such spectacles are, in fact, component lateral parts of a larger lens, out of which they may be cut; and the same effect is produced when we look with both eyes through a large lens, such as forms part of the instrument called the graphoscope, at an object placed in its principal focus. Each eye then looks through a lateral part of the lens; and, if we were to cover most of the lens with paper, leaving two holes at a proper distance apart for the two eyes to look through them easily, we should have the same thing as a pair of orthoscopic spectacles. Hence the two lenses, whatever their prismatic angles and their foci, are only orthoscopic when fixed at some definite distance apart; and a simple test of the orthoscopic character of any pair of spectacles is furnished by the fact that, if they are so, the two images of a flame, thrown upon a screen by the two lenses, will be combined into a single image at their focal length. This again follows from the fact that the two lenses are parts of a larger one. The larger one itself would cast only one image, and two of its component parts, when they retain their original relations, act in a precisely similar manner. The annexed table shows six combinations of lenses and prisms which are orthoscopic when the centres of the glasses are sixty-six millimetres apart.

*Orthoscopic Combinations.*

| Dioptrics. | Degrees. | Dioptrics. | Degrees. |
|---|---|---|---|
| 0·5 | 1° 30′ | 1·75 | 6° 0′ |
| 1·0 | 3° 0′ | 2·0 | 7° 30′ |
| 1·25 | 4° 30′ | 2·50 | 9° 0′ |

The orthoscopic spectacles were not found, in practice, to fulfil the expectations of their inventor, because they possess a property upon which he had not sufficiently reckoned. When we look through the lens of a graphoscope, at a painting or other plane surface bounded by straight lines, the surface appears convex, and the boundary lines appear concave. Orthoscopic convex spectacles produce the same effect. They are necessarily very heavy, from the thickness of their basal sides and from the amount of glass which they contain; and they cause the centre of a page to appear prominent, while at the same time they distort its outlines. To spectacles which are composed of lenses and prisms, but which are not orthoscopic, Scheffler gave the name of combination glasses; and he went so far as to assert that they should be used in almost all cases. His general principle was that we should test, for every pair of eyes, the full amount of their convergence range, and for each eye singly the full amount of its accommodation; and that we should then give such a combination that the pair, for any desired distance at which the objects of vision were to be held, should use exactly half of their accommodation and exactly half of their convergence. The principle will not admit of being fully carried out in practice, for the reason, if for no other, that the range of accommodation is constantly being curtailed as life advances, and that the combination necessary to fulfil Dr. Scheffler's requirement would therefore be constantly changing; but it is none the less worthy of being held in remembrance, on the ground that a disruption of the accustomed harmony between accommodation and convergence is in most cases at the root of any discomfort which emmetropic persons, when they become presbyopic, receive from spectacles, especially if the latter are at all stronger than they need be. Such discomfort may often be relieved by the simple expedient of having the centres of the lenses displaced inwards, so that they exert a prismatic action of a kind to diminish the convergence strain. When I myself first used spectacles, and had all my needs fulfilled by glasses of one dioptric, I have often tried the experiment of putting on stronger ones, say of two dioptrics, and I invariably found, after using them during a few minutes for objects at their focal length, that weariness and discomfort of the eyes was produced. If now I added to these lenses a pair of prisms of seven and a half degrees, with their bases inwards, so as to form with the lenses an orthoscopic combination, all discomfort was at an end. There was the nuisance of weight, and there was the nuisance of the convexity and altered shape of the page; but, except for these, the comfort was complete. I have read for hours with such glasses without experiencing a single sensation which could remind me that I had eyes. As a general rule, we may satisfy all the wants of the presbyopic by glasses of such moderate power that the consequent disruption of the previously existing relation between accommodation and convergence is not sufficient in degree to be a source of discomfort; but we shall sometimes meet with a case in which the patient is unusually sensitive upon this point, or in which the nature of the occupation is such as to render an unusually high magnifying power desirable. In either of these cases we may overcome the difficulty by having the glasses decentered—that is to say, so cut that the patient, at the accustomed line of his convergence, does not look through the centres of the two lenses, but through a portion at the outer side of the centre of each, in the manner shown in Fig. 22. It is immaterial how much the lens is decentered, the effect being much the same as long as the visual line passes through it to the outer side of its axis. Each glass is then a prism with its base inwards, and the pair enable the eyes to obtain single vision of an object which is nearer to them than the point to which they are actually directed. In other words, the prismatic element in such spectacles diminishes the demand for convergence, just as the convex lens element diminishes the demand for accommodation. It is not necessary that the lenses should be orthoscopic, should diminish the two demands precisely in the same degree, because there is, as we have seen, a certain play, or relative range, of each function independently of the other. As long as we keep the two so nearly together that the limits of this range are not exceeded, nor even too nearly approached, we shall find that the eyes, supposing them to be emmetropic and presbyopic, can be used for all ordinary purposes and for any reasonable time.

While we may thus sometimes avail ourselves of the designed decentration of lenses, it is necessary to be upon our guard against the accidental decentration which may be effected by careless opticians. I have lately seen a case of presbyopia in which the use of a pair of spectacles, seemingly of suitable strength, and in a well fitted frame, was attended by unbearable discomfort; and I only discovered the source of this discomfort accidentally, by testing the spectacle lenses in the phakometer. I found they had been cut so carelessly that their optical centres were far external to the centres of the rings in which they were mounted; and hence that all the evils commonly incidental to too great a width of frame were produced. My patient, in using them, was not only looking through convex lenses, but also through prisms which compelled increased convergence. Whenever an otherwise inexplicable strain is produced by spectacles, the use of the phakometer should not be omitted.

Upon the grounds previously stated, therefore, I should put aside entirely, as an exploded error, the still prevailing notion that middle-aged or elderly people, previously of good sight, are liable to injure their eyes by the use of strong spectacles; and instead of allowing them to remain—tottering, so to speak, on the brink of their constantly increasing presbyopia, I am accustomed, as soon as the change becomes an inconvenience, to prescribe glasses sufficiently strong to relieve them completely, and for some little time to come. If I may venture to quote a passage which I have already published, it will be to point out that the effect of the gradual impairment of accommodation becomes harassing, to emmetropic persons who are engaged in sedentary occupations, generally between the forty-fifth and the fiftieth year; but very frequently the use of glasses is still improperly deferred. It is important for it to be understood that spectacles, instead of being a nuisance or an encumbrance, or an evidence of bad sight, are to the presbyopic a luxury beyond description, clearing outlines which were beginning to be shadowy, brightening colours which were beginning to fade, intensifying the light reflected from objects by permitting them to be brought nearer to the eyes, and instantly restoring vision to a standard from which, for ten or a dozen years previously, it had been slowly and imperceptibly, but steadily, declining. This return to juvenility of sight is one of the most agreable experiences of middle age; and my general principle, therefore, is to recognise presbyopia early, and to give optical help liberally, so as to render the muscles of accommodation not only able to perform their tasks, but able to perform them easily. When, as will happen after a time, more power is required, the stronger glasses should at first be taken into use only by artificial light; and the original pair should still be worn in the daytime. If the glasses fail to relieve discomfort, or if they become sources of discomfort themselves, the action of the convergence muscles must be taken into account, and an endeavour should be made to give relief by means of decentred or prismatic lenses. It is seldom worth while to begin the treatment of presbyopia with lenses weaker than a dioptric; and lenses stronger than three dioptrics will scarcely ever be required, except possibly in extreme old age. Between these limits I generally make four gradations —namely, 1·5, 1·75, 2·0, and 2·50. With these six powers nearly every case of emmetropic presbyopia may be successfully treated; and the ametropic forms will require a separate consideration.

When I first called your attention to the diagram in Fig. 15, in which Donders has drawn the curve of gradually failing accommodation which constitutes presbyopia, I mentioned his belief that the emmetropia of adult age often, or even generally, passes into hypermetropia as life advances. It is unquestionably often true that, after the age of fifty, distant vision is in some slight degree improved, or at all events is not impaired, by looking through a weak convex glass. The smaller curve of the diagram shows what is an ordinary course of things; that is to say, that a convex quarter dioptric will be tolerated for distance at the age of sixty, half a dioptric at sixty-five, 0·75 at seventy, 1·0 at seventy-five, and 1·50 at eighty. There can be no doubt about the facts; but I venture to think there may be doubt about the right interpretation of them. I am disposed to regard such cases not as instances of acquired hypermetropia, but as instances of manifest hypermetropia which was previously latent, or entirely concealed by the accommodation. Donders assumes that emmetropic eyes are not uncommon; I almost doubt whether they exist. I use the term, in common parlance, to include all those very small degrees of hypermetropia which are not disturbing to vision, and which are perhaps too slight to be readily estimated or even identified; but, speaking with precision, I can hardly imagine an eye that is truly emmetropic. We talk about men who are six feet high, but the chances against any particular man being precisely of that height are so great as to be almost incalculable. So they are, as it seems to me, against the focal distance and the axial length of any eye being precisely identical; and, of the two forms which ametropia may assume, hypermetropia is greatly the more common. When Dr. Cohn first investigated the refraction of children in the schools at Breslau, he found only 239 in 10,060, or 2·38 per cent., who were hypermetropic; but it has since been well established that the tests which he used were not fine enough for the discovery of the slighter grades of the condition; and that, in children who are not myopic, a slight degree of hypermetropia is the rule. I have lately been told, by Dr. Hirschberg, of Berlin, of some investigations, the precise reports of which I have not yet been able to procure, but according to which the hypermetropic eye is the normal formation in children, and in all the lower animals as far as they have been examined; and I strongly incline to the belief that it must also be regarded as the normal formation in the human adult, and that we must be content to look upon emmetropia as a merely ideal standard, constantly and closely approached, but seldom or never attained. We shall often find that even high degrees of hypermetropia are completely concealed, and rendered latent, by the accommodation; and it need not be a matter for surprise if the slighter grades, even up to an advanced period of life, remain entirely unsuspected.

We have already seen, in the first lecture, that the measure of hypermetropia is the power of the lens which will correct it; that is to say, which will render parallel rays just so far convergent that the refracting media of the passive eye may bring them to a focus upon the retina. We have also seen that the effort of accommodation is practically the addition of a lens to the eye; and, for the correction of hypermetropia, it is a matter of indifference, optically speaking, whether the required lens be added externally, by art, or internally, by natural effort. The eye shown in the second line of Fig. 16, which is hypermetropic to four dioptrics, would be undistinguishable from an emmetropic eye if it were exerting four of its nine dioptrics of accommodation; and, as with an emmetropic eye, its vision for distant objects would be impaired by even the weakest convex glass, unless a part of the four dioptrics of accommodation effort could be relaxed. It would only be distinguishable from an emmetropic eye by the circumstance that it would have less than the normal amount of accommodation for divergent rays; so that its near-point would be farther away than that of an emmetropic eye at the same period of life. Taking the conditions shown in the figure, it would have only five dioptrics of working accommodation, and its near-point would be at eight inches instead of at four inches and a half. Even this condition might be due to weakness of accommodation; and, while it could hardly fail to excite suspicion of hypermetropia, it would by no means afford certainty. Such cases would be sources of great embarrassment in practice, were it not for the power which we possess of paralysing for a time the accommodation by the application of atropia; so as

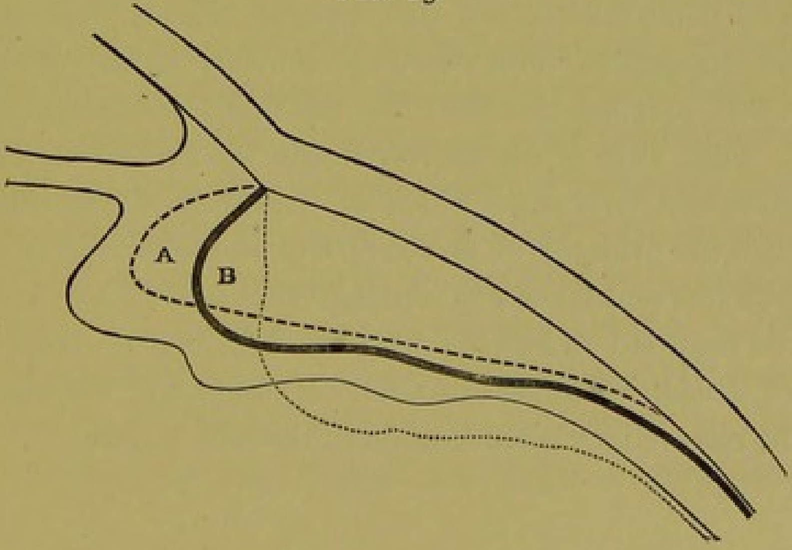
F 2

to obtain an absolutely passive eye, the refraction of which may be accurately tested. It is manifest, however, that the examinations thus made will be misleading, if any part of the accommodation should be still retained, in cases in which it was supposed to be entirely set aside.

Now, Donders taught, and writers generally have followed him, that the instillation of a drop of a solution of sulphate of atropia, of the strength of four grains of the salt to an ounce of distilled water, would completely paralyse the accommodation of the eye so treated. He says that the accommodation begins to diminish in from twelve to eighteen minutes, that the diminution is still trifling at the end of twenty-six minutes, that it then proceeds, at first rapidly and afterwards more slowly, until, at the end of one hundred and three minutes, the near-point and far-point coincide, and the accommodation is *wholly removed.* This statement was published in 1864, and it is repeated, word for word, and without comment, by Mauthner, one of the most recent writers upon the subject of the defects of accommodation. At the Royal London Ophthalmic Hospital, however, it has long been the custom of the staff to act upon the assumption that Donders was in error, and that the accommodation cannot be completely paralysed thus easily. It is not uncommon for them to apply a solution of atropia three times a day for a week or longer; and they confidently affirm that in this way they bring out, and render manifest, degrees of hypermetropia which were still concealed by the accommodation after a single application. I am not aware that anything has been written upon this subject, or that any precise data have been placed on record with regard to it; but I have myself often followed the practice of saturating the eye with atropia, and I entertain no doubt that this practice affords the only means of paralysing the accommodation entirely. I think that the eye clings, so to speak, to the last shred of its accommodating faculty, and surrenders it tardily and unwillingly; and I feel sure that many eyes have been pronounced to be emmetropic, because they rejected the weakest convex glass for distant objects after a single application of atropia, which were really hypermetropic to the extent of a dioptric, or of a dioptric and a half. The latent hypermetropia of such eyes would be disclosed by perseverance in atropinisation; and it is disclosed also, in course of time, by the total loss of accommodation which occurs at advanced periods of life. It must be remembered that the optical effect of a dioptric, or of a dioptric and a half, of hypermetropia, would be extremely small. A reference to Fig. 16 will show that a hypermetrope of one dioptric, with nine dioptrics of accommodation, would have his near-point at five inches instead of at four and a half; and that an additional half-dioptric of defect would remove the near-point only one-third of an inch farther away. With ordinary accommodation such a degree of hypermetropia as this would entail no inconvenience; or at most would cause presbyopia to become declared a year or two sooner than in an emmetropic eye.

It may further be remarked, with reference to the statement made by Donders, that this appears to have been founded upon experiments upon the eye of his assistant, Mr. Hamer; and it by no means follows that what was true of Mr. Hamer must be true universally. It follows still less, because Mr. Hamer is in a slight degree myopic; and some recent researches by Iwanoff tend to support the belief that the structure and strength of the ciliary muscle, in the two forms of ametropia, differ materially and in opposite directions from those of the emmetropic standard. Fig. 23, which is taken from Iwanoff's drawing, represents a diagrammatic

FIG. 23.



section of the ciliary region of the eye, and shows the outline of the muscle in emmetropia, in myopia, and in hypermetropia. The thick continuous line shows the emmetropic muscle, the dotted line the myopic, and the broken line the hypermetropic. It will be seen that the anterior border of the emmetropic muscle is nearly at right angles to the sclerotic; while that of the hypermetropic muscle comes more forward, and that of the myopic muscle recedes. The hypermetropic muscle is more bulky than the emmetropic by the whole mass of the triangle A; and the emmetropic muscle is more bulky than the myopic by the whole mass of the triangle B. The anterior portion of the muscle, moreover, contains nearly the whole of the circular fibres; which in the hypermetropic eye are more numerous, and in the myopic eye less numerous, than in the emmetropic; and it is reasonable to suppose that these circular fibres may be chief agents in the work of accommodation, and that in this muscle, as in all others, work is a stimulus to development. It is intelligible that in the hypermetropic eye, which has constant need to exert its accommodation, the muscle subservient to the function should be stronger, better nourished, and less ready to yield up all its power under the influence of atropia, than the corresponding muscle of a myopic eye, in which the demand for accommodation would be only of an occasional and comparatively trivial nature. So far as this we should be led by reasoning, even if Iwanoff's investigations had not been made; and it must be admitted that these investigations still need confirmation, and that Iwanoff himself does not assert that the proportions above stated are of invariable occurrence. He asserts that they are the rule; but the rule is not without exceptions. Still, even if the sections made by Iwanoff were wholly deceptive, any error into which he may have fallen would not invalidate the evidence of analogy; and on the ground of analogy alone the frequent latency of the smaller grades of hypermetropia must be regarded as highly probable. The higher grades of this form of defect, which are discoverable always and without doubt, must be reserved for consideration in the next lecture.

LECTURE IV.

# HYPERMETROPIA AND MYOPIA.

Mr. President,

THE definition already given of hypermetropia, as a state in which the length of the eyeball is less than the focal length of the refracting media, so that parallel rays, if they could pass through the ocular tunics, would be united in a focus behind them, implies, of course, that such an eye, when in a state of rest, can only obtain clear images from convergent rays. Such rays, however, do not exist in nature—that is, they are not reflected from any natural objects; and hence the passive hypermetropic eye can only see clearly when convergent rays are supplied to it by art. The simplest way of supplying them is by refraction through a convex lens; and we have seen already that the degree of hypermetropia is to be measured and expressed by the power of the lens which, in each case, will render parallel rays so far convergent, before they enter the eye, that the refracting media will unite them in a focus upon the retina. We have seen also, that the act of accommodation is precisely analogous to the addition of a convex lens to the passive eye; and, for the relief of hypermetropia, it is a matter of indifference, optically speaking, whether the required lens is added within the eye by accommodation, or externally to it by art. A person who has hypermetropia of five dioptrics, and who has also five dioptrics of accommodation, will be able to overcome the defect by the exercise of the faculty. It is obvious, however, since he thus uses all his accommodation in order to obtain clear images from the parallel rays which come from distant objects, that he will have no accommodation available for the ordinary purpose of obtaining clear images from the divergent rays which come from near objects; and hence, to use a happy phrase taken from Donders, a patient, who is compelled by his hypermetropia to use some of his accommodation for distant objects, starts with a deficit for all the other requirements of life. The amount of this deficit will depend upon two factors—the degree of the hypermetropia, and the range of accommodation.

The degree of hypermetropia varies from those slight forms of the affection which are only discoverable by very careful examination, up to conditions which may fairly be described as microphthalmos. I have already assigned reasons for my belief that a small degree of hypermetropia may be regarded as almost the normal formation of the eye; but the higher grades are comparatively seldom met with. Among the 239 hypermetropes found by Cohn in his examination of 10,060 school-children none were included in whom the defect was less than 0·75, or three-quarters of a dioptric; and the highest grade found was 4·50 dioptrics. Between this highest grade and 3·0 dioptrics, there were only seven cases in all; and many more than half the cases (168 out of the 239) were between 1·9 and 1·75. Donders has recorded a case, observed by Mr. Bowman, in which the hypermetropia amounted to twenty dioptrics; but such an eye as this is quite exceptional; and I should say that six dioptrics would be the highest grade which would be passed by in practice without exciting attention as a matter of singularity; while the great majority of patients support Cohn's figures, and present grades of about two dioptrics or even less. Of course it must be remembered that nearly all instances of the higher grades are forced to seek optical assistance; while many persons with the lower grades contrive to carry on their work unaided; and, in this way, surgeons may often obtain erroneous ideas of the relative prevalence of the slighter and of the more pronounced degrees of the affection.

If we refer again to the diagram of the range and the region of accommodation, given at Fig. 16 in the second lecture, we shall see the amount of deficit which hypermetropia would produce in every case. Assuming the patient to be twenty-one years of age, and to be in possession of the nine dioptrics of accommodation which are to be expected at that period of life, the second line of the diagram shows the precise effect of a hypermetropia of four dioptrics. Four of the nine dioptrics of accommodation are required for parallel rays—that is, for seeing the horizon clearly; and only five dioptrics remain for divergent rays—that is, for seeing near objects clearly. These remaining five dioptrics will bring the near-point no nearer than to eight English inches from the eye; and, as few can continuously exert more than half of the entire range of accommodation, which half, in the case supposed, would be four and a half dioptrics, the actual and practical near-point for sustained vision would be at eighty inches away. If two-thirds of the accommodation could be continuously employed, this amount would bring the near-point to twenty-inches; but even this distance is too great to allow very small print to be read without assistance. Other grades are not laid down on the diagram, but their construction upon the same lines is simple and easy. The average hypermetropia of two dioptrics would leave seven dioptrics of accommodation at liberty for brief efforts; and the 4·50 dioptrics which can be employed habitually or constantly would afford only 2·50 for divergent rays, so as to bring the near-point for sustained vision to sixteen inches from the eye. If the hypermetropia exceeds 4·50 dioptrics, no sustained effort will be possible for any point nearer than the horizon; although for a short time such an effort could be made successfully. If the hypermetropia exceeds nine dioptrics, the near-point will be always beyond infinite distance; or, in other words, no exertion of accommodation will suffice to unite parallel rays upon the retina, and vision of all distant objects will be indistinct, unless aided by a convex lens.

As stated in the first lecture, the measure of the degree of hypermetropia is given by the strongest convex lens through which the eye obtains clear images of distant objects; but, in order to apply this test correctly, the accommodation must first be rendered passive. In all hypermetropic eyes the habitual state of the muscle of accommodation is one of contraction, rendered necessary by the instinctive craving for clear images—a craving which cannot be gratified in any other manner without optical assistance. In the case already supposed, where there is hypermetropia of four dioptrics and accommodation of nine dioptrics, four of the dioptrics of accommodation would always be in use. If this amount of effort were laid aside, all distant objects would appear dim and undefined; and such a condition of vision is not only unsatisfying, but it would in many people give rise to vertigo. Hence, the eye never fully relaxes its accommodation; and the muscle is so habituated to a certain amount of effort that this amount becomes its nearest approach to relaxation during waking hours. The eye is always enough accommodated to see distant objects clearly; and hence, if we place before it a convex lens, say of four dioptrics, the power thus given would be an unnecessary addition to its own accommodation, and would render distant objects dim until the accommodation effort was laid aside. Even the weakest convex lens might act in a similar manner; the eye not recognising the presence of the lens as a reason for relaxing its accommodation, or perhaps not having the power of relaxing it. In other cases, again, the eye constantly exerts some accommodation, but not enough to give the best distant vision which is attainable; and then it derives aid from a weak convex lens, but rejects the stronger one which would fully compensate for its defect. The hypermetropia which at once declares itself, the patient saying that a convex lens of given power improves distant vision, is said to be *Manifest;* and its amount is expressed in the ordinary way, by the power of the strongest lens which can be thus employed. In most cases, however, at least in young people, the accommodation is still at work together with the lens; and then, when the accommodation has been paralysed by atropia, a still stronger lens is accepted as the best. The additional hypermetropia thus revealed is said to have been *Latent;* and the manifest and the latent together make up the *Total.* Thus, in the assumed standard case, if only three dioptrics of accommodation were constantly employed, a convex lens of one dioptric would improve distant vision, and there would be manifest hypermetropia to this extent. When the accommodation was fully paralysed, a lens of four dioptrics would be required; and the three dioptrics of defect which had been previously latent, or concealed by the accommodation, would become apparent and serve to make up the total.

The proportion which the latent bears to the manifest or to the total hypermetropia must evidently be constantly changing, as the power of accommodation diminishes with advancing life. According to Donders, we may often have as much as six dioptrics of hypermetropia latent in childhood. By the age of twenty, as much as half of this, and by the age of forty more than three-fourths of it, will have become manifest. By the age of seventy, the whole of the hypermetropia will be manifest; and even a higher grade may be found than that which was at first supposed to be the total. Donders regards this apparent higher total of old age as being partly made up of what he calls *hypermetropia acquisita;* but, as I have already set forth, I think there is much reason to regard it as the real total, part of which had been concealed, in earlier life, by the resistance of the ciliary muscle to any single application of atropia.

From considerations which have been already urged, it is manifest that the effort of accommodation, which is required in order to overcome hypermetropia, will be most easily made in conjunction with an effort of convergence. We have seen, in Fig. 18, that the emmetropic eyes of the subject from whom the diagram was taken, with their visual lines parallel, could exert only three dioptrics of accommodation; but that, when the visual lines were convergent to thirteen inches (11° 21′), the same eyes could exert seven dioptrics of accommodation. In hypermetropia, the conditions, although not exactly parallel, are strictly analogous; and hence cases of hypermetropia were divided by Donders into three classes, with reference to the relation of the defect to the convergence function. He calls the hypermetropia *Absolute*, when accommodation for parallel rays is unattainable, even with the strongest convergence of the visual lines; *Relative*, when there is accommodation for a near-point, but only during convergence to a point still nearer (*e.g.*, when it is possible to accommodate for a point sixteen inches away by convergence to a point twelve inches away); and *Facultative*, when objects can be correctly seen with parallel visual lines, and either with or without convex glasses. Another definition is that hypermetropia is absolute, when the focus of parallel rays remains behind the retina, even with the strongest possible tension of accommodation and of convergence; relative, when the focus of parallel rays can be brought to the retina by accommodation and convergence; facultative, when the focus of parallel rays can be brought to the retina by accommodation alone, the visual lines remaining parallel. These distinctions are met with in books, and it is necessary to be acquainted with their meanings; but they are of little practical value, if only for the reason that in every case the conditions are constantly being changed by time, as the range of accommodation becomes confined within narrower and narrower limits. The facultative hypermetropia of childhood becomes relative in adult age, and absolute in the decline of life.

Another result of the connexion between accommodation and convergence is that a pair of hypermetropic eyes, in order to accommodate to the extent rendered necessary by the requirements of vision, keep their muscles of convergence in a state of constant tension. As shown by Dr. Loring's experiments, already quoted, this tension of the interni may be overcome by similar tension of the externi, exerted in the interests of single vision; but, in a large proportion of cases, the interni preponderate, and the eyes are brought into a state of habitual convergence, as a consequence of the habitual exercise of their accommodation. The convergence thus produced is at first equal on both sides, and it generally becomes declared during the third or fourth year of life. After a time, in consequence of the double vision caused by the faulty position of the eyes which is thus produced, it becomes necessary for the child to correct this position by voluntary effort; and this is accomplished, when both externi are unequal to the task, by associating one externus with the internus of the other eye.

Both eyes being convergent when at rest, and parallelism being unattainable, the patient sometimes brings the right eye into the middle of its palpebral fissure by looking to the right, sometimes the left eye by looking to the left. It is plain that the effort which, in the natural state, would roll the right eye outwards, will stop short of this by precisely the degree in which the eye was previously rolled inwards by its habitual convergence; and, thus stopping short, will direct its visual line straight forwards. While the action of one of the externi, starting from a position of convergence, produces only the middle position for the eye on which it acts, the associated effort of the opposite internus, also starting from a position of convergence, rolls its eye completely inwards. It would do this, even if the natural relations of the two muscles remained unchanged; but, as a matter of fact, the internus which thus acts is one which is in a state of exaggerated development from constant work. The externus and internus receive the same motor stimulus from the centre; but the stronger muscle responds to this stimulus more powerfully than the weaker one. The result is, that the eye on which the internus acts is turned inwards in a greater degree than its fellow is turned outwards by the externus; and in this way the common concomitant convergent squint is produced. As long as the subject uses one or the other eye indifferently, this form of squint is only objectionable because it is unsightly, and because it prevents binocular vision. In most cases, however, either because one externus is stronger than its fellow, or because one eye has better vision than its fellow, one after a time is always directed forwards, and the other always directed inwards. As soon as this happens—as soon as one is always the working eye, and the other always the squinting eye—the vision of the latter begins to suffer; and it is then generally desirable to operate for the cure of the squint without delay, in order to prevent the deterioration of vision from attaining any considerable degree. It follows, from the account thus given of the mechanism of squint, that the affection is really binocular; and that both interni should be divided in nearly all cases. It is often possible to produce parallel visual lines for distance, by dividing one tendon only;

but such an operation, although it may be coarsely successful, leaves one eye with a weak and the other with a strong internus, and the two cannot respond in equal degrees to the convergence stimulus. The result is that they are never found to act comfortably together when directed to near objects; and the eye which has been operated upon, under such circumstances, is apt apparently to squint outwards, its real position not being one of divergence, but of imperfect convergence only. When the total squint is of small magnitude, it is desirable to divide the tendon of the squinting eye first, and to let this regain a firm attachment before dividing the other. In some instances, the neglect of this precaution has led to too extensive an operation, and hence to a divergent squint which would be permanent unless removed by another operation of a contrary tendency to the first. When the effect of the first operation is fully declared, that of the second may generally be precisely calculated.

Although hypermetropia is the cause of nearly all the cases of convergent squint, and although perhaps 90 per cent. of all who squint convergently are hypermetropic, the reverse of this proportion does not hold good. Cohn, in his already quoted statistics, found 239 cases of declared hypermetropia. Of these, 158, or almost precisely two-thirds, were the subjects of convergent squint. The reason why some hypermetropes squint, and others do not, requires further investigation. It would seem, at first sight, as if the difference must depend upon difference in the equilibrium, or proportionate strength, of the externi and the interni; that is, as if squinting would be obviated in those eyes in which the externi were able, on Loring's principle, to resist, for the sake of fusion, the heightened tension of the interni incidental to constant strain of the accommodation. It is also possible that the desire for fusion may be stronger in some persons than in others; and again, that in some the heightened tension of the interni produced by accommodation may be less considerable than in others. It is certain that many hypermetropes may be withheld from squinting by the habitual use of convex glasses, which diminish or remove the demand for accommodation; but this element in the question would not have any appreciable influence upon Cohn's figures, because only nine of the scholars included in his tables were so provided. If we remove these altogether, the proportion of squinting to non-squinting hypermetropes remains practically unchanged.

The diagnosis of hypermetropia rests upon the appearance of the eye, upon the conditions of vision, and upon the relief afforded by suitable convex glasses.

The appearance of the eye, at least in pronounced cases, is such as to show that the affection is due to arrested or imperfect development. The eye is smaller than natural in all its dimensions; and its small size is generally most manifest when it is adducted to the fullest possible extent. The orbits also are in most cases small; and these peculiarities of formation are often hereditary, and are often shared by other members of the family. The popular belief about squint arising from imitation seems to have no better foundation than its frequent occurance, as a result of similar physical formation, in several brothers and sisters. Not long ago, I operated for squint, at St. George's Hospital, upon six sisters and their mother; and it is the exception, rather than the rule, for only one child in a family to be affected.

The conditions of vision depend entirely upon the degree of the hypermetropia, checked by the power of accommodation. If the hypermetropia is of small degree, as of one dioptric, and the range of accommodation normal, no inconvenience will be experienced until the accommodation is curtailed by the advance of years, and then the only symptom will be the early on-coming of presbyopia. Such a patient will require reading-spectacles by the age of forty, and always thereafter will require for all purposes glasses a dioptric stronger than his period of life would indicate. When his power of accommodation is lost, he will require glasses of one dioptric for clear distant vision.

When the hypermetropia is originally of such a degree as to consume for its correction nearly half the power of accommodation, so that the use of the eyes upon near objects can only be accomplished by means of the remaining half, or whenever this state of things is brought about later in life by decline of the accommodation, any attempt at sustained effort of the eyes is soon rendered impossible by muscular fatigue. The symptoms of this fatigue have been known for many years as constituting one of the forms of the malady called asthenopia; but it was reserved for Donders to trace this form of asthenopia to its origin, and to show that it is neither more nor less than a result of overstrain of the accommodation. Until this discovery was made, the asthenopia was incurable, and the unfortunate sufferers from it were advised to relinquish all pursuits in which employment of the eyes upon near objects was required. Not an uncommon prescription was to go to Australia and to turn sheep farmer; and this, when it was followed, had the twofold advantage of diminishing the discomfort of the asthenopia, and of getting rid of a patient who did little credit to any of his generally numerous advisers. The discovery of the nature of the affection disclosed the means of curing it by substituting for the accommodation effort the employment of convex glasses; and the form of asthenopia which depends upon hypermetropia alone is now no longer a source of trouble either to patient or doctor. The hypermetropia must be corrected, either wholly or partially, by suitable lenses, and the fatigue in which the asthenopia had its origin will be at once relieved. The principles on which the lenses must be chosen are very simple, but I must reserve certain matters of detail which bear upon this point until the last lecture of the course, in which the treatment of all the forms of asthenopia will be discussed after their several causes have been described.

In very high degrees of hypermetropia, the diagnosis of the affection is sometimes less easy than in the lower grades, and the symptoms may even simulate those of myopia. The patient (necessarily a child, because these high degrees always interfere with education, and call for relief long before adult age is attained) is said by parents and friends to be "shortsighted." We find, on examination, that he cannot see distant objects distinctly, and that he brings a book very close to his eyes. We sometimes find that he declares distant vision to be improved by a weak concave lens. The explanation of these conditions is as follows:—The patient cannot see distant objects clearly, either because his accommodation is insufficient to neutralise his defect, or because the muscle of accommodation, always contracted, passes into a state of spasm and over-corrects the defect. The book is brought near to the eyes, because the larger visual angle subtended by the near object gives a correspondingly larger image on the retina, and thus facilitates recognition. The diffusion of light due to the hypermetropia is at the same time increased; but Donders has shown that the magnitude of the retinal image increases more rapidly than the magnitude of the diffusion circle, so that the balance of advantage remains on the side of approximation of the object. The balance is the more decided, because the highly hypermetropic eye is not accustomed to perfectly defined images, and therefore appreciates magnitude more highly than clearness. The preference for a weak concave glass, when it occurs, is a result of over-correction of the hypermetropia by spasm of accommodation. Such cases as those now described present little difficulty to any who have been warned of them; for the eyes have always the hypermetropic formation in a marked degree, and the thorough application of atropia at once clears up any doubt which may be felt. It is in such cases that we find the necessity of repeated and systematic atropinisation, and discover the error of trusting to one application alone. I have seen instances in which there was apparent myopia to the extent of a dioptric, and in which, after the use of atropia twice or thrice daily for three or four days, as much as six dioptrics of total hypermetropia became revealed.

The principle on which hypermetropia should be treated is manifestly by the use of spectacles with convex lenses, such that they as nearly as possible correct the faulty shape of the eye, by rendering the rays which reach the cornea so convergent that they may be brought to a focus on the retina with little or no effort of accommodation. In a hypermetropia of four dioptrics, lenses of four dioptrics might not unreasonably be supposed to enable the eyes to be passive, as if they were emmetropic, during vision of distant objects, and to release all their accommodation for employment upon near objects. We find, however, that this expectation is not entirely fulfilled. The muscles of accommodation have usually been brought, by constant exercise, into a state of tonic spasm ; and they show little inclination to become relaxed. If we correct the total hypermetropia, we render the patient short-sighted, because he has correction and accommodation too. It is therefore generally necessary to feel our way, and to accustom the eyes to partial correction, and to the abandonment of some of their customary accommodation effort, before they are called upon to abandon the whole of it. Donders laid down the good practical rule that we should correct the whole of the manifest hypermetropia and about one-fourth of the latent. The glasses which do this will usually relieve any discomfort which had been produced by accommodation strain ; and the patient will for a time be delighted with them. After a while, the amount of accommodation effort which is still required becomes irksome ; and the old symptoms show signs of returning. The patient may again be relieved by strengthening his glasses to the extent of perhaps half of the still uncorrected defect ; and then, if after another interval he is again distressed, he may receive full correction, and may go away freed from the consequences of his defect, and able, ever afterwards, "to forget that he has eyes." But, in order that such a result may be obtained, the patient must wear the glasses constantly. If they are sometimes off and sometimes on, the eyes will never learn to lay aside their accommodation effort for distance ; and consequently will always be fatigued, and, with the glasses, will always see the horizon indistinctly.

By way of illustration, let us suppose the case of a patient who has one dioptric of manifest hypermetropia, and whose eyes, when thoroughly under atropia, show five dioptrics, four of which were previously latent, or concealed by the accommodation. In order to correct all the manifest and one-fourth of the latent, we give spectacles of two dioptrics, directing them to be worn constantly. In a few months, when the old symptoms return, we correct half of the remaining defect—that is, we increase the power of the glasses by a dioptric and a half, which raises them to three and a half dioptrics. If the symptoms return again, we give five dioptrics; and then the patient will require nothing more until he reaches the time of life at which presbyopia commences. His spectacles for near work must then receive an addition of as much power as an emmetropic person would use for the same purposes at the same period of life.

I pass on now to the opposite condition of Myopia, which, as contrasted with hypermetropia, presents a long visual axis instead of a short one, and a focus of parallel rays which is situated in front of the retina. In order that the focus of rays may fall upon the retina, the rays themselves must be divergent; and this divergence may be given to them either by the approximation of the object from which they proceed, or by the refraction produced by a concave lens of the necessary power.

When a person is able to read small print easily and fluently in the hand, but has not the normal standard of vision for distant objects, we may at once infer that he is the subject of myopia; and, if his distant vision is improved by a concave glass, the inference may be accepted as a fact. We then proceed to estimate the degree of the myopia in dioptrics, by test-lenses applied in the ordinary way; always bearing in mind that the weakest concave which affords the best attainable vision must be taken as the standard of the defect. If we find, for instance, that a patient has normal vision, or nearly so, with a concave of three dioptrics, we must not at once conclude that this is the degree of his myopia, but must try whether a result equally good cannot be attained with two dioptrics and a half. Myopic persons often prefer over-correction for a time, and would choose glasses that were too strong if they were left wholly to their own devices. If the lens of two dioptrics and a half, although it improves vision, does not enable the person to decipher the same letters which were legible with three dioptrics, then the correctness of the original choice is confirmed.

The definition of myopia, it will be remembered, rests upon the fact that the *far-point* of clear vision is at some finite distance; and the degree as stated in dioptrics corresponds precisely with this finite distance. To say that a patient has a myopia equal to one dioptric, means, primarily, that a lens of one dioptric renders parallel rays sufficiently divergent to allow them to be united in a focus upon the retina. But a lens of one dioptric renders these parallel rays as divergent as if they proceeded from a point one metre distant; and it follows that the eye would not require any lens for rays which really proceeded from a point at this distance. In other words, the patient can see clearly at the distance of one metre, but not farther away. His far-point is one metre from the eye. The degree of myopia has reference to the far-point, and to that alone. If the myopia increases, the far-point approaches the eye; if the myopia diminishes, the far-point becomes more distant. The myopic eye, like all others, has a near-point as well as a far-point; and its near-point is determined by its power or range of accommodation, and recedes in the usual way as life advances. But the near-point has nothing to do with the degree of the myopia. From imperfect knowledge of this very simple matter, many errors have become firmly rooted in popular belief, and some errors have been promulgated by persons who ought never to have fallen into them. It is commonly said that myopia diminishes as life advances. The fact is, that a person who at twenty-one years of age has a myopia say of four dioptrics, and an accommodation of nine dioptrics, as in line four of Fig. 16, has his far-point at ten and his near-point at three inches from the eye. He can read at either of these distances, or at any point between them. At the age of forty, when he has lost half of his original accommodation, his far-point will still be at ten inches, but his near-point will have receded to about five inches, and he will be unable to read at any nearer distance. He will often say, "I am not so short-sighted as I was," although he has gained nothing, and has simply lost the front two inches of his range of vision. Some few years ago, certain operations upon the eye were vaunted on account of their supposed power to diminish myopia; but it is melancholy to relate that their only claim to this power was based upon recession of the near-point; the position of the far-point either not having been recorded, or having remained unaltered.

The operations diminished the accommodation, and thus curtailed the range of vision at its proximal extremity, instead of extending it at its distal extremity. The belief that short-sight diminishes with the approach of old age does not, however, rest entirely upon the recession of the near-point, but also upon the contraction of the pupil which is incidental to advancing years. The pupils of young myopes are generally large, and the magnitude of the pupil increases the size of those diffusion circles on the retina, by which clear vision of objects beyond the far-point is hindered. As the pupils become smaller, the diffusion circles diminish; and thus, while the degree of myopia remains the same, remote objects are seen somewhat less indistinctly than before.

The immediate cause of myopia is, of course, the elongated shape of the eye; but the causes in which this elongation originates are not completely understood. Myopia is a condition incidental to civilised life, and is said to be unknown among savage races. I am not aware of any trustworthy observations upon the eyes of new-born infants, such as to support or disprove the hypothesis that the myopic formation is sometimes congenital; but myopia is so often inherited from parents that the tendency to the formation must at least be congenital, whether the formation itself may or may not be so regarded. The affection does not declare itself in early childhood by any subjective signs, although it would be discoverable by the ophthalmoscope; and it is only at the age of five or six years that it is noticed by parents of average intelligence and observation. Very often it is first discovered at the commencement of school life; and only then after some blundering teacher has punished the child repeatedly for the offence of not knowing what was written on a black board situated beyond his range of vision. When once declared, however, the tendency of the higher degrees of myopia is to increase; and this increase seems to be almost entirely due to the enforced convergence which the affection renders necessary. If we consider the points of attachment of the interni, it is easy to see how the tension which they exert upon the ocular tunics must express itself in a tendency to bulging of the posterior hemisphere of the eye; and, when the tension is considerable and frequently repeated, the tunics may become seriously weakened, and may stretch with constantly increasing facility. As a rule, it may be said that all cases of myopia, which require habitual convergence to a distance of eight or nine inches as a condition of binocular vision, will undergo progressive increase if binocular vision is maintained; and it follows that every increase of the affection renders farther increase more inevitable and more rapid. Dr. Cohn, from whose highly meritorious work I have more than once quoted, was the first systematically to investigate the occurrence of myopia in schools; and he found that not only the amount of myopia, the numerical proportion to non-myopic pupils, increased with every year of school life, but also that the average degree of the myopia increased in a corresponding ratio. His inquiries have been repeated by other observers in various places, notably by Dr. Erismann in Russia, and by Dr. Agnew in America, always with full confirmation of his results; and it is now beyond doubt that badly-arranged schools form a great machinery for the cultivation of myopia. It is presumed that they may even originate the affection, as well as cause its active development; and the influences which may do either one or the other are mainly defective lighting, books printed in too small a character, and forms and desks so constructed that the pupils sit a long way from their work, and hence fall into stooping positions over it. All these conditions imply the unnecessary or avoidable approximation of the eyes to the books, with a consequent strain upon the accommodation and upon the convergence; and it is easy to perceive in what way myopia may result from such conditions, and how, once commenced, it must necessarily go on increasing.

According to Donders, who has analysed so may cases of myopia, and has observed them for so long a time, that he has left little to be learnt with regard to the facts of its natural history, there are three principal types of the affection: the stationary, the temporarily progressive, and the progressive. He describes as stationary a degree of myopia which does not exceed two dioptrics at ten years old, nor two and quarter at forty; often declining to one and a quarter or one at eighty. The temporarily progressive may increase from four to eight dioptrics between the ages of ten and thirty, the increase being most rapid between the ages of eighteen and twenty-two; and the progressive, starting from a high degree at an early period of life, increases steadily and constantly.

The subjects of myopia, more than other persons, are liable to suffer annoyance from the floating particles known as *muscæ volitantes.* The vitreous humour contains a certain amount of very fine filamentous tissue, studded here and there with the remains or the nuclei of cells; and this tissue, when its elements, although transparent, are of a different index of refraction from the fluid which surrounds them, is liable to cast shadows upon the retina. The shadows are then projected into space as apparent objects. Their magnitude depends, of course, on the distance of the bodies which cast them from the retinal screen on which they fall; and this distance will obviously be greater in the elongated myopic eye than in any other. Hence, in myopia, the shadows are often large and conspicuous; and they sometimes occasion much distress to sensitive people. True muscæ never intervene between the eye and the object looked at, but float about in the lateral parts of the field of vision. As long as they preserve this character, and as long as the bodies which cast the shadows are undiscoverable by the ophthalmoscope, the muscæ may be entirely neglected. They point, at most, to an exaggeration of a natural condition; and they have no pathological significance.

When myopia is increasing, the tension upon the ocular tunics, to which the increase must generally be ascribed, is apt to entail other consequences also. The most familiar of these is the so-called myopic crescent, a patch of choroidal atrophy on the outer side of the optic nerve, just where the tension upon the tunics would be most powerfully exerted. As the choroidal tissue wastes, it no longer conceals the sclerotic, which is seen with the ophthalmoscope in its glistening whiteness at the affected part; and the patch of atrophy, losing its originally crescentic form, increases in size, assumes irregular boundaries, and sometimes completely encircles the optic nerve. Many hypotheses have been framed to account for the formation of this crescent; but perhaps the most simple of them has most to recommend it to our acceptance. The wasting commences at a place where the choroid is firmly united to the sclerotic, and where, from the mechanical relations of the eyeball, the strain produced by convergence must be chiefly felt. The mere stretching of the delicate vascular membrane impedes its circulation, interferes with its blood-supply, and inflicts a shock upon its nutrition. At the point where these effects are produced in the greatest degree, atrophic changes are first set on foot, and they gradually extend to neighbouring parts as the causes which produce them are increased in intensity. Beyond the region of the white patch, we may often discover by careful examination that the choroid is thinned and weakened; and, as in nearly all the disturbances of choroidal nutrition, there is often an unnatural formation or deposition of pigment about the affected part. In some instances, we may see cloudiness of the retina, effusion from its vessels or from those of the choroid, and manifest signs of inflammation.

When the myopic crescent was first discovered, it was looked upon as an inflammatory change, and the higher degrees of myopia, in which there were large crescents, were said to be attended by *sclerotico-choroiditis posterior*. So formidable an appellation is sufficient to excite in the minds of all who hear it an intense longing to be able to lay it aside; and I confess that I have not been able to satisfy myself that any kind or degree of inflammation is at all essential to the most complete development of the choroidal atrophy of myopia; or that, supposing inflammation to occur, it is anything more than an accidental complication, probably due to stretching and irritation of the delicate structures which are involved. But, however produced, internal inflammation of the posterior hemisphere of a myopic eye is a very serious and alarming condition. It tends to obscure the transparency of the vitreous body by the formation of films or floating opacities, to extend to the region of the macula lutea and destroy central vision; and even, in many cases, to produce detachment of the retina and hopeless and complete extinction of sight. To speak at length of these changes would be foreign to the scope of discourses which profess to deal only with conditions remediable by optical appliances; and I must therefore pursue this part of my subject no farther. I have only referred to it in order to point out some of the chief dangers to which the myopic eye is exposed, and to say that against these dangers optical appliances will often furnish us with effectual safeguards.

It is necessary in this place to refer to a hypothesis, with regard to the formation of the myopic crescent, which has been put forward and defended with conspicuous ability by Dr. Thomson, of Philadelphia. He looks upon the crescent as a change which occurs only in eyes in which myopia is complicated by astigmatism; and he holds that a line crossing the widest part of the crescent would nearly correspond to the direction of one of the chief meridians. My own observations have not allowed me either to confirm or to controvert Dr. Thomson's conclusions; but it is undeniable that there is discoverable astigmatism in nearly every instance of a high degree of myopia.

As, in hypermetropia, the eyes are constantly called upon to exert accommodation in excess of their convergence, so in the opposite condition of myopia they are constantly called upon to exert convergence in excess of their accommodation. A person with a myopia of four dioptrics, for example—and hence with a far-point only ten inches distant,—would scarcely ever require to exert accommodation at all. He would scarcely ever desire to bring an object of vision nearer than ten inches, and he would be unable to see it clearly when farther away. His ordinary visual effort, therefore, would be convergence to ten inches in repose of his accommodation; but in many persons, if not in all, repose of the accommodation cannot be maintained during convergence to ten inches; while any effort of accommodation which the convergence produced would bring the point for distinct vision still nearer to the eyes, and would thus require a further increase of convergence to keep pace with it. In this way, by the reaction of the two functions upon each other, we have a potent influence towards rendering the myopia progressive; and it seems probable that this influence would be most powerfully exerted in those eyes in which the union between accommodation and convergence retained most nearly its natural or typical character. The liability to accommodation effort as a consequence of convergence effort should never be lost sight of in estimating the degree of myopia; and we shall frequently find, in the higher degrees of the affection, that saturation of the eye with atropia will reduce the apparent myopia by as much as one or two dioptrics. In all cases of myopia above six dioptrics I am accustomed, after determining the degree in the ordinary way, to determine it again under the influence of atropia. If any material difference is occasioned by the mydriatic, the fact serves as a valuable guide to the proper management of the case.

The indications of treatment in myopia are mainly these:—to display the world; to prevent an injurious degree of convergence; and to prevent spasm of accommodation.

If we consider for a moment what must be the state of a person who has grown up to manhood or womanhood with an uncorrected myopia say of only two dioptrics, we shall not fail to perceive that the first-named indication is one of no small importance. An emmetropic subject may produce the condition artificially by placing convex spectacles of two dioptrics before the eyes. The artificial myopia thus produced would be deprived of half its inconveniences by the previously acquired knowledge of the exact forms and characters of numerous objects which would be only dimly seen; but the subject of it would find, for example, that instead of being able to tell the hour by an ordinary drawing-room clock from any part of the room, he would have to approach within three or four feet of the dial in order to perceive dim indications of the hands. He would lose all the play of expression on the faces of persons with whom he was engaged in conversation. I once prescribed glasses to correct the myopia of a lady who had for many years been engaged in teaching, and who had never before worn them. Her first exclamation of pleasurable surprise, as she put the glasses on and looked around her, was a curious commentary on the state in which her life had until then been passed. She said, "Why! I shall be able to see the faces of the children!" If we think what this exclamation meant, and if we apply the lesson which it teaches to other pursuits, we shall not fail to perceive that the practical effect of myopia is to shut out the subject of it from a very large amount of the unconscious education which the process of seeing the world involves, and thus to occasion losses which can hardly be made up in any other way. Taken in detail, these losses, the mere not seeing of this or that seeming trifle, may appear insignificant; it is their aggregate which becomes important. A very distinguished man of science, who is myopic in a high degree, and who did not receive glasses until he was nineteen or twenty years old, has often told me how much he had to do in order to place himself upon the same level, with regard to experience of quite common things, with many of his normal-sighted contemporaries; and it will be manifest on reflection that the matters which are lost by the short-sighted, as by the partially deaf, make up a very large proportion of the pleasures of existence. I am accustomed, on this ground, strongly to urge upon parents the necessity of correcting myopia in their children; and I am sure that a visual horizon of ten or even twenty inches, with no distinct perception of objects at a greater distance, has a marked tendency to produce habits of introspection and reverie, and of habitual inattention to outward things, which may lay the foundation of grave defects of character. Landscape painters are the only people to whom a small degree of myopia can be useful. I once accompanied a landscape painter on a sketching expedition, and after a time asked him whether he intended to omit a certain house from his sketch. He looked up with surprise, and said, "What house? There is no house there!" I at once understood a certain haziness of aspect with which it was his custom to clothe distant scenery in his pictures, and which was very much admired by persons who mistook it for a skilful rendering of an uncommon atmospheric effect. In fact, it was only what the short-sighted man saw always before him; and I am sure he must himself have been greatly puzzled by much of the praise which he received. Soon after I first published, in the *Practitioner* for 1874, a reference to this effect of myopia upon painting, Mr. Liebreich attempted to account for some of the peculiarities of Turner's style by the peculiarities of his vision; but, as I shall have to explain when speaking of astigmatism, the view thus advanced appears to me to be erroneous.

The indication to display the world may be fulfilled, generally speaking, by complete correction of the myopia; that is to say, by the use of glasses of the same strength as those which express the measure of the defect. If the accommodation were perfect, and bearing its proper relation to the convergence, these glasses would obviously convert the myopic eye into a normal one; giving it clear vision at infinite distance without accommodation, and rendering the assistance of accommodation necessary in looking at near objects. We find some myopic eyes in which these conditions are nearly fulfilled; and, in most cases, when the myopia does not exceed four dioptrics, and when the range of accommodation is fairly good, we may prescribe full correction of the defect for all purposes; always remembering that this prescription may require to be modified after we have gained experience of its effects. In many instances, and probably in most of those in which the myopia exceeds four dioptrics, the range of accommodation is only limited; and then, whether the limitation be due to mere disuse of the muscle, from the absence of any demand for its services, or to the structural formation described by Iwanoff, and shown by the dotted line in Fig 23, the practical result will be that the eyes, when corrected for the horizon, cannot exercise enough accommodation to bring their near-point within reading distance, or cannot exercise this amount for more than a short period without fatigue and distress. When this happens we must lay aside the full correction when the eyes are to be employed about near objects, and must be content to fulfil the second indication — the prevention of undue convergence — by the use of glasses which are just sufficient to keep the visual distance at about fourteen or fifteen inches from the eyes. For this purpose, it is a good general rule to leave two dioptrics of myopia uncorrected by the reading glasses; as by giving reading-glasses of three dioptrics for a myopia of five. With glasses of three dioptrics, the two uncorrected dioptrics of myopia will leave the far-point twenty inches from the eye; and there will generally, except in very high degrees, be sufficient range of accommodation to bring the reading distance five or six inches nearer without fatigue. With myopia under four dioptrics, therefore, my rule is to prescribe full correction for all purposes, ordering the glasses to be worn from morning to night, and warning the patient that a book must never be brought nearer than fourteen inches from the eyes. In order that this injunction may be fulfilled, it is necessary to give a caution against the use of books printed in very small type, and also against attempts to read by defective light, whether natural or artificial, as this would require the approximation of the object. Myopic people, because they can see at a nearer point than others, can also see by a smaller degree of illumination; and hence, as children, they often contract a habit of reading by twilight, or moonlight, or firelight. It is also necessary to warn the patients that the spectacles will call upon the ocular muscles to work under conditions which, although better than those which precede them, are still new; and which, while they are new, will inevitably be more or less irksome. If, after two or three weeks of trial, any discomfort which was felt at first passes away and is forgotten, then the completely correcting spectacles may be used continuously; but if fatigue in reading is experienced, we may infer that the full correction throws too great a strain upon the accommodation when the eyes are employed about near objects, and we may order weaker spectacles, which leave two dioptrics of myopia uncorrected, to be used only for reading and analogous occupations. When the myopia exceeds four dioptrics, it is usually best to prescribe two pairs of glasses in the first instance, so commonly will they be required; and, in every case, we should endeavour to make the patient understand that the use of glasses for distance, although it will enable him to see the world, and to participate in all the advantages of doing so, is of small importance as regards the preservation of sight. On the other hand, the use of glasses for reading, " not that the patient may see better, but that he may see farther off," is an absolute necessity in all cases of progressive myopia, and should always be enjoined during school life, or during periods of close study, as the only means of preventing increase of the myopia in consequence of habitual over-convergence. It is the more necessary to render this clearly understood, because patients are naturally most disposed to prize and to use glasses for doing what cannot be accomplished without them; that is, for seeing distant objects. They are often unwilling to use them for near work, alleging, and for a time with perfect truth, that they can see better and more comfortably without them. It is not uncommon, indeed, for short-sighted people, when asked if they have used glasses for reading, to assume a tone almost of self-righteousness in their denial of the imputation. They say, "Oh, no, I have never done that!" and are often greatly exercised in their minds when the urgent necessity for a total change of their habits in this respect is explained to them.

The last indication—the avoidance of spasm of the accommodation—is often sufficiently fulfilled by spectacles which keep the work at a distance, and thus exclude the excessive convergence by which the spasm is generally excited. Where spasm exists in a marked degree—that is, where the full use of atropia much diminishes the apparent myopia, it is usually prudent to cause the application of atropia to be continued for some two or three weeks, until the habit of spasm has been effectually broken, and the eyes placed, by proper optical aid, under such conditions that the habit is not likely to recur when the drug is laid aside. For this purpose, after the muscle has once been thoroughly relaxed, it is not necessary to use a very strong solution; and one containing a grain of the neutral sulphate to an ounce of water will generally fulfil all that is desired. A solution of this strength may be applied twice daily for several weeks, unless it should produce symptoms of local irritation.

In either high or low degrees of myopia, if the above described method of treatment should leave the eyes incapable of prolonged exertion, or liable to suffer pain from use, the case passes into the category of asthenopia, and under that designation will be considered in the concluding lecture.

## LECTURE V.

# ASTIGMATISM.

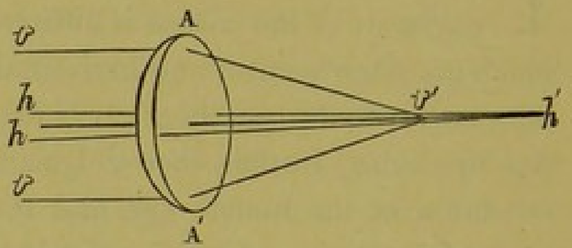
---

Mr. President,

I HAVE already defined astigmatism to be a state in which the curvature of the cornea is different in two different meridians, which are often vertical and horizontal or nearly so, and always at right angles to one another. It is necessary to enlarge this definition by saying, further, that astigmatism is probably the normal condition of the human eye, and that it must be present in an unusual degree in order to be disturbing to vision. As contrasted with a portion of a sphere, the most familiar example of an astigmatic surface is furnished by the bowl of a spoon, which is turned upon a shorter radius, in a direction transverse to the line of the handle, than in a direction continuous with it. The former is the meridian of greatest curvature; the latter is the meridian of least curvature. In the human eye, the meridian of greatest curvature is most frequently vertical; the meridian of least curvature is most frequently horizontal. This rule applies not only to the normal or moderate degree of astigmatism, but also to the abnormal degrees; although many instances are upon record in which the ordinary directions of the meridians have been reversed, and the greatest curvature has been in the horizontal direction. As a rule, again, the astigmatic formation is symmetrical or nearly so in the two eyes; but to this rule we find numerous exceptions.

When parallel rays of light are refracted by passing through a medium which presents a convex spherical surface, all the rays of which the light is composed become united in a single focal point, except for some trifling irregularities due to what is called aberration. Disregarding these, and assuming the refracting medium to be of circular outline, the light forms a cone between the medium and the focus, and any section of this cone in a plane perpendicular to its axis is necessarily a circle. Hence, the diffusion patches which are formed on the retina of a hypermetropic or of a myopic patient, from rays of light which have not united or which have united and overcrossed, are ordinarily circular; but those formed in astigmatism are only circular if the retina happens to coincide with one particular point of the refracted bundle. In Fig. 24, AA′ represents a lens which is more strongly curved in the vertical than in the horizontal direction. The result is, that parallel rays *vv*, which fall upon the surface of the lens in a vertical plane, are brought to an earlier focus, at *v′*,

Fig. 24.




than the rays *hh*, which fall upon the lens in a horizontal plane, and are brought to a focus at *h′*. If we suppose AA′ to be the cornea, *v′* will be the focus of the meridian of greatest curvature; *h′* the focus of the meridian of least culvature; and the space between the two, *v′ h′*, is called the focal interval. If we were to intercept the course of the rays by a screen, placed between the cornea AA′, and the focus *v′*, the diffusion patch would not be a circle, but an ellipse with its major axis horizontal. The rays *vv* would have approached each other more nearly than the rays *hh*. At the point *v′*, where the rays *vv* are united, *hh* not being yet united, the diffusion patch would be a horizontal line. A little farther, *vv* having overcrossed, and *hh* approaching each other more nearly, the diffusion patch is a smaller ellipse in the same position as before; and this passes into a circle as soon as the overcrossing of *vv*, and the approach of *hh*, form equal magnitudes. A continuance of the same process of refraction causes the rays to pass into a small upright ellipse beyond the circle, into a vertical line at the point *h′*, and into a larger upright ellipse when both the vertical and the horizontal rays have overcrossed each other. These successive forms of the diffusion patches are represented in the

FIG. 25.

series of diagrams which make up Fig. 25, and which are taken from Professor Donders.

When a cornea is so curved as to bring the rays which fall upon it in one meridian to an earlier focus than those which fall upon it in a meridian at right angles to the former, the resulting astigmatism may assume five different forms, which are governed by the position of the retina with regard to the two foci. In the following figures, *v* always represents the focus of the meridian of greatest curvature, and *h* the focus of the meridian of least curvature. It will be convenient to assume that the former is vertical, and that the latter is horizontal.

It the first form, Fig. 26, the focus of the vertical meridian is in front of the retina, and that of the horizontal meridian is upon the retina. In other words, the eye is myopic for parallel rays refracted in a vertical plane, and emmetropic for parallel rays refracted in a horizontal plane. This is called simple myopic astigmatism.

FIG. 26.

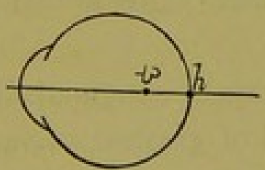
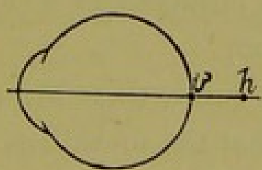



FIG. 27.




In the second form, Fig. 27, the focus of the vertical meridian is upon the retina, and that of the horizontal meridian is behind it. In other words, the eye is emmetropic for parallel rays refracted in a vertical plane, and hypermetropic for parallel rays refracted in a horizontal plane. This is called simple hypermetropic astigmatism.

In the third form, Fig. 28, the foci of the two meridians are both in front of the retina, but the focus of the vertical meridian is anterior to that of the horizontal. In other words, the eye is

FIG. 28.

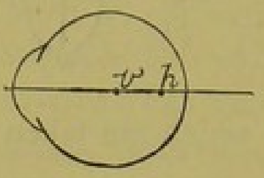



FIG. 29.

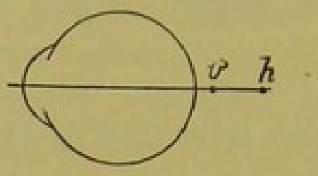
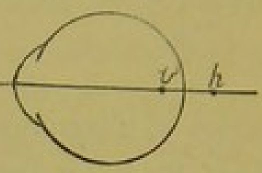



FIG. 30.




myopic for parallel rays refracted in both meridians, but in a greater degree for rays refracted in a vertical plane than for those refracted in a horizontal plane. This is called compound myopic astigmatism.

In the fourth form, Fig. 29, the foci of the two meridians are both behind the retina, the focus of the vertical meridian being anterior to that of the horizontal. In other words, the eye is hypermetropic for parallel rays refracted in both meridians, but in a greater degree for rays refracted in a horizontal plane than for rays refracted in a vertical plane. This is called compound hypermetropic astigmatism.

In the fifth form, Fig. 30, the retina is situated in the focal interval, so that the focus of the vertical meridian is in front of the retina, and the focus of the horizontal meridian is behind it. In other words, the eye is myopic for parallel rays which are refracted in a vertical plane, and hypermetropic for parallel rays which are refracted in a horizontal plane. This is called mixed astigmatism.

Besides these, there are no other forms of astigmatism, excepting only that the meridians of least and of greatest curvature may be in any other directions, so long as they are always at right angles to each other.

The degree of astigmatism is the measure of the distance between the foci of the two chief meridians; or, that is, the measure of the difference between the refraction of these meridians, expressed in dioptrics in the usual way. Thus, in a case of simple myopic astigmatism, where the eye is emmetropic for rays refracted in a horizontal plane, with a myopia of two dioptrics for rays refracted in a vertical plane, we say that the astigmatism is equal to two dioptrics. In a case of compound myopic astigmatism, with myopia of two dioptrics for rays in the horizontal plane, and of three dioptrics for rays in the vertical plane, we say that the astigmatism is the difference between the refraction of the two planes, or one dioptric. The degrees of hypermetropic astigmatism are expressed in a precisely similar way; and those of mixed astigmatism by the sum of the two forms of ametropia. Thus, if the eye shown in Fig. 30 had one dioptric of myopia for rays refracted in a vertical plane, and one dioptric of hypermetropia for rays refracted in a horizontal plane, the resulting astigmatism would be equal to two dioptrics.

The correction of astigmatism, that is to say, the equalisation of the refraction in the two chief meridians, is effected by means of plano-cylindrical lenses. In these, as their name implies, the curved or refracting surface, instead of being a portion of a sphere, as in ordinary lenses, is a portion of a cylinder. In Fig. 31, A A represents a plano-convex cylindrical lens; and the dotted lines show the cylinder of which it forms part. A plano-concave cylindrical lens is of analogous form, only its refracting surface is concave instead of convex.

FIG. 31.

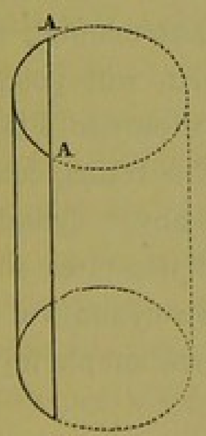
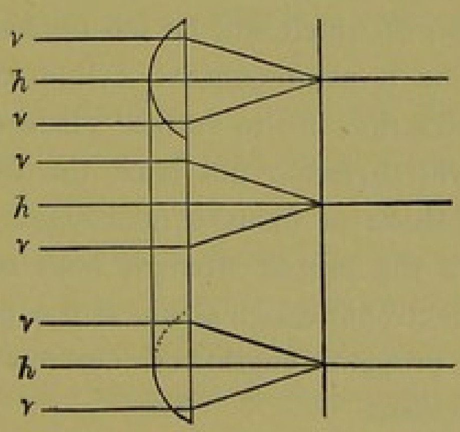



FIG. 32.



The action of a plano-convex cylindrical lens upon light is shown in Fig. 32. In this figure, the parallel rays of light, *hhh*, which fall upon the convex surface of the lens in a vertical plane, or in a plane coincident with the axis of the cylinder of which it forms part, are not refracted at all. They only encounter and pass through a piece of glass with parallel sides, and this does not change their direction. They enter the lens parallel, and they emerge parallel on the other side. But the rays *vv*, *vv*, *vv*, which fall upon the glass in successive horizontal planes, that is, in planes perpendicular to the axis of the cylinder, encounter a strongly curved refracting surface, and are brought to foci accordingly. We therefore start from the position that a plano-convex cylindrical lens, with its axis in a vertical direction, exerts no influence upon rays of light which fall upon it in a vertical plane, while it refracts rays which fall upon it in a horizontal plane. In Fig. 27, which illustrates simple hypermetropic astigmatism, we have an eye which exerts a contrary action, bringing rays which fall upon it in a vertical plane to an earlier focus than rays which fall upon it in a horizontal plane. It is manifest that there must be a plano-convex cylindrical lens of such a power that it will just correct the error of refraction of the eye; and this lens, if placed in front of the eye with its axis vertical, will increase the total refraction of the rays in the horizontal meridian until their focus coincides with that of the rays which were previously more strongly refracted in the vertical meridian. In other words there must be a lens which will bring the focus *h*, Fig. 27, back to the retina, and render it coincident with focus *v*, the position of which will be left unchanged. In like manner, there must be a plano-concave cylindrical lens which will postpone the refraction in the vertical plane of the eye shown in Fig. 26, and will therefore put back the focus *v* to the retina, leaving the position of focus *h* unchanged. A plano-convex cylindrical lens of the proper strength both corrects and measures simple hypermetropic astigmatism, and a plano-concave cylindrical lens of the proper strength both corrects and measures simple myopic astigmatism.

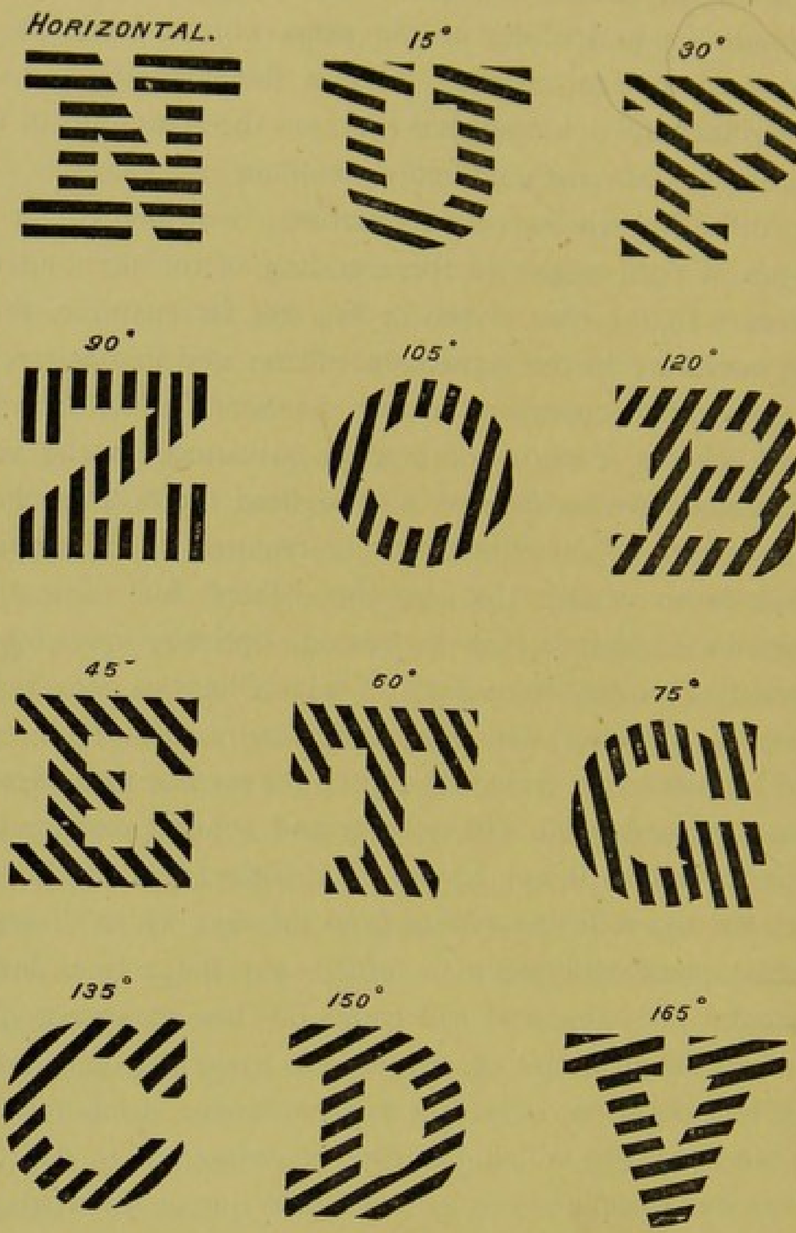
If we look again at Figs. 26 to 30, we shall see plainly that the correction of either of the two forms of simple astigmatism leaves the eye emmetropic as far as its two chief meridians are concerned; and although the emmetropia is not absolute, on account of the impossibility of exactly correcting the refraction of the intermediate meridians, it is yet sufficient for all the practical requirements of life. In the compound forms, however, the correction of the astigmatism still leaves the eye ametropic; and the correction of the mixed form may be accomplished in such a manner as to produce the same effect. Thus, in Fig. 28, the astigmatism may be corrected in two ways, either by a plano-convex cylinder which would bring forward the focus *h* to *v*, and leave the eye highly myopic, or by a plano-concave cylinder which would put back the focus *v* to *h*, and would still leave the eye myopic, although in a less degree. Hence, however the astigmatism is corrected, there must still be a myopic eye; and the myopia will require a concave lens of the ordinary spherical kind. In like manner, the astigmatism of Fig. 29 may be corrected by a plano-convex cylinder, to bring the focus *h* up to *v*; or by a plano-concave cylinder, to put back the focus *v* to *h*. Either course would leave the eye hypermetropic, the former in a much less degree than the latter; and in either case the hypermetropia would require a spherical convex lens for its correction. Both the above-described conditions are of frequent occurrence, and they are met by the so-called spherico-cylindrical lenses, which are ground to be portions of a spherical surface on one side and to be portions of a cylindrical surface on the other. Such lenses are made, of course, of any desired curvature on either side.

Mixed astigmatism, as shown in Fig. 30, may be corrected either by a plano-concave cylinder, to put back focus *v* to *h*, combined with a spherical convex to correct the resulting hypermetropia, or by a plano-convex cylinder, to bring up focus *h* to *v*, combined with a concave spherical to correct the resulting myopia. Usually, however, a better way is to employ a bi-cylindrical lens; that is, one which has a convex cylindrical surface on one side, and a concave cylindrical surface on the other, the axes of the two being precisely at right angles. In this arrangement, the concave cylinder should be of the power to put back focus *v* to the retina, and the convex side should be of the power to bring up focus *h* to the retina. The two foci will then coincide, and the eye will be left emmetropic or nearly so. There is, however, a difficulty in this mode of correction, arising from the fact that it will not be accurate unless the axes of the two cylindrical surfaces are precisely at right angles to one another. This requirement may be defeated by the smallest rotation of the lens during the process of grinding; and its fulfilment can only be secured by the employment of an optician of adequate skill and carefulness. It may be laid down as a general rule, in the correction of astigmatism, that we should always endeavour to obtain the desired result by the simplest combination, and by means of glasses of the smallest refracting power, which will fulfil the indications in each case; but it is always proper to think over the various ways in which the correction may be accomplished, and it is sometimes desirable to try the possible combinations experimentally, before finally deciding upon any one of them. We sometimes find that, with no apparent reason, one combination will give better vision than another which seems to be its optical equivalent.

The influence of astigmatism upon the sight is very considerable, and is exerted in various ways. Its first and most obvious effect is to produce differences in the apparent distinctness of equal lines, which are drawn in different directions; and in this way it produces indistinctness of some of the linear boundaries of figures, leaving others clearly defined. Thus, an astigmatic person, in reading a printed page, may be able to see clearly the vertical lines which enter into the formation of many letters, and so, for example, to distinguish an m from an n. But he would have to place the page at a different distance, or to alter the accommodation of his eyes, in order to distinguish the horizontal lines with equal clearness, and to tell readily an n from a u. The indistinctness of many boundary lines produces a corresponding diminution in the acuity of vision; and the necessity constantly to alter the accommodation in looking at the same object produces great fatigue of the ciliary muscle. Hence, defective sight, coupled with weariness and aching of the eyes, are the symptoms of which astigmatic persons most commonly complain.

The defective vision of astigmatism is primarily for lines which are at right angles to the meridian of the preponderating ametropia. In the case shown in Fig. 26, for example, there is myopic curvature in the vertical meridian; and in Fig. 27, there is hypermetropic curvature in the horizontal meridian. The effect of myopia, that is, of myopic curvature, in the vertical meridian, is to render the eye short-sighted for horizontal lines; and the effect of hypermetropic curvature in the horizontal meridian is to render the eye dim-sighted for vertical lines. The reason is, that a line is formed, optically speaking, of a succession of points, from each of which light is reflected. In the case of a vertical line, any diffusion circles which may be formed from the rays which diverge from successive points of the line in a vertical plane will overlap and conceal one another in that plane, and will not impair the distinctness of the retinal image; but any diffusion circles from the rays which diverge in a horizontal plane will serve to widen out the retinal image in a horizontal direction, and will cause the line to appear diffused or spread. Hence, the eye which has hypermetropic formation in the horizontal meridian has hypermetropic vision for vertical lines; and the eye which has myopic formation in the vertical meridian has myopic vision for horizontal lines. In writing upon this subject, it is necessary to adopt some uniform system of nomenclature in order to avoid confusion; and my own practice is to neglect the formation and to describe the vision. By vertical myopia, therefore, I mean myopic vision for vertical lines; and I disregard the fact that the vertical myopia is a result of faulty curvature in a horizontal direction. This method of description has a farther advantage in the direction of simplicity; because the axis of the correcting cylinder must always be placed in the same direction as the visual defect.

FIG. 33.




Since astigmatism always diminishes the acuity of vision, astigmatism of any appreciable degree is excluded whenever that acuity is normal; and, as astigmatism is often combined with general ametropia, so the acuity of astigmatic vision is often increased by common spherical lenses. But when, in any case of ametropia, common lenses fail to bring the acuity of vision nearly to the normal standard; and especially when the patient does not express any decided preference between two or more lenses of about the same power, astigmatism should be suspected and searched for. A test object for this purpose may be supplied by any figure which presents equal lines inclined in different directions; and among the many which have been devised for the purpose I know of none so good, and so generally useful, as the striped letters designed by Dr. Orestes Pray, which are shown in Fig. 33, and which may be obtained, in a size convenient for the consulting-room, from the Autotype Fine Art Company in Rathbone-place. An astigmatic eye, when its ametropia has been as completely as possible corrected by spherical glasses, will see the stripes in Dr. Pray's letters in different degrees of distinctness; and in high degrees of astigmatism the difference will be very marked indeed. The direction of the stripes which are most clearly seen indicates the direction of one of the chief meridians; and the other chief meridian will be at right angles to the former. Thus, if the patient says, "I see the stripes most plainly in the letter N." we know that the chief meridians are vertical and horizontal; and, if he sees them most plainly in E or C, we know that the chief meridians are diagonal. The same applies to any other direction. When once the fact of astigmatism, and the directions of the chief meridians, have been determined, Pray's letters are no longer useful; since their various lines are distracting to the attention when we are about to determine the state of refraction in each meridian singly. For this purpose, the best object is such a disc as is shown in

FIG. 34.

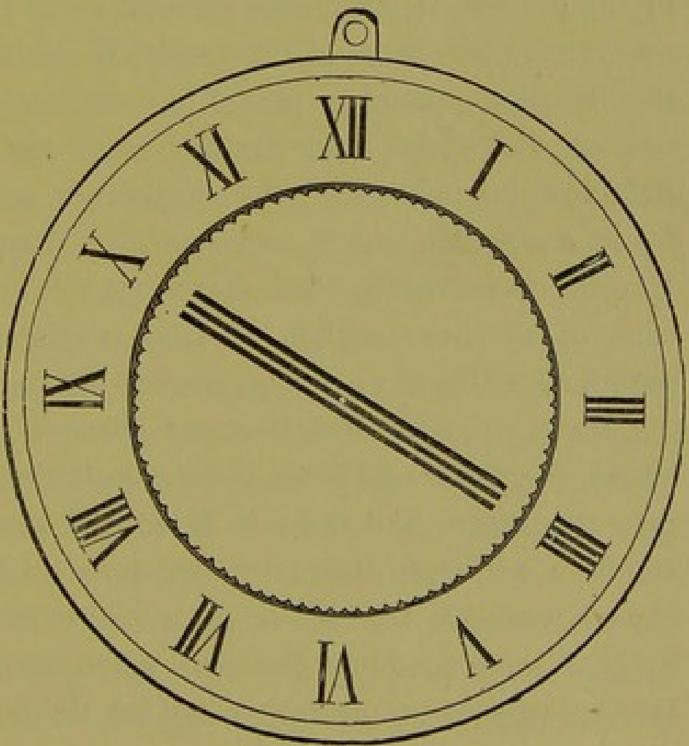


Fig. 34, which consists of an outer circle, nine inches in diameter, inscribed with the figures of an ordinary clock face, and an inner circle, six inches in diameter, inscribed with three parallel lines, and turning on a central pivot which is concealed from view. The apparatus is of tin, painted white, and was made for me by Messrs. Carpenter and Westley, of 24, Regent-street. The first disc of the kind which I employed was of home manufacture in cardboard, and was put together thirteen or fourteen years ago; but Dr. Green, of St. Louis, U.S.A., claims to have been the originator of the contrivance, and it is possible that I may have derived it from him in some indirect fashion. At all events, I am more than willing to concede to him the merit of the invention.

Having approximately determined the chief meridians, and the eye being fully under the influence of atropia, the inner disc should be so turned as to make its three lines coincide in direction with one of the meridians; and then the ametropia for these lines, in that position, should be tested with the greatest possible care by spherical lenses. When the best lens is found, the inner disc should be moved a little in both directions, in order to discover, by the position in which the best vision of the lines is obtained, the precise direction of the meridian under examination; and then the lines should be placed in a position at right angles to the one so discovered, and the ametropia tested again. When a definite result is obtained, the astigmatism, and the lenses required for its correction, may be ascertained by a very simple calculation. In order to make this clear, it may be well to take examples from each of the five possible varieties of the condition. For this purpose I will select actual cases from my note-books.

*Case 1. Simple Myopic Astigmatism.*—On looking at Pray's letters, the patient said that the stripes in the top line were clearer than the others, and those in N and U were the clearest. Her attention was then directed to the lines on the disc, which were placed from IX to III, or in a horizontal direction, and she counted them readily. No glass improved her vision for them. Her answers about the letters had left the *precise* direction of the chief meridians uncertain ; but on moving the disc a little, she declared that the lines were most distinct when their right hand extremities were depressed about 10° below the horizontal position —that is, to one-third of the distance between III and IV on the clock face. For lines so placed she was emmetropic. On turning them to be at right angles to this position, or with their upper extremities one-third of the distance from XII to I on the dial, they became extremely dim, but were rendered clearly visible by a concave lens of one dioptric and a half. Here, then, was the condition shown in Fig. 26, with the difference that the greatest corneal curvature was nearly horizontal, thus producing myopia for vertical lines. A plano-concave cylinder of a dioptric and a half, with its axis corresponding with the direction of the visual defect, that is, with its upper extremity inclined 10° to the right of a vertical line, restored vision nearly to the normal standard, and relieved all the inconvenience which the patient had previously suffered.

*Case 2. Simple Hypermetropic Astigmatism.*—On looking at Pray's letters, the patient said that the lines in D were quite clear, and, on placing those of the disc in the corresponding position, that is, from II to VIII on the dial, no glass rendered them more distinct. They also became less clear by any change of position. On placing them in the reverse direction, from XI to V, they were obscurely seen, but were rendered distinct by a convex lens of two dioptrics. Hence, there was the condition shown in Fig. 27, with the difference that the chief meridians were inclined 30° from the horizontal and vertical positions. A convex plano-cylinder of two dioptrics, with the upper extremity of its axis 30° to the left of the vertical line, corrected the defect.

*Case 3. Compound Myopic Astigmatism.*—Pray's types showed that the chief meridians were horizontal and vertical. For the right eye, for horizontal lines, there was a myopia of eight dioptrics ; and for vertical lines a myopia of five and a half dioptrics. For the left eye there was myopia for horizontal lines of seven and a half dioptrics, and for vertical lines a myopia of four and a half dioptrics. Both eyes, therefore, resembled Fig. 28, the preponderance of myopic curvature being in the vertical meridian, and the preponderance of myopic vision being for horizontal lines. Taking the right eye, a plano-concave cylinder of two and a half dioptrics —the difference between the myopia of the two meridians— equalised this difference, put back focus *v* to coincide with focus *h*, corrected the astigmatism, but left five and a half dioptrics of myopia in all meridians. The case required therefore, for complete correction, a spherico-cylindrical lens, one side of which was a concave spherical lens of five and a half dioptrics, the other side a concave cylinder of two and a half dioptrics. The cylindrical side of this lens corrected the astigmatism, the spherical side corrected the residual myopia; and the axis of the cylinder was so placed as to correspond with the direction of the highest degree of myopic vision—that is, it was horizontal. The defect of the left eye was corrected in a similar manner; and the patient has now worn the glasses with comfort for nearly four years.

*Case 4. Compound Hypermetropic Astigmatism.*—In the right eye Pray's types showed that the meridians were vertical and horizontal; in the left they corresponded with the lines in letters P and B. In the right eye there was hypermetropia of half a dioptric for horizontal lines, and hypermetropia of three dioptrics for vertical lines. In the left eye there was half a dioptric of hypermetropia in the direction of the lines in P; and there were two dioptrics in the direction of the lines in B. The right eye precisely resembled Fig. 29; the preponderance of hypermetropic formation being in the horizontal plane, and the preponderance of hypermetropic vision being for vertical lines. The left eye differed from Fig. 29 in that its chief meridians were inclined thirty degrees from the horizontal and vertical positions. Taking the right eye, a convex plano-cylinder of two and a half dioptrics, with its axis vertical, corrected the astigmatism, and left half a dioptric of uncorrected hypermetropia. This small amount of hypermetropia might in most cases be neglected without harm; but the patient in this instance was past forty, her accommodation was very limited, and so I prescribed a spherico-cylindrical glass, by which both the hypermetropia and the astigmatism were corrected. The left eye was treated on the same principle.

*Case 5. Mixed Astigmatism.*—A girl of eighteen, with simple hypermetropic astigmatism of her left eye, has the chief meridians of the right in the directions of the lines in the letters E and C of Pray's types. For the lines in C she had myopia of one dioptric; and for the lines in E she had hypermetropia of half a dioptric, making a dioptric and a half of astigmatism. Her eye differed from Fig. 30, in that its chief meridians were diagonal. Three forms of correction were possible. A concave cylinder of a dioptric and a half would have carried back focus *v* to *h*, leaving the eye hypermetropic to half a dioptric; and this plan might have answered very well. A convex cylinder of a dioptric and a half would have brought up focus *h* to *v*, leaving the eye with a myopia of one dioptric, which would have required correction, at least for distant vision, by a concave spherical surface on the other side of the lens. A lens having two cylindrical surfaces, at right angles to each other, one a convex of half a dioptric, the other a concave of one dioptric, served by the former surface to bring forward focus *h* to the retina, and by the other to put back focus *v* to the same position. The visual result of this combination left nothing to be desired.

In considering the possible methods of correcting any particular case of astigmatism, it is necessary to think about the way in which the eye is to be used, with especial reference to its accommodation. Like all others, astigmatic eyes become presbyopic; and, if we so correct astigmatism as to leave them emmetropic,—or, still more, if we leave them hypermetropic—they will need convex spectacles in addition to the correction, for reading and other close occupations, as soon as the presbyopia begins to assert itself. This requirement may sometimes be fulfilled by the original manner of correction, sometimes by an addition to the plane (or to the spherical, as the case may be) side of the correcting lens. Thus, in Case 2, where the correction of a simple hypermetropic astigmatism of two dioptrics left the eye approximately emmetropic, this emmetropic eye will have its near-point receding as life goes on. It will then be easy to correct the presbyopia, without interfering with the astigmatism, by grinding on the other side of the cylindrical lens whatever convex power may be required; remembering that the compound lens so made will only be needed for near work, and that the original must still be used for all distant objects. Sometimes the requirements of presbyopia may be met in a different manner. I was consulted by a gentlemen forty years of age, upon whom I had previously performed iridectomy in the treatment of iritis. The eye had recovered from the disease and from the operation, but was the subject of an acquired astigmatism, probably due to alteration of curvature consequent upon the wound. I found it emmetropic for horizontal lines, and with two dioptrics of myopia for vertical lines. A concave cylinder of two dioptrics, with its axis vertical, gave perfect vision for distance; but the eye thus furnished had but small power of accommodation, and, being rendered emmetropic, required convex spectacles for reading. By giving a convex plano-cylinder of two dioptrics, with its axis horizontal, the eye was rendered as myopic in the horizontal as it was previously in the vertical meridian, the astigmatism being corrected in the direction of rendering the eye as a whole myopic, and not in the direction of rendering it emmetropic. The result was that the patient read perfectly with the plano-cylinder alone; and this, as it subjected the rays of light to simpler conditions of refraction than a spherico-cylindrical lens would have done, afforded the best, because the simplest, means of correcting the defect. In many analogous cases the surgeon will find ample opportunity for the exercise of ingenuity and resource; always bearing in mind that the office of the cylindrical lens is to equalise the refraction of the chief meridians, and so to correct astigmatism, leaving any ametropia which may be residual to the astigmatism to be dealt with, if necessary, by a spherical lens with which the cylindrical one may be combined. The conditions which are to be fulfilled are of the most extreme simplicity, and nothing but the perverted ingenuity of authors has appeared to deprive them of this character.

The method of testing astigmatism which I have described, although it seems to me the best which can be used under ordinary circumstances, has many rivals. Dr. Green, of St. Louis, has invented a most elaborate series of test-objects ; and so many others have been devised by various persons that it would exceed my limits even to enumerate them. The optometer of Hirschberg, mentioned in the first lecture, is fitted with metal caps, each pierced by a narrow slit, for the testing of astigmatism, the *rationale* of this arrangement being that looking at ordinary objects through a slit produces effects analogous to those of looking at a line. The slit is turned first in the direction of one chief meridian, and then in that of the other, and the ametropia is ascertained for both. From the data thus obtained the astigmatism is deduced in the ordinary way. In cases in which the replies given by the patient are uncertain or unsatisfactory, it is often well to check the results afforded by one test by the subsequent application of another.

The only other method which requires notice is that by means of the erect ophthalmoscopic image—and I have deferred until now what I have to say upon this method as applied not only to astigmatism, but also to ametropia generally. The method is based upon the principle that the rays of light which are returned from the retina of an emmetropic eye leave the cornea parallel; while those which are returned from the retina of a myopic eye leave the cornea convergent, and those which are returned from the retina of a hypermetropic eye leave the cornea divergent; the degree of convergence or of divergence, in either case, being the measure of the degree of ametropia. The passive emmetropic eye can only obtain a clear image from parallel rays; and hence an emmetropic observer, looking into an ametropic eye with his own accommodation absolutely at rest, would require to add to his ophthalmoscope a lens sufficient to correct the ametropia, as a condition of seeing the retina clearly. In other words, the passive emmetropic eye, in order to look into the ametropic one, requires the same lens which the ametropic eye itself requires for distant objects. Again, if the observer himself is not emmetropic, but ametropic, his own ametropia will be a known quantity for which allowance can be made. If he be myopic, his myopia must be added to the convex lens required for a hypermetropic eye, and must be deducted from the concave lens required for a myopic eye. Thus, suppose an observer with two dioptrics of myopia. In examining another eye, he requires a concave lens of four dioptrics to give him a clear image. It is manifest that two of the four dioptrics will be the correction of the observer's myopia; and that the other two dioptrics will represent the myopia of the observed. In examining an emmetropic eye, the same observer would require a concave of two dioptrics; and, hence, an eye for which he required no lens would be hypermetropic to two dioptrics; the defects of the observer and of the observed precisely neutralising each other. In the same way, if we suppose the observer to be hypermetropic, his hypermetropia would increase by its own amount the apparent hypermetropia of another eye, and would decrease to the same extent the apparent myopia. In a case of astigmatism, it is said to be easy to determine with the ophthalmoscope, by the different degrees of clearness of the retinal vessels which course in different directions, not only the directions of the chief meridians, but also the degree and kind of ametropia in each. In order to facilitate such observations, ophthalmoscopes are now made with an abundant supply of concave and convex lenses, so placed upon a disc behind the mirror that they may be brought in rapid succession over the sight-hole; and the latest and best of these ophthalmoscopes, that of Dr. Loring, of New York, has its mirror hung in such a manner that it can be inclined to the angle required for illumination independently of the disc, so that the observer may look always through the axis of the auxiliary lens, and may thus avoid distortion of the retinal image from looking obliquely. We are told that it is quite possible to determine ametropia and astigmatism in this way, and to prescribe spectacles for their correction, without putting a single question to the patient. While admitting some of the premises, I must express my dissent from the conclusion.

It is obvious, and therefore undeniable, that an experienced observer, looking into the eye of another with an ophthalmoscope arranged to give the erect or virtual image of the fundus, will see at a glance whether the eye so examined is in any marked degree ametropic, and the form of the ametropia. He will also see whether it is astigmatic; in which case vessels running in some one direction will be more clearly defined than any others.

In order to do more than this, to determine with precision the degree of the ametropia, or the degree and nature of the astigmatism, conditions would be required which I believe can never, or scarcely ever, be fulfilled.

In the first place, there is no object in the fundus of the eye which is of such a nature as to show plainly when the best definition of it is obtained. Ametropia depends upon the distance between the yellow spot and the apex of the cornea, and the optic disc will not serve as the required object, because it is situated at a variable distance from the yellow spot, and sometimes, especially in myopic eyes, is distinctly anterior to it. At the yellow spot itself there are no bloodvessels to serve as test objects, and there is nothing visible in a normal eye but the somewhat granulated looking surface of the pigmented epithelium, seen through the transparent layers of the retina, and more or less obscured, in this position, by the image of the flame which affords the necessary illumination. The appearance of this surface may vary a little, when a change is made in the power of the lens through which it is looked at; but there is nothing to show which variation should be accepted as the best representation. The observer must carry his eye a little way from the yellow spot, to a region where there are small retinal bloodvessels, which, if he knew their diameter, might answer his purpose. But he does not know their diameter in any given case, and they are upon a background of a colour only slightly different from their own. The observer cannot tell whether he his looking at a vessel of the smallest calibre, a little out of focus and so made to appear broader by diffusion, or at a vessel of the next degree of magnitude seen clearly. The examination does, in fact, test the vision of the observer instead of that of the patient; and the first essentials of accurate testing—objects of known aspect, known distance, and known magnitude—are wanting and cannot be supplied. On this ground alone, I believe it is impossible to arrive within a dioptric of trustworthy results.

In the next place, the optical state of both the eyes concerned is liable to be continually, and in an unknown degree, disturbed by variations in their accommodation. The eye of the patient may, indeed, be atropinised; and this is often essential. The ophthalmoscopic mode of testing has been recommended, however, upon the ground, among others, that it renders atropia unnecessary, because the observed eye, having no definite object of vision, will completely relax its accommodation. I am sure that this idea is a delusion; and that neither in hypermetropia nor in myopic spasm will the accommodation be completely relaxed by the absence of an object of vision. In these cases, if the test were otherwise fine enough, the observer would get the refraction of the observed eye, *plus* the unknown amount of accommodation which it was at the moment exerting. The application of atropia to the eye of the observer would be impossible in ordinary practice; but some tell us that this is immaterial, for that they have acquired by training the power of knowing how much accommodation they are exerting at any given time. I have not the smallest doubt that all who thus profess do so in perfectly good faith; but none the less I find it impossible to give credence to their professions. I know of no instance in which the muscular sense of any other organ has been trained to anything like equal delicacy. Even that of the fingers is clumsy by comparison. We are asked to believe, it must further be remembered, that this extraordinary degree of muscular sense is exercised with regard to a function in the performance of which the same amount of muscular effort produces, every year, a smaller amount of result; and also that it is exercised at a time when the attention is occupied by something else—namely, by the aspect of the retinal image. To me it seems certain that the observer, looking at the retina of the observed eye, would have his attention concentrated upon the object of vision, and that he would exert, quite unconsciously, whatever accommodation within his range might be needed in order to give him a clear view, His conjectural estimate of the amount of this accommodation could only be an afterthought, coming at a time when the effort itself had been discontinued.

On these grounds, then, from the uncertain character and position of the only available objects of vision, and from the further uncertainty due to unknown and unknowable variations in the accommodation of the observer, I regard the ophthalmoscope as affording only a rough test of ametropia or astigmatism —trustworthy, perhaps, within a dioptric or two, but having no valid claim to greater accuracy. I have been confirmed in this opinion by some cases in which spectacles, especially for astigmatism, have been prescribed as the result of ophthalmoscopic investigation, and in which they have entirely failed to meet the requirements of the patient. I remember one such instance particularly, in which the patient was himself a medical man. He had mixed astigmatism, and came to me wearing plano-concave cylindrical glasses. The myopia of one meridian had been discovered, but the hypermetropia of the other had been wholly overlooked. The only case in which I can imagine accuracy being attained by the ophthalmoscope is when the observer is myopic in so high a degree as to have little or no use for his accommodation, and to be accustomed to work at a perfectly definite far-point. Given these conditions, he might be able to keep his accommodation passive during the act of looking; but eyes which are highly myopic are so often defective, from choroidal or other changes, that it seems scarcely desirable to rely upon them for the conduct of fine and accurate observations.

As a cylindrical lens corrects astigmatism, so, of course, it renders a normal eye astigmatic; and by wearing cylindrical lenses it is easy to feel and realise the conditions of vision which astigmatism produces. It has been said, and is often supposed, that astigmatism produces distortion of the shape of objects; but, as a matter of fact, it has no such effect. If we place a cylindrical lens in the dioptric apparatus of a magic lantern, we shall obtain distortion of the images cast upon the screen; but this is due to the fact that the rays of light, after their refraction, travel a sufficient distance to allow the distortion to take place. The distance between the cornea and the retina is not sufficient for this purpose; and the only effect of astigmatism is to obscure certain boundary lines, rendering them hazy and ill-defined. If we place cylindrical glasses, with their axes vertical, close to the eyes, and look at any well-known object, such as a postage-stamp, we shall see no alteration in its shape; but its lateral boundaries, and the lateral boundaries of the Queen's head, will look fuzzy and diffused. If we remove the lenses a little way from the eyes, so as to give the distance necessary for distortion, distortion will take place, the object appearing extended in a vertical direction if the lenses are concave, and extended horizontally if they are convex. It is unimportant whether the object looked at is near or distant. As long as the cylindrical lenses are close to the eyes, an obscuration of the boundary lines of the object, in a direction transverse to the axes of the cylinders, is the only effect observed; but, as soon as the lenses are held at a distance, alteration of shape becomes apparent. As the seat of ordinary astigmatism is in the cornea, what is true of the lens held close must be true, *à fortiori*, of the astigmatic eye itself; and hence the suggestion that the correctness of figure drawing can be disturbed by astigmatism is one which appears to me to have no sort of foundation in the facts of the case.

Although, in testing for astigmatism, cylindrical glasses are not required, it is nevertheless useful to be provided with them, as means of demonstrating to the patient how much his vision will be improved by their use. Whatever may be the variety of the affection, the examination should always be conducted under atropia, since in no other way can perfect accuracy be attained. Even in the myopic forms, we constantly find that we do not obtain the same answer to a question about the effect of a given lens after a short interval of time; the accommodation undergoing frequent variations, consequent upon efforts to see now this and now that boundary line of some neighbouring object. The use of atropia involves a few days of inconvenience, but this time may be curtailed by the occasional instillation of a drop of a solution of sulphate of eserine after the examination has been concluded; and, even if the action of the atropia is left to run its course, the eyes will only be better for the rest afforded them. The examination, if complete and accurate, need only be made once in a lifetime; and hence no pains should be spared in order to arrive at full knowledge of the truth. An additional reason for the use of atropia is furnished by the fact, of which my experience leaves me in no doubt, that the astigmatism of an eye in its natural state is sometimes apparent only, and is due to the circumstance that the accommodation-change is greater in some one meridian than in others. This applies chiefly, I think, to hypermetropia; and I have seen many instances in which, with a marked degree of apparent astigmatism before atropia was employed, complete paralysis of accommodation has removed the astigmatism, and has left only hypermetropia to be corrected. The temporary inconvenience which attends upon the use of atropia is a very small matter when the future comfort of vision is at stake. An effect sufficient for all practical purposes may be obtained by three applications of a drop of a four-grain solution of the neutral sulphate. One of these applications should be at bedtime on the night preceding the examination; the others in the morning, at intervals of two hours, and the last of them two hours before the examination is commenced. If this method should leave some shred of accommodation remaining, the amount will not be sufficient to vitiate the conclusions which will be reached. In some instances it will be better to atropinise the eyes singly, allowing one to recover before the other is examined; but this is a matter which in astigmatism, as in other forms of ametropia, may depend solely upon the arrangements and the convenience of the patient.

The efficacy of the glasses, however accurately they may be prescribed, will depend upon the positions of their axes; since a position at right angles to the correct one will double the defect. Hence it is usual to make cylindrical spectacle lenses circular, so that any slight deviation from correct position may be rectified by turning them a little in the rings of the frame. In prescribing, the surgeon should not only specify the position of each axis in writing, but he should also use a diagram of a frame, and should draw a line across this diagram to show the position. When the spectacles are otherwise ready, the patient should himself give the lenses their final adjustment before they are fixed; and in this way the most precise accuracy may be attained.

Inasmuch as almost all eyes are to some extent astigmatic, it is manifest that the defective curvature must reach a certain degree before it calls for optical assistance. It may perhaps be assumed that a small amount of astigmatism is useful in giving to the eyes some amount of that quality which is called penetration in microscopic object-glasses; and that, if the curvatures of the chief meridians were identical, accurate vision would be too closely limited to objects lying in a single plane. According to Donders, astigmatism of less than a dioptric is seldom disturbing to vision; but there are great individual differences in this respect. As a general rule, we may parody the legal maxim, and may say, "*De minimis non curat oculus;*" but we shall nevertheless see, in treating of asthenopia, that under some circumstances even very small defects of refraction will require to be carefully estimated and corrected.

## LECTURE VI.

# ASTHENOPIA.

---

Mr. President,

In a large proportion of cases of ametropia, and in some in which no ametropia is discoverable, we find that the employment of the eyes is limited by conditions of time. After a period of use, longer or shorter according to circumstances, either the vision becomes indistinct, or pain is experienced in the eyes themselves, in the orbital regions, or even generally about the head. In many instances the symptoms of distress commence with indistinctness, which, if the visual effort be continued, leads on to pain. In many there will be found some form of obstinate conjunctival trouble. In a few the headache is the precursor of sickness, vertigo, palpitation, and other symptoms, which may collectively occasion the belief that the patient is suffering from some obscure cerebral or cardiac affection. The foregoing conditions are conveniently included under the general term of asthenopia, or weak sight, depending, as they all do, upon some cause which renders sustained visual effort impossible. The word is only a convenient way of saying that the patient cannot use the eyes for long together; and it requires to be supplemented, in every case, by one which is descriptive of the precise nature and apparent cause of the affection.

In some cases asthenopia is associated with manifest defect of vision; in others the vision is little, if at all, below the normal standard.

For many years, asthenopia, although well known to ophthalmic surgeons, was regarded as incurable. The ordinary prescription for it was to abandon all endeavours to use the eyes in near vision; and, as a means of carrying out this recommendation, patients were often farther advised to become farmers or emigrants.

When Donders discovered the existence and the nature of hypermetropia, he saw at the same time that many cases of asthenopia were dependent on the strain thrown upon the accommodation of hypermetropic eyes, and that such cases could be effectually relieved by the use of convex spectacles. He was even disposed, for a time, to look upon all cases of pronounced asthenopia as being of this kind. The increased attention which was soon given to the subject was not long, however, in producing evidence that many asthenopic patients were not hypermetropic, but myopic; and it was assumed by Von Graefe that in these the cause of the distress was in the strain thrown upon the interni in maintaining the convergence of the visual axes to some given distance. He described this as muscular asthenopia, and the hypermetropic form as accommodative asthenopia; and to these two categories nearly all cases of asthenopia were for some time referred. Later experience has shown that emmetropic eyes sometimes suffer from asthenopia, and that the causes of the affection may be exceedingly obscure; but still the two forms first mentioned, the accommodative and the muscular, may be taken to include the large majority of the cases which present themselves in ordinary practice. In the former, inability to maintain the accommodation effort; in the latter, inability to maintain the convergence effort, is the immediate cause of the failure of sight.

I think it must be conceded that the liability to asthenopia in any community, whatever may be the immediate cause of the affection in any case, bears a great relation to the general nervo-muscular excitability of the people. In England we are sufficiently familiar with asthenopic patients, and their ailments form an appreciable portion of the claims upon the attention of ophthalmic surgeons. There can be little doubt that in the United

States asthenopia is more prevalent than on this side of the Atlantic. At the International Ophthalmic Congress, held at New York in 1876, two of the ophthalmic surgeons of that city read papers on asthenopia—one of them founded upon an analysis of 1079 cases, and the other upon an analysis of 1060 cases; all, as I understood, observed in private practice. I much doubt whether any two practitioners in any other capital in the world could have cited similar numbers; and I feel sure that the conditions of life in America must be largely contributory to the state of things which these numbers disclose.

I have already said that asthenopia is often associated with conjunctival troubles; and that this should be the case is not surprising. Asthenopia has one universal character; which is that some one or more of the muscles of the eye are unduly fatigued or strained by exercise of the visual function; and such fatigue or strain tends naturally to the production of active congestion while it continues, and of passive congestion when the effort is temporarily laid aside. Extending to the conjunctival surface, this congestion relieves itself by over-secretion of mucus; and leads, after a time, to hypertrophy of the papillæ and to consequent roughness of the lids. These troubles react upon and increase the irritability of the eye; and sometimes occasion nutritive changes of a still more serious kind. The chief peculiarity of asthenopic conjunctival affections is their obstinate and recurrent character; and, if any form of conjunctival disorder either resists treatment, or shows a marked tendency to relapse after improvement when the eyes are once more taken into regular use, asthenopia should be suspected and sought for. In many cases the patient will attribute the symptoms of asthenopia to the conjunctivitis, and careful examination will be required in order to determine their actual nature.

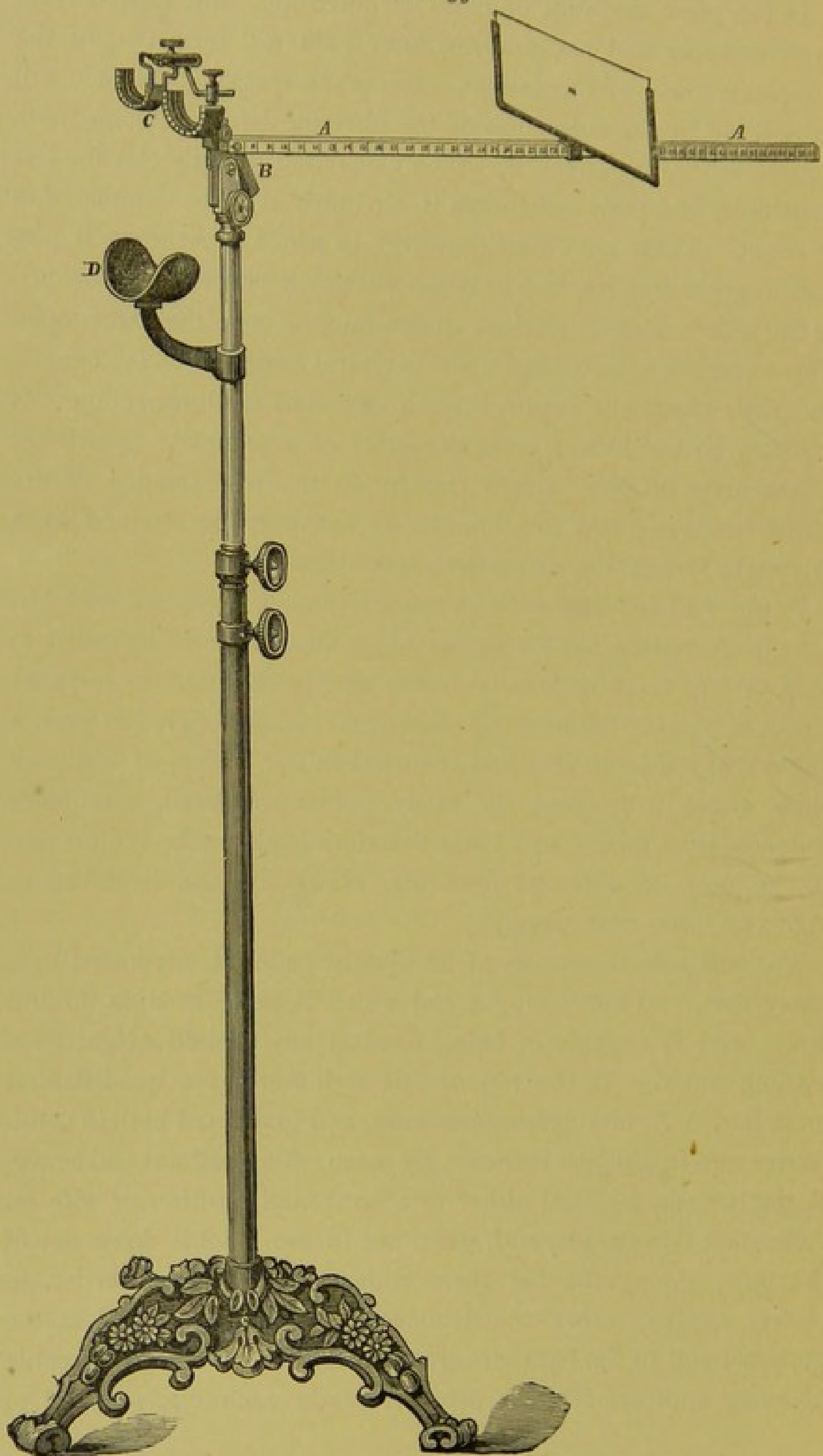
During many years the ophthalmoscope served to surround cases of asthenopia with all manner of unreal or imaginary dangers. The congestion already mentioned is not limited to the ocular surface, but may extend also to the deeper parts of the organ, notably to the optic disc and its immediate surroundings. In this region it may even give rise to some slight effusion into the fibre layer of the retina. Congestion of the optic disc and retina, when first made known by the ophthalmoscope, and when coupled with incapacity for continued use of the eyes, were eagerly accepted as signs of threatened, or impending, or actual retinitis; and, when coupled with symptoms of head distress as part of the asthenopia, were accepted as signs of impending or actual mischief in the brain. It is wearisome to think of the amount of nonsense which has been talked and written on the basis of these two errors; which have also been answerable for a vast deal of misdirected and even mischievous treatment. The idea of retinitis, or the idea of brain disease, led directly to the prescription of "rest" for the eyes; a prescription which I long ago ventured to describe as utterly wrong in principle, and as leading invariably to unfortunate results in practice. Setting aside manifest inflammation, such as iritis or irido-choroiditis, we may lay it down as a rule, almost if not quite without exception, that pain as a result of visual effort is symptomatic of some purely muscular trouble, that congestion associated with the pain is due to disturbed or excessive muscular action, and that the remedy is always to be sought in careful analysis of the muscular elements of the visual act, in the relief of any strain which this analysis may disclose, and in the regular and systematic employment of the eyes under improved conditions. To rest asthenopic eyes may be to relieve them from pain while the rest continues; but such relief is dearly bought at the cost of rendering the disused muscles even less fit for exertion than they were before. The brain troubles which occasion loss of sight—*e.g.*, intra-cranial tumours—may be associated with headache, but only with headache which is independent of visual effort; and retinal affections, such as neuro-retinitis leading to nerve atrophy, and the like, are even characteristically painless. The attention of the patient is usually first called to them by the discovery that his sight is fading away without pain. I have come to regard pain, other than glaucomatous or inflammatory pain, as a symptom which alone is almost sufficient to justify a favourable prognosis in any case of imperfect or conditioned vision.

In the great majority of cases of ametropia, and especially in hypermetropia and astigmatism, some pain will form part of the complaint made by the patient. Generally speaking, the pain will be relieved by the correction of the obvious defect, and no more trouble will be experienced. Such cases are primarily classified as ametropia, and their asthenopia is obviously a mere complication or result. There are others, however, in which asthenopia is present in great severity, and in which either the cause is not obvious, or the relief of some obvious defect fails to cure the asthenopia. These cases may be looked upon as typical examples of asthenopia, and their treatment requires much care and circumspection. It can only be conducted upon the basis of a complete knowledge of the state of every single element in the performance of the visual function; and this knowledge can only be attained by a thorough, systematic, and orderly examination.

In order to facilitate such an examination, I designed, and Mr. Hawksley constructed for me in 1875, an optometer intended to hold certain combinations of lenses and prisms, and to carry an object of vision at convenient distances. In America, last year, I found that the same idea had occurred to Dr. Risley, of Philadelphia, whose instrument, in many points of detail, was more complete than mine; and I was therefore glad to take it into use. It can now be obtained from Mr. Hawksley, and is shown in Fig. 35. (See next page.)

The instrument consists of an upright pedestal, supported by a heavy foot, and containing a rod which is made to slide up and down, and is capable of being fixed at any desired height by a binding screw. At the top of this rod there is a quadrilateral brass bar, A A, fifty centimetres long, and graduated both in centimetres and in English inches. By means of a quadrant and screw, B, the bar can be fixed either in a horizontal position or with an inclination downwards, and, when not in use it folds down out of the way. Along the bar there slides a slight metal carrier, to receive cards or other contrivances for test objects; and at the proximal end of the bar there are two semicircular clips, C, capable of being approximated or separated, and each one grooved to

FIG. 35.



receive three lenses. On the sliding-rod there is a chin-rest, D, which may be turned aside when not wanted; and, when the object-carrier is removed, the bar is also made to support a quadrant intended to be used as a perimeter. For testing vision, the apparatus being first set at a comfortable height, and the bar at a convenient angle, the clips are so adjusted that their centres may be as far apart as the pupils of the eyes. A suitable test object—a word, line, dot, star, or whatever may be necessary—is placed in the carrier, and any required lenses or prisms in the clips, which, having three grooves, admit of all sorts of combinations. The apparatus can in no sense be described as essential to a complete examination of the visual functions; but it has the merit of rendering such an examination more easy, and of saving much time in its accomplishment.

An orderly and systematic method of proceeding is also a means of saving time; and it has the additional advantage of insuring that no part of the examination shall be forgotten or neglected. My own course of proceeding is as follows:—

First, to ascertain, for each eye singly, the apparent refraction, the acuity of vision, the manifest degree of any ametropia which may be discovered, the presence or absence of evident astigmatism, and the distance of the near-point for the smallest type that the patient can read near at hand.

Secondly, to find whether there is binocular vision, and, if so, to discover the distance of the binocular near-point.

Thirdly, to observe the characters of the ocular movements; whether they are regular and steady or jerky and uncertain.

Fourthly, to ascertain what are the strongest prisms which can be overcome, first by abduction, with their bases inwards, and next by adduction, with their bases outwards, while the eyes are directed to a word printed in small type, and placed at the binocular near-point. The evidence of overcoming the prisms is furnished by the maintenance of single vision.

Fifthly, to ascertain what is the nearest point to which the visual axes can be directed, accommodation being reinforced by convex lenses.

Sixthly, to test the powers of abduction and of adduction once more; the eyes being directed to an object, preferably a steady candle-flame, placed at a distance of from eight to twenty feet.

Seventhly, to prescribe a solution of neutral sulphate of atropia, of the strength of four grains of the salt to the ounce of distilled water, a drop of which is to be applied to one or both eyes at bed-time, and twice, with an interval of two hours, on the following morning. Two hours after the last application, the refraction should again be very carefully examined, with especial reference to small degrees of either ordinary ametropia or of astigmatism.

By following this routine, and by noting down the results as we proceed, we obtain a precise account of the state of the refraction, the accommodation, and the convergence; and we ascertain whether the normal relations of these functions are disturbed. In a general way, the first part of the examination, up to the use of atropia, may be easily accomplished at a single interview; but it is better to see the patient a second time than to run any risk of being misled by careless answers when the eyes are tired. Whether the atropia should be applied to one or to both eyes, should generally depend upon the engagements of the patient. As a rule, I prefer to apply it to both at once; but, where there is any business which requires attention, it is best to let the first eye recover its power of accommodation before the other is taken in hand. The results of the examination may be most quickly and conveniently recorded by filling up blank spaces in a printed form; and this method is also the best way of obtaining materials for tabulation when a sufficient number of cases has been observed.

When all the facts bearing upon the question have been investigated and set down in order, they will at once suggest the most probable reply to the inquiry whether the asthenopia must be attributed primarily to strain of accommodation, or primarily to strain of convergence.

Strain of accommodation may be produced by any of the following conditions:—

1. Deficient power of the ciliary muscle, either as a matter of formation, or as a result of enfeebling illness.

2. Impaired elasticity of the lens, as in presbyopia.

3. Excessive demand, as in hypermetropia.

4. Constant variation of demand, as in astigmatism.

5. Unequal demand in the two eyes, as in anisometropia or antimetropia.

The cases which belong to the first three classes have the common characteristic that the need for the exercise of accommodation is greater than the power of exercising it; and they differ chiefly in respect of the side from which the inequality arises. In some, as in presbyopia, the difficulty is on the side of the lens; in others, as in weakness, it is on the side of the muscle; in others, as in high degrees of hypermetropia, the demand is in excess of the normal activity of the function. In all these varieties we may lay down the general rule to which I have already referred—namely, that if the demand for accommodation, whether it be normal or abnormal, is in excess of half the power of the function in the particular case, the demand will not be continuously satisfied without pain and distress; and hence, that the strain of the accommodation, in all such cases, may be accepted as a probable explanation of the asthenopia, and should be relieved by spectacles as a first step in treatment. If the spectacles prescribed for this purpose are not successful, they will at least clear the ground for further investigation. It is obvious that some patients will be able to exert habitually something more than half their accommodation, while others will only be able to exert habitually something less than half; but in this, as in all analogous cases, no rule can be laid down which will be more than an approximation to the truth, or which will not require modification in practice in order to adapt it to individual necessities. Still, if the working distance of the patient does not demand the exercise of half, or nearly half, his accommodation, and if neither of the conditions mentioned under the last two headings is present, the first hypothesis about the asthenopia would be to seek its cause in some undue strain of the convergence.

The following cases may be cited as typical illustrations of their respective kinds; it being supposed that each patient requires to apply the eyes continuously to an object of vision at a distance of fifteen inches from them.

*A*. Emmetropic; age twenty-one. In consequence of paresis of the ciliary muscle, produced by diphtheria, has only four dioptrics of accommodation. Half this range, or two dioptrics, would bring the near-point to twenty inches; and, to bring it to fifteen inches, 2·66 dioptrics are required—an amount about equal to two-thirds of the total range.

*B*. Emmetropic; aged forty-three. Accommodation normally reduced to four dioptrics by presbyopia. Excess of demand the same as in the preceding case.

*C*. Hypermetropia of two and a half dioptrics; aged twenty-one. Accommodation of nine dioptrics. Of the 4·5 dioptrics of accommodation which can be continuously exercised, 2·5 are consumed by the hypermetropia, leaving only 2 dioptrics available for near objects, and hence the same conditions as in the former cases.

In estimating the strength of the convex glasses which should be prescribed for these three patients, it must be borne in mind that, under favourable hygienic conditions, the accommodation of patient *A* will probably be restored to the normal standard in a few weeks or months; and hence it is not desirable to give him more help than is absolutely necessary. Convex glasses of too high a power, which completely relaxed his accommodation, would deprive his ciliary muscles of wholesome exercise. He should therefore receive lenses of 0·75 only, and should be encouraged to use his eyes in a reasonable degree. Patient *B*, on the other hand, is at a period of life when his accommodation will decline rapidly; and he may at once receive lenses of a dioptric and a half. The accommodation of patient *C* will, at his age, change but slowly; and his hypermetropia may be corrected completely, either at once or by two or more gradations of glasses, on the plan described in the fourth lecture. When it is fully corrected he will need no farther assistance until he arrives at the age of commencing presbyopia. When that times comes he will need an addition to his spectacles equal to the power which an emmetropic person would require at the same period of life.

In cases of the fourth class, although there is often great strain of the accommodation, the degree of this strain can no longer be measured by the total range of the faculty. In astigmatism the strain arises from the constant variation of the demand, which has to provide in quick succession, and with unchanged convergence, for clear vision of those boundaries of figures which correspond with the chief meridians of corneal curvature. Supposing these meridians to be vertical and horizontal, the patient, in every act of seeing, accommodates first for the vertical and then for the horizontal boundaries of the object, or *vice versâ*. The effort is even greater than that which would be necessary if the object—a printed page, for example—were moved quickly to and fro before the eyes, because in such movement the convergence would be altered together with the accommodation. The effect of the constantly varying accommodation will depend, in some degree, upon the amount of the variation—that is, upon the grade of the astigmatism, but even in low grades it is often beyond the powers of the normal function. When different forms of astigmatism are compared, my experience is that the hypermetropic forms occasion more distress than the myopic, the compound more than the simple, and the mixed forms most of all; but the difference between the susceptibilities of different persons is too great to allow any general rule of this kind to be laid down. Donders originally expressed the opinion that astigmatism of less than a dioptric was scarcely disturbing to vision; but such a degree is certainly highly disturbing in some cases; and in every instance of obscure asthenopia any discoverable astigmatism, however small, should be corrected, more especially if it should be of the mixed variety. The correction of even half a dioptric has been followed by excellent results in certain instances.

In the fifth class, comprising anisometropia and antimetropia, the accommodation strain is often felt when the range of the faculty, for each eye singly, is normal, and it then appears to depend upon the inequality of demand in the two. The nerve stimulus which produces accommodation is believed to be transmitted from the centre in an equal degree to each eye, and no inequality of accommodation is thought to be possible, except from peripheral failure in one of them. Supposing the eyes, although unlike in their refraction, to be in all essential respects healthy, and to be directed to the same object, it is assumed that only one of them will receive a perfectly sharp image, or will be correctly accommodated for the object; the other being incorrectly accommodated, and therefore receiving an image which is less sharp, but which may still be sufficient to maintain binocular vision. It would seem, at first sight, as if such an arrangement must lead to the constant employment of the eye which is most easily adjusted, and to a practical neglect of the dim image received by the other, such as obtains in ordinary squint. If this were so, there would be no apparent cause for asthenopia, unless the accommodation of the eye most used was itself unduly strained. But, as a matter of fact, we find asthenopia in a certain proportion of such cases; and it may possibly be brought about by the relations which exist between the two eyes. There is much reason to believe that, in ordinary binocular seeing, although both eyes are concerned, they are not, at any given moment, both concerned equally; but that one of them is active, and the other more or less passive or complementary, the two exchanging their functions in this respect from time to time, and each becoming, so to speak, anode and cathode by turns. Assuming this relationship between them to exist, so that each eye takes up the more active seeing alternately with its fellow, we shall have a demand for a corresponding variation of accommodation whenever the change of function takes place; and I am disposed to think that this is the true explanation of the occasional asthenopia of unequal eyes. Let it be supposed that the right eye has a myopia of one dioptric, and the left a hypermetropia of the same degree. There would then be an increase or a relaxation of accommodation equal to two dioptrics, whenever the transference of the more active seeing occurred; and the familiar experiment of looking at a star with one eye only, until it disappears from view, leads to the supposition that such a transference must occur every few minutes. If this be so, the alternate tension and relaxation of the accommodation, for the same degree of convergence, may very well become a source of visual strain.

It would appear, at first sight, that the correction of anisometropia or of antimetropia would be simple, and would require only the application, to each eye, of the lens necessary for its own defect. Sometimes this plan will answer well, but sometimes it is impracticable. Every lens, placed before an eye, alters the size of the retinal image; and hence, when two unlike lenses are employed, the effect is to give the two eyes images of unequal magnitude, which cannot always be fused into one. We shall find some persons who fuse the unequal images readily, and others who cannot fuse them at all. My impression is, that the cases in which fusion is resisted are usually those in which binocular vision was previously sacrificed to the defect; and that in these we seldom meet with asthenopia as a consequence of it. The only possible rule of practice is to test the power of fusion with unequal glasses, and, if it exists, to let such glasses be worn continuously. When fusion cannot be accomplished, the requirements of the better eye of the two must chiefly be taken into account, and the patient must be encouraged to use it singly. At the same time, the worse eye must not be neglected; but, being furnished with a lens suitable to its wants, it also should be used singly at regular intervals, in order to keep its retina duly exercised and receptive. By reading with it systematically, even for a few minutes at a time, three or four times a day, its vision may often be improved; and I have sometimes seen the increased attention thus paid to its impressions result in the restoration of binocular vision, so that each eye could eventually be separately corrected, and yet the two be employed in unison.

When the original examination of the patient affords no reason to suspect strain of accommodation as a cause of the asthenopia, attention must next be directed to the convergence; and here we enter upon ground which is no longer secure. Von Graefe was the first to point out that, in a certain number of cases, asthenopia is dependent upon inability to maintain the necessary convergence, instead of upon inability to maintain the necessary accommodation; and he invented the phrase "insufficiency of the internal recti," to fulfil the double purpose of describing the condition and of conveying his hypothesis about its nature. He appears to have meant, by insufficiency, a state of weakness which bears no resemblance to paralysis or to paresis, and which is attended by no paralytic symptoms, but which renders the affected muscles unable to discharge continuously their most important natural function. In the majority of the cases, the internal recti, when tried by any test which would be applicable to other muscles, are found to be in full possession of their powers. The range of adduction of each eye, in correspondence with the abduction of its fellow, may be complete, and may cover a much greater extent of movement than any which can be possibly called for in convergence for binocular vision. The binocular near-point may be as close to the eyes as in the normal state, and the power of overcoming prisms by adduction may leave nothing to be desired; but, notwithstanding, when the maintenance of a given convergence is difficult or impossible, we are asked to believe that "muscular insufficiency" is the ordinary cause of the trouble. We are even told by some writers that this mysterious affection is one of "very common occurrence."

A man of commanding and fertile intellect, like Von Graefe, can hardly fail at times to suggest hypotheses which will not bear the test of examination; and I have little doubt that, if his life had been spared, he would long ago have repudiated this one. Many of his pupils, however—some, perhaps, from a laudable veneration for the memory of their master, others from a less laudable conviction that the chief use of a great philosopher is to save other people from the labour of thinking,—have continued to repeat his words as if they were necessarily the exponents of verity; and hence the notion of insufficiency of the interni has taken deep root in the literature of ophthalmology. It has done so the more effectually, beeause Von Graefe devised two tests of insufficiency, according to which this condition may be found in almost every case of myopia in which it is looked for. His successors, when they have met with apparent muscular asthenopia, have applied Von Graefe's tests, and the results which he declared characteristic of insufficiency have been produced. The diagnosis has then been considered to be complete, and the real value of the tests themselves, until quite recently, has remained unquestioned.

Von Graefe's first test for insufficiency was to direct the patient to look steadily at some object in the median line, at a distance of six or eight inches from the eyes. A screen, or the hand of the surgeon, was then interposed in such a manner as to conceal the object from one eye. If the eye so excluded from vision retained its direction unchanged, the interni were supposed to be normal; but if the covered eye deviated outwards, the interni were supposed to be insufficient. In order to ascertain the degree of the insufficiency, another and more delicate test was next to be applied.

In this more delicate test, the object of vision is a small black dot, bisected by a vertical line. A card thus marked is fixed in the median line, at a distance of eight or ten inches from the eyes, and the patient is directed to look at it steadily. A prism of ten or twelve degrees, with its base either upwards or downwards, is then placed before one eye; and, as the power of the superior or inferior rectus to overcome double vision is very limited, this prism necessarily produces a vertical diplopia. The patient will therefore see two dots, one above the other. If the original convergence for the object is accurately maintained, the duplication of the vertical line will only cause it to appear elongated; and the two dots will be seen one above the other on the same line. If, on the contrary, the convergence is not maintained, the patient will see two lines with a dot upon each; and when the diplopia is a consequence of relative divergence of the optic axes, the double images will be crossed, and the extent of the divergence will determine the distance between them. A second prism, with its base inwards, will produce approximation or fusion of the images; and the prism which brings them back to the same vertical line is assumed to be the measure of the insufficiency, as it certainly is of the relative divergence. In other words, the assumed test of "sufficiency" of the interni is that they shall be able to maintain an unchanged convergence when one eye is excluded from vision of a near object to which both were originally directed; and that they shall also maintain an unchanged convergence notwithstanding an artifically produced vertical diplopia. When the requirements of these tests are not fulfilled, the existence of "insufficiency" has been taken for granted; and it has also been taught that the best method of treatment for this insufficiency is by tenotomy of one or both of the external recti. It has been assumed, generally speaking, that the insufficiency is relative rather than absolute; that is, that in any given case the strength of the interni did not preponderate over that of the externi in a sufficient degree to allow of the maintenance of convergence, and that division of the externi, by weakening them, would redress the balance of power. In this assumption, another is manifestly involved, namely, that both the external and internal recti muscles live in a state of continual tension, and that the externi, even when not receiving any motor impulse, present an impediment to the free performance of ocular adduction.

In dealing with this piling up of hypothesis upon hypothesis, this continued postulation of something to explain something else, the chief difficulty is to select among the many objections which oppose themselves to the acceptance of Von Graefe's doctrine. In my own case, this difficulty is enhanced by the consideration that I have never seen any non-squinting asthenopic patient who seemed to me to require tenotomy of the externi; so that my knowledge of the operation is practically limited to cases in which it has been done without beneficial effect by some one else. As far as I am aware, there is no other instance in which abductor muscles have been supposed to present impediments to the ordinary range of movement of unparalysed adductors; and there is no other instance in which it has been proposed to divide an abductor or an extensor muscle as a means of relieving the weakness of its assumed antagonist. The affection called "scrivener's palsy" may by a trifling stretch of imagination be described as an "insufficiency" of the flexors of the thumb and fingers; but I have never heard that division of the extensors has been suggested as a possible means of treatment. As soon as the ordinary range of movement of any set of muscles is exceeded, their antagonists come into play as inhibitory structures; but within the ordinary range the antagonists exert no such influence. Acrobats of the class called contortionists differ from untrained persons in the degree in which the opponency of antagonistic muscles has been overcome by stretching; but no such stretching is needed until the limits of customary movement are overpassed. An acrobat, who can allow his feet to separate until his perineum touches the ground, has overcome by exercise the natural rigidity of the adductor muscles of his thighs; and, in like manner, a person who could perform adduction of the eyes until the corneæ became invisible, would have overcome the natural rigidity of the externi. It is clear, however, from all analogy, that the natural rigidity of the externi does not come into play, as an inhibitory power, within the limits of the ordinary movements effected by the interni; that is, for example, within the limits of the customary adduction of either eye in looking to the right or to the left with both. The assumption that volitional visual convergence can be impeded by the preponderating strength of the externi is likewise opposed to all analogy; for there is no other instance in which the strength of a muscle interferes with the free use of its antagonist. We never hear of an athlete whose flexors are so strong that he cannot extend his limbs, or whose extensors are so strong that he cannot flex his limbs. Even the showman's little dog, whose tail was so tightly curled that he could not put his hind legs to the ground, would be a less strange phenomenon. The convergence required for fusion, if impeded by the externi at all, can only be impeded by some condition analogous to spasm; and liability to spasm is characteristic of weak muscles rather than of strong ones.

My attention was first called to the relation between the convergence function and sustained vision by the writings of Dr. Scheffler; and, in the *Practitioner* for 1874, I published some papers on the hygiene of vision which indicated some divergence from the generally accepted view. In consequence of these papers, Dr. Theobald, of Baltimore, was good enough to send me a copy of an essay of his own, which had appeared in the American *Monthly Journal of the Medical Sciences* for the preceding January, and in which he discussed the value of Von Graefe's tests, and showed, I think conclusively, that they would not bear the interpretation which had been placed upon them. Still later, Dr. Krenchel and Dr. Hansen, both of Copenhagen, have written very lucidly upon the question of insufficiency; and I believe it must now be generally conceded that Von Graefe's fabric of postulates has been overturned. The difficulties in the way of sustained convergence, whatever they may be, are certainly not due to "insufficiency of the interni," and cannot be rationally treated by tenotomy of the antagonists.

We have seen already that the purpose of ocular convergence is the fusion of the two retinal images into a single sensory impression; and hence that single vision with the two eyes, and not clear vision, is the proper stimulus to the performance of the convergence function. To afford clear vision is the office of the accommodation; and, since accommodation and convergence are normally exercised in corresponding degrees, a certain correlation, probably in part structural and in part acquired, usually exists between them. We have seen also that this correlation between accommodation and convergence is more or less elastic—that is, that the accommodation may be varied while the convergence remains the same, and that the convergence may be varied while the accommodation remains the same; the extent of this relative play between the two functions being different in different persons, so that the accommodation and the convergence are sometimes more and sometimes less closely united. The performance of fusion, however, requires exact convergence; and the smallest deviation of the visual lines is followed by the appearance of double images. In Von Graefe's first test, the exclusion of one eye from perception of the object prevents the possibility of fusion, and excludes the demand for fusion from operation; so that the test only shows what degree of convergence will continue to attach itself, in the case of the individual under examination, to the amount of accommodation which the seeing eye is at the moment exerting. If, as commonly happens, the patient is myopic, and the object is not much within his far-point, he will require very little accommodation, and this little will only call for a correspondingly small amount of convergence; so that the visual lines will naturally diverge from the position in which the requirements of fusion had originally placed them, and will assume a position which is determined by the requirements of accommodation alone, without the aid of fusion. There is here no question of strength or weakness, of sufficiency or insufficiency, but there is simply a diminution of convergence consequent upon a diminution of the nerve stimulus by which the convergence effort is called forth. If the patient is not myopic, but if his accommodation and convergence faculties are only loosely united, having a large amount of relative play, precisely the same result will be produced. The withdrawal of the fusion stimulus will leave the interni at liberty to assume a position of smaller effort; and, like all other muscles, they will undergo relaxation when there is nothing to call them into action. It is only when the relation between accommodation and convergence is close and intimate, so that the two functions are inseparably united, that the test would establish "sufficiency." It is only in such a case that the withdrawal of fusion would leave the position of the visual lines still held unchanged by the accommodation; and this result would follow whether the interni were strong or weak. The test points to the intimacy of the relation between accommodation and convergence, and it points to nothing else.

The second of the two tests differs but little from the first. The immediate stimulus to convergence being the desire for single vision, this desire itself appears to arise from the confusion produced by double images of surrounding objects. Von Graefe's test-object, however, is of such a nature that double images produce no confusion, because it is quite as natural to see two dots, or two lines, upon a piece of card as to see one only; and hence the fusion stimulus to convergence is wanting. As in the former test, the degree of convergence which follows the removal of the desire for fusion is solely determined by the accommodation; and the test only shows the degree of convergence which the eyes assume, as the result of being accommodated for a given distance.

In every case of myopia the tendency of the visual axes would be towards divergence, and in every case of hypermetropia the tendency would be towards convergence, as soon as the control exercised by the demand for fusion was withdrawn.

The ordinary clinical history of a case of so-called insufficiency of the interni is that the patient is myopic, say to five dioptrics, which would place the far-point at eight English inches. At this distance, or even a little within it, he is unable to read continuously, and the effort to do so is attended by various distressing symptoms. In one case, which I have formerly published, these symptoms were of such a kind as to lead to a diagnosis of obscure intracranial disease; and the patient, who wanted nothing but a pair of spectacles, was sent to Australia and back in order to afford rest to his brain by a long voyage. In such an instance the effort to read means an effort to maintain convergence to eight inches in absolute repose of the accommodation. To an emmetrope this would be impossible, even for a few minutes; as may be proved by any young emmetropic person who will put on convex spectacles of five dioptrics, and will attempt to read in them. The strain and tension of the eyes will soon become unbearable; and it may be shown by a simple experiment, that this strain is not due to the convergence effort *per se*, but solely to the fact that the convergence effort is made during repose of the accommodation. If we combine with the convex lenses prisms with their bases inwards, of sufficient power to rest the convergence as well as the accommodation, reading immediately becomes easy. If we then give the same person concave spectacles, such that he is able to overcome them by accommodation, and bid him look at the horizon, the strain upon his eyes will again become unbearable. He will be exerting a good deal of his accommodation to overcome the glasses, but he will be exerting no convergence, because the distance of the object of vision requires that, for the sake of fusion, he should keep his visual lines parallel. We may relieve the strain instantly by placing before the concave lenses prisms with their bases outwards, which will call for a convergence effort in addition to the accommodation effort; so that we create strain by causing either function to be performed singly, and we relieve strain either by placing both at rest or by calling both into play. This applies chiefly to emmetropic persons; for, in the ametropic, habit and necessity cause the functions of accommodation and convergence to be less strictly dependent upon each other; and the supposed myopic patient will be able, especially for the sake of fusion, to converge to some extent without accommodating, although probably not to the full extent which the state of his refraction would require. If we give him concave lenses of three dioptrics, according to the rule which I have already laid down in speaking of myopia, they will remove his far-point to twenty inches; and then, in order to read at twelve or fifteen inches, he will have to exert both accommodation and convergence, and both, perhaps, in an approximately equal degree. If distress should continue, we have next to ascertain which of the two functions is working in excess as compared with the other—whether the accommodation or the convergence; and the simplest method of investigation is to try whether diminishing or increasing the convergence will afford relief, We may do this either with Risley's optometer, or by a spectacle-frame with double clips. We let the patient read with the lenses of three dioptrics, at the stated distance, until the eyes begin to feel fatigue; and then we add to the lenses prisms, say of four degrees, with their bases inwards, so as to diminish the convergence. A very few minutes will show whether these prisms, so placed, facilitate reading; and, if they do, we know that the patient was previously exerting too much convergence for the amount of his accommodation. If the prisms increase the difficulty instead of diminishing it, they should be turned, so as to bring their bases outwards, when they will require a greater degree of convergence than was originally necessary. If they give relief in this new position, we learn that with the concave lenses alone the eyes were exercising too much accommodation for the degree of their convergence.

Under either of the foregoing conditions, it was once my practice to use combinations of concave and prismatic glasses; but of late years, whenever the range of accommodation is sufficient, I have adopted a more simple method. I assume convergence to fifteen inches to be an invariable requirement, and modify the concave lenses in such a way that the demand for accommodation shall be such as can most easily be combined with this invariable convergence. If the prism test shows that the patient is exerting too much convergence for the degree of his accommodation, I increase the demand for accommodation by strengthening his concave lenses; and, if the prisms show that his convergence is too little for his accommodation, I diminish the accommodation to the level of the convergence requirment by weakening the lenses. Thus, if the patient in the case supposed were to read more easily with the addition to his lenses of prisms with their bases inwards —that is, with less convergence effort—I should redress the balance, not by diminishing the convergence effort, but by increasing the accommodation effort to keep pace with it. I should give him concaves of three dioptrics and a half, or of four dioptrics, or should even wholly neutralise his myopia; and the result would be, as a general rule, that the convergence effort to fifteen inches, which was irksome when combined with a less degree of accommodation effort, would become easy when the accommodation effort was increased. In like manner, if the patient was relieved by prisms with their bases outwards—that is, by increased convergence effort —I should say, "With this amount of accommodation he wants more convergence in order to bring the two functions into harmony." Hence, in order to maintain the convergence unchanged, he must be called upon for less accommodation, and his concave lenses must be reduced in strength. Lenses of two dioptrics and a half would render the accommodation almost passive for fifteen inches; and the patient might be perfectly well able to converge to fifteen inches with passive accommodation, although the effort of convergence to eight inches was more than he could continously accomplish.

I assume, therefore, that insufficiency of the interni is a condition which has no real existence, that all unparalysed interni are strong enough to maintain convergence to fifteen inches, and that the difficulty sometimes experienced depends either upon an excessive convergence demand, as in a myopia which brings the far-point much nearer than fifteen inches, or upon a disruption of harmony between the accommodation effort and the convergence effort. In the former case, concave lenses which put back the reading distance to fifteen inches are all that will be required; and in the latter, taking the convergence distance as a fixed point, it is only necessary to vary the accommodation demand by lenses until the harmony between the two functions is restored. By this means we may in most cases relinquish the use of prismatic spectacles, and may cure our patients by glasses which are everywhere procurable.

Dr. Hansen has pointed out that, besides these cases of somewhat high degrees of myopia, we may have apparent insufficiency in other conditions. In emmetropia, in hypermetropia, and in minor degrees of myopia, we find a few persons who preserve the parallelism of their eyes in testing equilibrium for distance, but in whom an excluded eye (as by Von Graefe's first test) becomes divergent at reading distance. If the divergence is small, it means that the relative play of accommodation and convergence is large; so that, fusion being suspended, convergence cannot be maintained unchanged by accommodation alone. If the divergence is large, it means that the normal relation between accommodation and convergence does not exist; so that, although fusion produces convergence, accommodation without fusion cannnot do so. In such cases the severance between accommodation and convergence is due to congenital or acquired central defect. He describes yet another form, in which there is the normal relation between accommodation and convergence, with absence of fusion. In these cases, which are also due to central defect, he describes as symptoms an exceedingly defective endurance alternating with diplopia, a small divergence at reading distance, and feeble adduction and abduction. Since I have been made acquainted with Dr. Hansen's views, I have been on the watch for examples of these two kinds of central defect, but I have not at present clearly identified either of them. Dr. Hansen's description of them is exceedingly graphic, and he speaks favourably of prismatic glasses as means of affording relief.

Putting aside these instances of central defect, which are few in number, and which certainly require a more careful examination than they have yet received, our plan of dealing with a case of asthenopia should be, in the first instance, to determine and to correct any obvious ametropia or astigmatism, even if only of small degree. If the symptoms are still unrelieved, we have next to consider whether accommodation and convergence stand in their normal relations to each other; and, if not, how these relations may be favourably modified. Wherever there is sufficient range of accommodation, the change should be made by altering the accommodation to meet an invariable convergence requirement—stronger convex or weaker concave lenses calling for less accommodation; stronger concave or weaker convex lenses for more. Sometimes, when the range of accommodation is very limited, this simple plan must be laid aside, and the convergence must be modified to suit the accommodation. Prisms with their bases inwards diminish convergence; prisms with their bases outwards increase it. When we employ prisms with their bases inwards to diminish convergence effort, there is always some liability to weaken the interni by diminished use; and in such cases it is generally prudent to use also prisms with their bases outwards, for a few minutes at a time and at regular periods, so as to strengthen the convergence muscles as if by gymnastic exercise. A convenient measure of the strength of the interni, by which they can be tested at any time, is furnished by their power to overcome the artificial diplopia produced by prisms with their bases outwards, when the eyes are directed to a moderately distant object.

In asthenopia of great severity or of long standing, even when we have corrected every discoverable ocular defect, and have brought the accommodation effort and the convergence effort into harmony, we shall sometimes find that the use of the eyes is as painful or difficult as before. For a time this will be so in many cases; and it is well to warn patients that their glasses will call upon the eyes to work under new conditions, which, although better than those which they supersede, may yet be irksome so long as they are new. We must not, therefore, expect immediate relief as a rule; and it is best to insist upon diligent use of any prescribed glasses for at least a fortnight, before we attempt to form a definite opinion about their probable efficacy. After the lapse of that time, if the patient is still complaining, and if we are sure that we have placed the ocular mechanism under the most favourable attainable conditions, we have next to develope the powers of this mechanism by carefully regulated exercise. We often have to deal with the effects of that most pernicious of all recommendations, the recommendation to "rest the eyes"; and, consequently, with organs of which the whole nervo-muscular apparatus has been brought by disuse into a state at once of debility and of excitability. Such conditions can only be relieved by careful strengthening of the weakened muscles; and for this purpose the employment of the eyes must be so regulated as not to impede nutrition by occasioning fatigue. The indications for the fulfilment of the required conditions were first clearly laid down by Dr. Ezra Dyer, of Pittsburgh, whose rules for this purpose have proved so useful, and their value has been so thoroughly established by experience, that, in the United States, the process is commonly called "Dyerising." Dr. Dyer first corrects any hypermetropia or astigmatism, and generally prescribes such glasses as will place the eyes under the most favourable optical conditions. The remainder of his instructions I will give in his own words, which, on this side of the Atlantic, are not so well known as they deserve to be:—

"The exercise of the muscles is best accomplished by reading. The patient is directed to select a book of good type, but not too absorbing, and to read regularly with the prescribed glasses three times a day. He must determine by trial the number of minutes he can read without discomfort. He may find this to be thirty seconds, five minutes, ten minutes, or even more. He must, however, find this initial point. Starting at this point, he must read regularly, and always with the glasses. The first reading must not be until one half-hour after breakfast, the second at noon, the third finished before sundown. The periods of reading must be regularly increased from day to day. No other use of the eyes should be allowed. In cases where discomfort occurs in less than five minutes, the increase should not be more than one half-minute per day until ten minutes are reached. In other cases the patient may increase one minute each day until he can read thirty minutes three times a day without pain. If this can only be done with pain, the patient must be encouraged to persist, notwithstanding the pain; the surgeon, however, exercising his judgment in not pushing the treatment too rapidly. Should the pain continue from one period to the next, it is evidence that he has gone beyond the maximum of his ability, and that he should fall back to a period at which he can read without discomfort, should regard that as a new point of departure, and proceed as before. As said above, reading is the best exercise; but it frequently happens that the patient is very desirous to write or sew. This may be attempted when thirty minutes has been reached in the middle period. After the exercise has begun by reading ten minutes, sewing or writing may be tried for ten minutes, and the period finished by reading. From this point I permit an increase of two minutes a day, and a relative increase in the time of writing. This may be gradually introduced into the morning and evening period. I do not consider the treatment completed until an hour and a half is reached."

"I have found it of great assistance to explain the *rationale* of the treatment to the patient. These cases rarely occuring except in the educated classes, they readily understand their nature, and are anxious to assist the surgeon. I tell them that, in reading, pure muscular action is required as much as in lifting a weight; that, through want of use, debility, or some derangement of the system, they have lost the power to exert the reading muscle without fatigue; that they can strengthen this muscle and increase its power of endurance by regular, constant, and systematic exercise, as well as with any other muscle in the body. The course of treatment serves to distract the mind of the patient, and restores his confidence in his ability to use his eyes. He has become discouraged; he has had the horror of blindness carefully instilled by friends, and sometimes by well-meaning physicians, who, not feeling quite sure of their ground, err on the safe side and prescribe entire rest. In these cases 'the safe side' is the wrong side. When the glasses are procured, and the patient is assured that there is no absolute disease of the eye as revealed by the ophthalmoscope, he commences his course of treatment with hope and zeal. The mere fact that he is told that he *must* use his eyes gives him, to a certain extent, the power to do so."

Dr. Dyer elsewhere lays great stress upon the importance of restraining impatience when improvement is beginning to be declared. The patient who finds that he can read for ten minutes without distress is very likely to go on for twenty minutes, or until pain warns him to stop; but to do this is to invite relapse. With an increase of only one minute a day, the duration of the treatment would be about three months; and it is better to submit quietly to this period of modified use, and of self-restraint, than to lose time at the beginning by fruitless endeavours to hasten a process which depends essentially upon the gradual improvement of muscular nutrition.

In many obstinate cases of asthenopia we shall find some derangement of the health, or some need for better regulation of the regimen and habits. Under such circumstances, the ophthalmic surgeon, if he should be so unfortunate as to be in the narrow sense a specialist, must call to his aid the advice of the general physician; and must not expect to render unnecessary, by the employment of spectacles, all the other resources of the healing art. When debility of the ciliary muscles and of the interni is a consequence of debility of a more general character, the condition of the eyes may, indeed, often be greatly improved by treatment specially directed to them; but complete functional restoration is hardly to be hoped for, except in conjunction with a corresponding degree of improvement in the state of the organism as a whole.

BEDFORD STREET, COVENT GARDEN, LONDON,

*May* 1876.

# *MACMILLAN & CO.'S MEDICAL CATALOGUE.*

## *WORKS in PHYSIOLOGY, ANATOMY, ZOOLOGY, BOTANY, CHEMISTRY, PHYSICS, MIDWIFERY, MATERIA MEDICA, and other Professional Subjects.*

**ALLBUTT** (T. C.)—ON THE USE OF THE OPHTHALMOSCOPE in Diseases of the Nervous System and of the Kidneys; also in certain other General Disorders. By THOMAS CLIFFORD ALLBUTT, M.A., M.D., Cantab., Physician to the Leeds General Infirmary, Lecturer on Practical Medicine, &c., &c., 8vo. 15*s*.

**ANDERSON.**—ON THE TREATMENT OF DISEASES OF THE SKIN: with an Analysis of Eleven Thousand Consecutive Cases. By Dr. McCALL ANDERSON, Professor of Clinical Medicine in the University of Glasgow, and Physician to the Western Infirmary and to the Wards for Skin Diseases. Crown 8vo. cloth. 5*s*.

**BASTIAN.**—Works by H. CHARLTON BASTIAN, M.D., F.R.S., Professor of Pathological Anatomy in University College, London, &c.:—

THE BEGINNINGS OF LIFE: Being some Account of the Nature, Modes of Origin, and Transformations of Lower Organisms. In Two Volumes. With upwards of 100 Illustrations. Crown 8vo. 28*s*.

EVOLUTION AND THE ORIGIN OF LIFE. Crown 8vo. 6*s*. 6*d*.

ON PARALYSIS FROM BRAIN DISEASE IN ITS COMMON FORMS. Illustrated. Crown 8vo. 10*s*. 6*d*.

"It would be a good thing if all such lectures were as clear, as systematic, and as interesting. . . . . It is of interest not only to students but to all who make nervous diseases a study."—*Journal of Mental Science.*

**CARTER.**—A PRACTICAL TREATISE ON DISEASES OF THE EYE. By R. BRUDENELL CARTER, F.R.C.S., Ophthalmic Surgeon to St. George's Hospital, &c. With Illustrations. 8vo. 16*s*.

"No one will read Mr. Carter's book without having both his special and general knowledge increased."—*Lancet.*

**CHRISTIE.**—CHOLERA EPIDEMICS IN EAST AFRICA. An Account of the several Diffusions of the Disease in that country from 1821 till 1872, with an Outline of the Geography, Ethnology, and Trade Connections of the Regions through which the Epidemics passed. By J. CHRISTIE, M.D., late Physician to H.H. the Sultan of Zanzibar. With Maps. 8vo. 15*s*.

**COOKE** (JOSIAH P., Jun.)—FIRST PRINCIPLES OF CHEMICAL PHILOSOPHY. By JOSIAH P. COOKE, Jun., Ervine Professor of Chemistry and Mineralogy in Harvard College. Third Edition, revised and corrected. Crown 8vo. 12*s*.

**COOKE** (M. C.)—HANDBOOK OF BRITISH FUNGI, with full descriptions of all the Species, and Illustrations of the Genera. By M. C. COOKE, M.A. Two Vols. Crown 8vo. 24*s*.

**CORFIELD** (Professor W. H.)—A DIGEST OF FACTS RELATING TO THE TREATMENT AND UTILIZATION OF SEWAGE. By W. H. CORFIELD, M.A., B.A,, Professor of Hygiene and Public Health at University College, London. 8vo. 10*s.* 6*d.* Second Edition.

**ELAM** (C.)—A PHYSICIAN'S PROBLEMS. By CHARLES ELAM, M.D., M.R.C.P. Crown 8vo. 9*s.*

**FLOWER** (W. H.)—AN INTRODUCTION TO THE OSTEOLOGY OF THE MAMMALIA. Being the substance of the Course of Lectures delivered at the Royal College of Surgeons of England in 1870. By W. H. FLOWER, F.R.S., F.R.C.S., Hunterian Professor of Comparative Anatomy and Physiology. With numerous Illustrations. Globe 8vo. 7*s.* 6*d.*

**FLÜCKIGER and HANBURY.**—PHARMACOGRAPHIA. A History of the Principal Drugs of Vegetable Origin met with in Great Britain and British India. By F. A. FLÜCKIGER, Ph.D., and D. HANBURY, F.R.S. 8vo. 18*s.*

"An almost faultless monograph. . . . . giving a trustworthy account of the botanical origin, history, chemical composition, source, and commercial relations of the principal drugs. It abounds in research of every kind."—*British Medical Journal.*

**FOSTER and BALFOUR.**—ELEMENTS OF EMBRYOLOGY. By MICHAEL FOSTER, M.D., F.R.S., and F. M. BALFOUR, M.A., Fellow of Trinity College, Cambridge. With numerous Illustrations. Part I. Crown 8vo. 7*s.* 6*d.*

**FOX.**—Works by WILSON FOX, M.D. Lond., F.R.C.P., F.R.S., Holme Professor of Clinical Medicine, University College, London, Physician Extraordinary to her Majesty the Queen, &c. :—

DISEASES OF THE STOMACH : being a new and revised Edition of "THE DIAGNOSIS AND TREATMENT OF THE VARIETIES OF DYSPEPSIA." 8vo. 8*s.* 6*d.*

ON THE ARTIFICIAL PRODUCTION OF TUBERCLE IN THE LOWER ANIMALS. With Coloured Plates. 4to. 5*s.* 6*d.*

ON THE TREATMENT OF HYPERPYREXIA, as Illustrated in Acute Articular Rheumatism by means of the External Application of Cold. 8vo. 2*s.* 6*d.*

**GALTON** (D.)—AN ADDRESS ON THE GENERAL PRINCIPLES WHICH SHOULD BE OBSERVED IN THE CONSTRUCTION OF HOSPITALS. By DOUGLAS GALTON, C.B., F.R.S. Crown 8vo. 3*s.* 6*d.*

**GRIFFITHS.**—LESSONS ON PRESCRIPTIONS AND THE ART OF PRESCRIBING. By W. HANDSEL GRIFFITHS, Ph.D., L.R.C.P.E. 18mo. 3*s.* 6*d.*

"We recommend it to all students and junior members of the profession who desire to understand the art of prescribing."—*Medical Press.*

**HOOD** (Wharton).—ON BONE-SETTING (so-called), and its Relation to the Treatment of Joints Crippled by Injury, Rheumatism, Inflammation, &c. &c. By WHARTON P. HOOD, M.D., M.R.C.S. Crown 8vo. 4*s.* 6*d.*

"Dr. Hood's book is full of instruction, and should be read by all surgeons."—*Medical Times.*

**HOOKER** (Dr.).—THE STUDENT'S FLORA OF THE BRITISH ISLANDS. By J. D. HOOKER, C.B., M.D., D.C.L., President of the Royal Society. Globe 8vo. 10*s.* 6*d.*

"Certainly the fullest and most accurate manual of the kind that has yet appeared."—*Pall Mall Gazette.*

**HUMPHRY.** —Works by G. M. HUMPHRY, M.D., F.R.S., Professor of Anatomy in the University of Cambridge, and Honorary Fellow of Downing College :—

THE HUMAN SKELETON (including the Joints). With 260 Illustrations, drawn from Nature. Medium 8vo. 28*s.*

OBSERVATIONS IN MYOLOGY. Illustrated. 8vo. 6*s.*

**HUXLEY** and **MARTIN**.—A COURSE OF PRACTICAL INSTRUCTION IN ELEMENTARY BIOLOGY. By T. H. HUXLEY, LL.D., Sec. R.S., assisted by H. N. MARTIN, M.B., D.Sc. Crown 8vo. 6*s.*

"To intending medical students this book will prove of great value."—*Lancet.*

**HUXLEY** (Professor).—LESSONS IN ELEMENTARY PHYSIOLOGY. By T. H. HUXLEY, LL.D., F.R.S. With numerous Illustrations. New Edition. 18mo. cloth. 4*s.* 6*d.*

"Unquestionably the clearest and most complete elementary treatise on this subject that we possess in any language."—*Westminster Review.*

**JONES**.—THE OWENS COLLEGE JUNIOR COURSE OF PRACTICAL CHEMISTRY. By FRANCIS JONES, Chemical Master in the Grammar School, Manchester. With Preface by Professor ROSCOE. New Edition. 18mo. with Illustrations. 2*s.* 6*d.*

**LANKESTER**.—COMPARATIVE LONGEVITY IN MAN AND THE LOWER ANIMALS. By E. RAY LANKESTER, B.A. Crown 8vo. 4*s.* 6*d.*

**LEISHMAN**.—A SYSTEM OF MIDWIFERY, including the Diseases of Pregnancy and the Puerperal State. By WILLIAM LEISHMAN, M.D., Regius Professor of Midwifery in the University of Glasgow; Physician to the University Lying-in Hospital ; Fellow and late Vice-President of the Obstetrical Society of London, etc. etc. 8vo. Illustrated. Second and Cheaper Edition. 21*s.*

**MACLAREN**.—TRAINING IN THEORY AND PRACTICE. By ARCHIBALD MACLAREN, the Gymnasium, Oxford. Second and Cheaper Edition, enlarged. Crown 8vo. 6*s.* 6*d.*

**MACPHERSON**.—Works by JOHN MACPHERSON, M.D. :—

THE BATHS AND WELLS OF EUROPE : their Action and Uses. With Notices of Climatic Resorts and Diet Cures. With a Map. New Edition. revised and enlarged. Extra fcap. 8vo. 6*s.* 6*d.*

OUR BATHS AND WELLS : The Mineral Waters of the British Islands. With a list of Sea-Bathing places. Extra fcap. 8vo. 3*s.* 6*d.*

**MANSFIELD** (C. B.)—A THEORY OF SALTS. A Treatise on the Constitution of Bipolar (two-membered) Chemical Compounds. By the late CHARLES BLACHFORD MANSFIELD. Crown 8vo. 14*s.*

**MAUDSLEY.**—Works by HENRY MAUDSLEY, M.D., Professor of Medical Jurisprudence in University College, London:—

BODY AND MIND: An Inquiry into their Connection and Mutual Influence, specially in reference to Mental Disorders: being the Gulstonian Lectures for 1870. Delivered before the Royal College of Physicians. New Edition, with Psychological Essays added. Crown 8vo. *6s. 6d.*

THE PHYSIOLOGY OF MIND. [*In the Press.*

**MIVART** (St. George).—Works by ST. GEORGE MIVART, F.R.S., &c., Lecturer in Comparative Anatomy at St. Mary's Hospital:—

ON THE GENESIS OF SPECIES. Crown 8vo. Second Edition, to which notes have been added in reference and reply to Darwin's "Descent of Man." With numerous Illustrations. pp. xv. 296. *9s.*

LESSONS IN ELEMENTARY ANATOMY. With upwards of 400 Illustrations. 18mo. *6s. 6d.*

"It may be questioned whether any other work on anatomy contains in like compass so proportionately great a mass of information."—*Lancet.*

**MORGAN.**—UNIVERSITY OARS: Being a Critical Inquiry into the After-health of the Men who rowed in the Oxford and Cambridge Boat-Race, from the Year 1829 to 1869, based upon the personal experience of the rowers themselves. By JOHN E. MORGAN, M.D., M.A., Oxon., F.R.C.P., late Captain of the John × (Coll. Univ.), Physician to the Manchester Royal Infirmary, Author of "The Deterioration of Races," etc. Crown 8vo. *10s. 6d.*

**MUNRO.**—THE SCIENCE AND ART OF NURSING THE SICK. By ÆNEAS MUNRO, M.D. Crown 8vo. *7s. 6d.*

**OLIVER.**—LESSONS IN ELEMENTARY BOTANY. By DANIEL OLIVER, F.R.S., F.L.S., Professor of Botany in University College, London, and Keeper of the Herbarium and Library of the Royal Gardens, Kew. With nearly 200 Illustrations. New Edition. 18mo, cloth. *4s. 6d.*

**PETTIGREW.**—THE PHYSIOLOGY OF THE CIRCULATION IN PLANTS, IN THE LOWER ANIMALS, AND IN MAN. By J. BELL PETTIGREW, M.D., F.R.S., etc. Illustrated by 150 Woodcuts. 8vo. *12s.*

"A more original, interesting, exhaustive, or comprehensive treatise on the circulation and the circulatory apparatus in plants, animals, and man, has never, we are certain, been offered for the acceptance of the anatomist, physiologist, or student of medicine."—*Veterinary Journal.*

**RADCLIFFE.**—Works by CHARLES BLAND RADCLIFFE, M.D., F.R.C.P., Physician to the Westminster Hospital, and to the National Hospital for the Paralysed and Epileptic:—

DYNAMICS OF NERVE AND MUSCLE. Crown 8vo. *8s. 6d.*

VITAL MOTION AS A MODE OF PHYSICAL MOTION. Crown 8vo. *8s. 6d.*

"This work is one which well deserves the most careful perusal, and for which the physiological world should be much indebted to Dr. Radcliffe."—*Medical Press.*

**RANSOME.**—ON STETHOMETRY. Chest Examination by a more Exact Method, with its Results. With an Appendix on the Chemical and Microscopical Examination of Respired Air. By ARTHUR RANSOME, M.D. With Illustrations. 8vo. 10*s.* 6*d.*

**REYNOLDS**—(J. R.).—A SYSTEM OF MEDICINE. Vol. I. Edited by J. RUSSELL REYNOLDS, M.D., F.R.C.P. London. Second Edition. 8vo. 25*s.*

Part I. General Diseases, or Affections of the Whole System. § I.—Those determined by agents operating from without, such as the exanthemata, malarial diseases, and their allies. § II.—Those determined by conditions existing within the body, such as Gout, Rheumatism, Rickets, etc. Part II. Local Diseases, or Affections of Particular Systems. § I.—Diseases of the Skin.

A SYSTEM OF MEDICINE. Vol. II. Second Edition. 8vo. 25*s.*
Part II. Local Diseases (continued). § I.—Diseases of the Nervous System. A. General Nervous Diseases. B. Partial Diseases of the Nervous System. 1. Diseases of the Head. 2. Diseases of the Spinal Column. 3. Diseases of the Nerves. § II.—Diseases of the Digestive System. A. Diseases of the Stomach.

A SYSTEM OF MEDICINE Vol. III. 8vo. 25*s.*
Part II. Local Diseases (continued). § II. Diseases of the Digestive System (continued). B. Diseases of the Mouth. C. Diseases of the Fauces, Pharynx, and Œsophagus. D. Diseases of the Intestines. E. Diseases of the Peritoneum. F. Diseases of the Liver. G. Diseases of the Pancreas. § III.—Diseases of the Respiratory System. A. Diseases of the Larynx. B. Diseases of the Thoracic Organs.

A SYSTEM OF MEDICINE. Vol. IV. [*To be published shortly.*

**REYNOLDS** (O.).—SEWER GAS, AND HOW TO KEEP IT OUT OF HOUSES. A Handbook on House Drainage. By OSBORNE REYNOLDS, M.A., Professor of Engineering at Owens College, Manchester. New Edition. Crown 8vo. cloth. 1*s.* 6*d.*

"Professor Reynolds's admirable pamphlet will a thousand times over repay its cost and the reader's most attentive perusal."—*Mechanic's Magazine.*

**RICHARDSON.**—DISEASES OF MODERN LIFE. Second Edition. Crown 8vo. 12*s.* 6*d.*

"The book is in a remarkable degree original, always interesting, often singularly graphic."—*Times.*

ON ALCOHOL. New Edition. Crown 8vo. 1*s.*

HYGEIA, A CITY OF HEALTH. [*Nearly ready.*

**ROLLESTON.**—THE HARVEIAN ORATION, 1873. By GEORGE ROLLESTON, M.D., F.R.S., Linacre Professor of Anatomy and Physiology, and Fellow of Merton College, in the University of Oxford. Crown 8vo. 2*s.* 6*d.*

**ROSCOE.**—Works by HENRY E. ROSCOE, F.R.S., Professor of Chemistry in Owens College, Manchester :—

LESSONS IN ELEMENTARY CHEMISTRY, INORGANIC AND ORGANIC. With numerous Illustrations, and Cromolithographs of the Solar Spectrum, and of the Alkalies and Alkaline Earths. New Edition. 18mo. cloth. 4*s.* 6*d.*

"We unhesitatingly pronounce it the best of all our elementary treatises on Chemistry."—*Medical Times.*

**ROSCOE.**—(*Continued.*)

SPECTRUM ANALYSIS. Six Lectures, with Appendices, Engravings, Maps, and Chromolithographs. Third Edition. Royal 8vo. 21*s.*

"The lectures themselves furnish a most admirable elementary treatise on the subject, whilst by the insertion in appendices to each lecture of extracts from the most important published memoirs, the author has rendered it equally valuable as a text-book for advanced students."—*Westminster Review.*

**SCHORLEMMER.**—A MANUAL OF THE CHEMISTRY OF THE CARBON COMPOUNDS, OR ORGANIC CHEMISTRY. By C. SCHORLEMMER, F.R.S., Lecturer in Organic Chemistry in Owens College, Manchester. 8vo. 14*s.*

"It appears to us to be as complete a manual of the metamorphoses of carbon as could be at present produced, and it must prove eminently useful to the chemical student."—*Athenæum.*

**SEATON.**—A HANDBOOK OF VACCINATION. By EDWARD C. SEATON, M.D., Medical Inspector to the Privy Council. Extra fcap. 8vo. 8*s.* 6*d.*

**SPENDER.**—THERAPEUTIC MEANS FOR THE RELIEF OF PAIN. Being the Prize Essay for which the Medical Society of London awarded the Fothergillian Gold Medal in 1874. By JOHN KENT SPENDER, M.D., Lond., Surgeon to the Mineral Water Hospital, Bath. 8vo. 8*s.* 6*d.*

**STEWART** (B.)—LESSONS IN ELEMENTARY PHYSICS. By BALFOUR STEWART, F.R.S., Professor of Natural Philosophy in Owens College, Manchester. With numerous Illustrations and Chromolithos of the Spectra of the Sun, Stars, and Nebulæ. New Edition. 18mo. 4*s.* 6*d.*

**THUDICHUM AND DUPRÉ.**—A TREATISE ON THE ORIGIN, NATURE, AND VARIETIES OF WINE. Being a Complete Manual of Viticulture and Œnology. By J. L. W. THUDICHUM, M.D., and AUGUST DUPRÉ, Ph.D., Lecturer on Chemistry at Westminster Hospital. Medium 8vo. cloth gilt. 25*s.*

"A treatise almost unique for its usefulness either to the wine-grower, the vendor, or the consumer of wine. The analyses of wine are the most complete we have yet seen, exhibiting at a glance the constituent principles of nearly all the wines known in this country."—*Wine Trade Review.*

**WALLACE** (A. R.)—CONTRIBUTIONS TO THE THEORY OF NATURAL SELECTION. A series of Essays. By ALFRED RUSSEL WALLACE, Author of "The Malay Archipelago," etc. New Edition. Crown 8vo. 8*s.* 6*d.*

**WILSON.**—RELIGIO CHEMICI. By the late GEORGE WILSON, M.D., F.R.S.E., Regius Professor of Technology in the University of Edinburgh. With a Vignette after a design by Sir NOEL PATON Crown 8vo. 8*s.* 6*d.*

**WURTZ.**—A HISTORY OF CHEMICAL THEORY from the Age of Lavoisier down to the present time. By AD. WURTZ. Translated by HENRY WATTS, F.R.S. Crown 8vo. 6*s.*

"The discourse, as a *résumé* of chemical theory and research, unites singular luminousness and grasp."—*Pall Mall Gazette.*