THE CLINICAL USE OF
PRISMS

MADDOX

THE CLINICAL USE OF PRISMS;

AND THE

Decentering of Lenses.

BY

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PREFACE.

The title of this little work indicates its chief features, but does not cover its ground completely. Its first object was to communicate a series of aids to precision in the use of prisms, worked out during several years, which it is hoped will be of some service in this difficult by-way of ophthalmic practice. They have, however, been introduced by a sketch of the simplest properties of prisms, and supplemented by a brief account of their chief clinical uses. For the sake of brevity, results are given rather than the geometrical processes by which they were obtained, while the mathematical formulæ are either suppressed or relegated to foot-notes. When possible, home-made appliances are suggested in preference to expensive apparatus. Some failure in prescribing prismatic spectacles and combinations has perhaps arisen, in the past, from the lack of precise methods and tables to work by; encouraging exceptions must stimulate the desire to extend their number, but it will not be supposed that the precision aimed at in these pages is necessary in the majority of refraction cases. It is chiefly anomalies of convergence, faulty tendencies of the ocular muscles, and the needs of the increasing neurasthenic class of patients that are kept in view. In these last cases, spectacles cause discomfort, however perfectly refraction may be corrected, unless the lenses are also suitably placed in respect of convergence, and sometimes even then, for a time.

Part of the manuscript was kindly read over by my friend, Dr. POULETT WELLS, to whom I am indebted for one or two valuable corrections, and, indeed, for suggesting the need of a book on prisms.

July, 1889.

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Part I.—PRISMS.

A.—SIMPLEST PROPERTIES OF PRISMS.

I.—GEOMETRICAL PROPERTIES.

IN Ophthalmology, as in Optics, the essential thought of a "prism" is a wedge of transparent material, having at least two *plane* faces parted by an angle.

This angle may be of any size, and is spoken of as the "*angle of refraction.*"

Fig. 1.—A rectangular prism.

In *Fig.* 1 we see the prominent features of a rectangular prism — the kind most commonly used by students of optics. The "*refracting angle*" is *d a c*; the plane faces, *a b d e* and *a b c f* are named "*refracting surfaces,*" and the line *a b* in which they meet, or would meet if prolonged, is called the "*edge.*"

The sections *a d c* and *b e f* being made in planes perpendicular to the refracting surfaces, are named "*principal sections*" The remaining surface *d c e f* is the "*base.*"

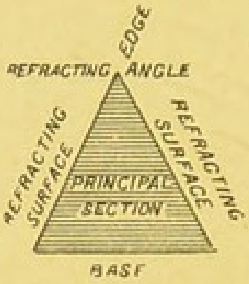

Fig. 2.—The same prism in section.

When prisms are designated "square," "rectangular," "circular," and so forth, it is of course understood that these expressions do not, as indeed they could not, apply to the angle of the wedge, but to *the shape of the two refracting surfaces.* Clinical prisms are almost universally circular to admit of their insertion in the same trial-frame as the lenses: the design in *Fig.* 3 shews how a circular prism is related to, as though it were cut out of, a rectangular one.

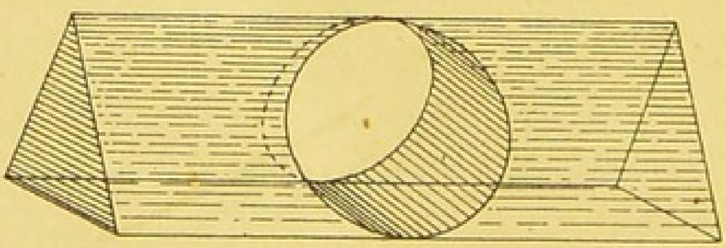

Fig. 3.—A hypothetical illustration to shew the relation of a circular prism to a rectangular one.

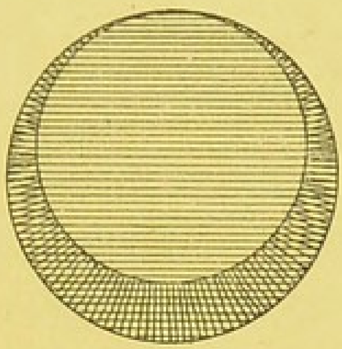

Fig. 4.—A circular prism.

2.—OPTICAL PROPERTIES OF PRISMS.

When rays of light traverse a prism they undergo "refraction," by which they are bent from their previous course and emerge in a new direction. In *Fig.* 5 this is illustrated.

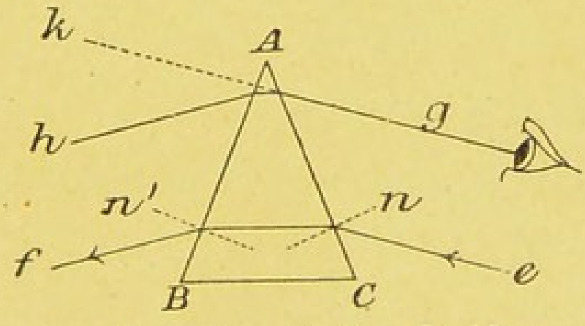

Fig. 5.—Refraction through a prism. Incident ray *e*; emergent ray *f*; incident ray in opposite direction *h*; emergent ray *g*.

An "incident ray" *(e)* is seen to impinge on the face *A C*, but here in passing out of the less refracting medium—air—into the more refracting medium—glass—it is bent *towards* the dotted line *n*, which, being perpendicular to the surface, is called the "normal."

The ray, after traversing the prism, emerges from the other face *A B*, but since, while doing this, it is now again entering the less refracting medium, it is bent *away from* the normal, *n'*. The ray thus experiences a double deflection, the combined effect of which is that it is turned from its previous course through an angle about half that by which the refracting surfaces are separated. It is important to notice that since the deflections take place only at the surfaces, the thickness of the prism, or the distance from its edge at which it is traversed by the ray, does not affect the result, provided the angle between the surfaces remains unchanged. Thus in the figure, the rays *g h* and *e f* are equally deflected, though the former is much nearer the edge of the prism than the latter: the greater the angle *(B A C)* between the faces, the greater is the deflection of both rays.*

MINIMUM DEVIATION.—When the points of incidence and emergence of a given ray are equi-distant from the edge of the prism,

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* For the index of refraction, the law of sines, etc., the reader is referred to the text-books. Their study is not essential for our subject.

as in the figure, the *ray* is said to traverse the prism in the "direction of minimum deviation;" or, to put it another way, the *prism* is said to be (in reference to the ray) in its "position of minimum deviation." By this it is meant that the ray under these conditions suffers less total deviation than if it passed through the prism in any other direction.† With weak prisms, however, and only slight departures from the "position of symmetry," the difference is so trifling that it may be neglected in ophthalmic practice.

Dispersion.—By dispersion, or "chromatic aberration," is meant the breaking up of light into its constituent colours. It is a property possessed in greater or less degree by all prisms, since the differently coloured rays, being unequally refrangible, are deflected

† This is beautifully defined, in an experimental way, by Deschanel: "When a beam of sunlight in a dark room is transmitted through a prism, it will be found, on rotating the prism about its axis, that there is a certain mean position which gives smaller deviation of the transmitted light than positions on either side of it: and that when the prism is in this position, a small rotation of it has no sensible effect on the amount of deviation. The position determined experimentally by these conditions, and known as the position of minimum deviation, is the position in which the ray passes symmetrically."

through different angles, the violet rays (or more correctly the lavender, if they are really part of the spectrum) experiencing the greatest deflection, and the red the least, while the paths of the rays of intermediate colours are spread out between these two extremes. The whole solar spectrum can thus be received upon a white screen arranged to intercept a pencil of light which has traversed a strong prism. This property of dispersion, so valuable in spectrum analysis, and to which also are due the various tints of dawn and sunset, is a serious disadvantage in the ophthalmological use of prisms, from the coloured margins it appears to give to objects, and the want of definition it occasions, just in proportion to the strength of the prism used.

It is only fairly weak prisms, therefore, that can be clinically employed with much advantage. The dispersive power of crown glass is so much less than of flint glass that it is invariably employed for clinical purposes. Achromatic prisms can be made by cementing together two prisms, one of crown, the other of flint glass, with the apex of one to the base of the other, since the ratio between the refractive and dispersive power is different in the two kinds of glass.* But though suggested long ago, such combinations have been precluded by their weight from clinical use.

3.—CLINICAL PROPERTIES OF PRISMS.

The only clinical use of prisms is to change the direction of the rays of light, but this is fruitful in its secondary applications. They always produce an optical illusion; in other words, they make objects appear in a different position from that which they actually occupy.

Clinical prisms, as we have seen, are generally circular; their thinnest point is called the "apex," and their thickest part the "base."

An imaginary line between the apex and base is called, for convenience, the "*base-apex line.*" All objects viewed through a prism appear displaced in a direction parallel to this

* The dispersive power of crown glass is to that of flint glass as 33 to 52; whereas the refractive power is about as 31 to 32, though it varies greatly with different specimens, and must be determined for each.

line, and *always towards the edge*, by which is meant the line in which the two plane surfaces would, if prolonged, meet. It is customary to say that objects appear displaced towards the apex, an expression which, if a little less correct, is still very convenient, provided it is not misunderstood. The accompanying diagram (*Fig.* 6) will make it clear, and a

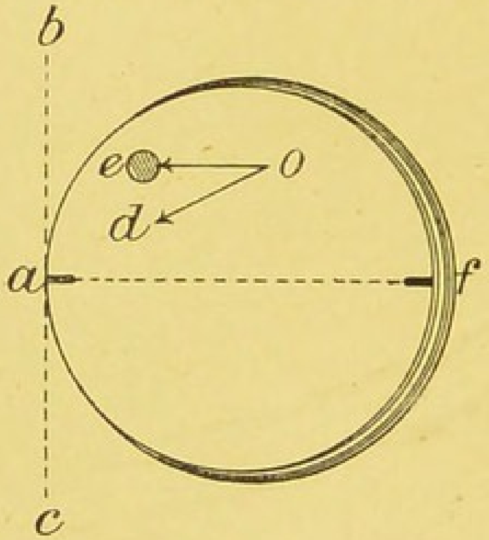


Fig. 6.—To shew how an object at *O* appears displaced, not in the direction *d* towards the apex *a*, but in the direction *e* towards the edge *b c*, and parallel to the "base-apex line," *a f*.

glance back to *Fig.* 3 may assist in understanding what is meant by the "edge," for since the refracting surfaces of the rectangular prism are extensions of those of the circular one (supposing the latter to be in place) the line in which they meet is the "edge" of both prisms. Thus, to give an experimental example, if we look at a vertical line on the wall, as *x x* in *Fig.* 7, through a prism

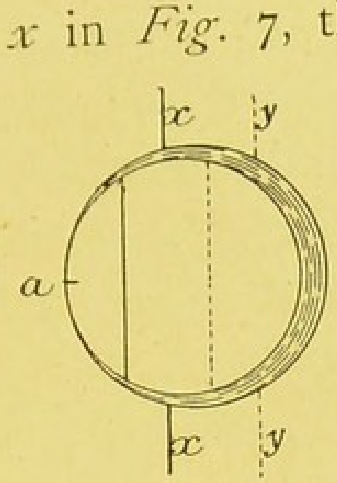


Fig. 7.—To shew the apparent displacement of lines through a prism.

held several inches from the eye, with its apex at *a*, we observe that the part of the line seen through the prism appears displaced towards its edge. The reason is apparent from a glance at *Fig.* 5 (on p. 9), where the ray *h g* from an object at *h* is deflected by the prism towards its base, so that it appears to come from *k*; or, in other words, it enters the eye in a direction as if it came from *k*, so that the object is mentally projected there. Since the refracting surfaces of any prism are of necessity inclined to each other by the same angle in every part of their area, it follows that the apparent displacement of an object is equally great, through whatever part of the prism it is viewed. Thus in *Fig.* 7 the lines *x x* and *y y* appear equally displaced. By this property prisms may be at once distinguished from lenses, or combinations of lenses and prisms. With a lens, lines viewed through different sides of its optical centre appear displaced in opposite directions; with a concave lens, both lines appear deflected towards the centre, and with a convex one both away from it. As regards *direction* of displacement, the edge of a convex lens is well known to act like a prism with its edge outwards, while that of a concave lens acts like a prism with its edge inwards, though in each case the *degree* of displacement increases with each approach from the centre to the edge. By viewing a distant line through an unknown lens, hard by its edge, and opposing to it lens after lens from the trial case till the line appears unbroken, the strength of the unknown lens can be determined to within a quarter of a dioptre, and the same principle is utilised in the now general practice of viewing some object through a moving lens, to observe whether the apparent movement of the object is with or contrary to that of the lens, which in the former event is concave, and in the latter convex.

To return to prisms, we have seen that they appear to *displace objects in the direction of their edge.* Since an eye tends to be diverted towards the (apparently) new position of the object, it follows that *the line of fixation is also displaced towards the edge,* and in working with prisms these two clinical properties are all that need be remembered. *Fig.* 8 illustrates both: a

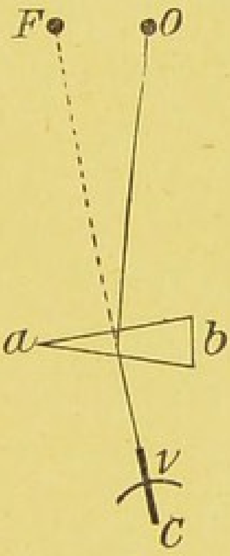
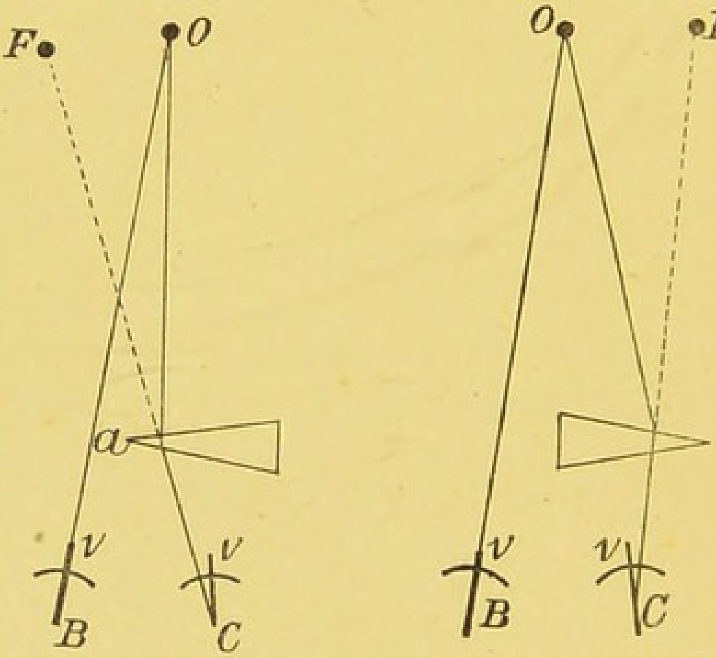


Fig. 8.—A prism before an eye, in monocular vision.

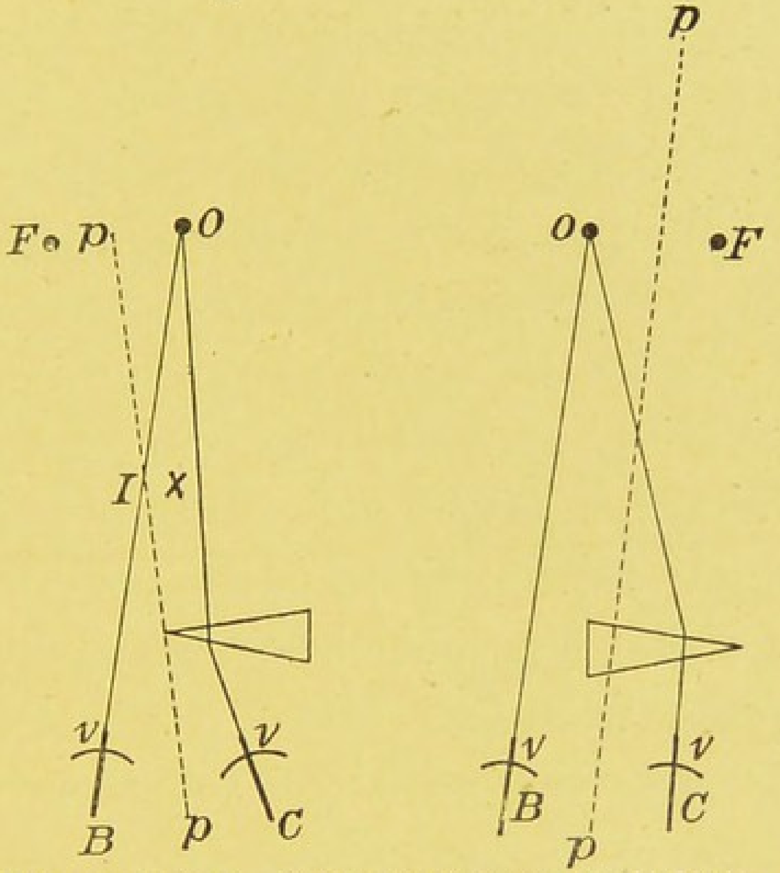
prism is placed before one eye, *the other being covered,* and it is evident that the object *O* appears displaced to *F*, and the line of fixation *v* is diverted from *O* to *F*,—both in the direction of the apex *a*. The line *F C* in which the false image lies is called the "line of projection," since it marks the direction in which the picture on the retina is mentally projected.

With binocular vision, as in *Figs.* 9 to 12, the conditions are not quite so simple. In all these figures the ruled lines shew the actual course of the rays from the object *O*, and the dotted lines are the lines of projection. They almost explain themselves: in all it will be seen that the object appears displaced towards the edge of the prism, though in some (*Figs.* 9 and 10) there is



Figs. 9 and 10.—Prisms not overcome, and therefore causing diplopia.

diplopia, since the object is seen in its true position *O* by the unclad eye at the same time that its false image *F* is seen by the other in the direction of the edge of the prism, which is directed inwards in *Fig.* 9, and outwards in *Fig.* 10. In *Figs.* 11 and 12



Figs. 11 and 12.—Prisms overcome; no diplopia.

there is no diplopia; it has been corrected by the desire for single vision, and the two images are fused into one. Still, the united image appears in a false position, though the angular displacement of the line of projection *p p*, is only half that in the previous examples. The diplopia is corrected by a rotation of the eye so as to receive again upon its fovea centralis the picture of the object which the prism had dislodged to another part of the retina; thus in these two figures the line of fixation *v C*, has come to be in line with the rays of light coming through the prism from the object, and since both eyes receive a picture on the fovea, vision is single. In *Figs.* 9 and 10 there is *no* definite line of fixation for the right eye, since it is fixing nothing, and it is clear that the picture must fall on the retina away from the fovea, though with every effort to unite the images and bring the axis of vision *v C*, into the line of the rays, the position of the picture on the retina will vary, and the images will move towards or from each other.

Prisms set with their edge inwards as in *Figs.* 8, 9, and 11, are called *adducting prisms*, and those with their edge outwards as in *Figs.* 10 and 12, are called *abducting prisms.* The former, when vision is binocular and without diplópia, by increasing the necessary convergence of the eyes, make objects appear nearer than they actually are, and the latter make them appear too far away. Thus in *Fig.* 11 the real object *O*, appears to be at *I*, where the two lines of fixation intersect.*

* Exceptions to this I have pointed out in Journal of Anat. and Phys. vol. 21, p. 21, but it is not desirable to enlarge on it here, or to enter deeply into the physiology of convergence, which would need a book to itself.

As Hering has shewn, convergence occurs as if for the cross and both eyes are turned towards *I* by an impulse of the conjugate innervation which turns the two eyes to the left: it is the mental cognizance of *this* effort which imparts corresponding obliquity to the line of projection, *p p*. The prism, therefore, does not test the strength of either rectus, since convergence is a single action affecting both eyes equally, but it estimates by how much convergence can be made to exceed accommodation, or *vice versa*. The two functions are so confederate that there are limits to the amount by which either can be increased or diminished without the other. Prisms should be placed as close as possible to the eye, then their angles of deviation nearly express the diplopia, or corrective squint, they occasion, or the sum of both if both are present.

One of three events therefore may happen on placing a prism before an eye. (1), If vision is monocular, one false image is seen, whose distance from the actual position of the object is unvarying, and dependent entirely on the deviating angle of the prism, *Fig.* 8. (2), With binocular vision the prism may be too strong to be overcome, in which case there is diplopia with an inconstant distance between the images, which approach each other spasmodically with every effort to overcome the prism. (3), The diplopia may be overcome and the object appear single, though its position in space is misjudged through an angle practically equivalent to half the deviating angle of the prism.

B.—MARKING THE APEX.

Circular prisms, as usually sold, have their apex and base indicated by a slight scratch from a diamond. It is to be feared, as we shall see, that experimental work with prisms has hitherto been frequently vitiated by the prevalent inaccuracy in marking the apex—a defect to which, as far as I am aware, no attention has yet been called. An obvious consequence of inaccurate marking is that prisms may not be quite squarely set in the trial-frame; yet the slightest departure from precision in this particular alters the experiment. For example, if it be desired to set a prism of 15° d, with its edge exactly in or out, an aberration of the base-apex line through only a ninetieth part of a circle has the effect of not only lessening in a trifling degree the desired horizontal deflection which it is the aim of the prism to produce, but also of introducing a new and unsuspected vertical deflection of more than 1°. This is shewn in *Fig.* 13, where the actual flame *o*, appears

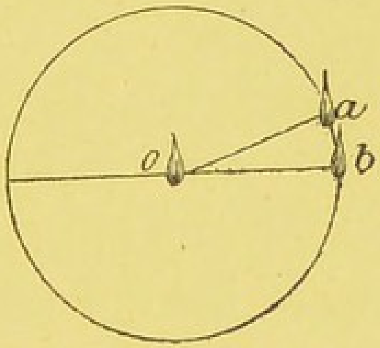


Fig. 13. Shewing the effect of setting a prism by a wrong mark. The marked apex is towards *b*, and the true apex is towards *a*, so that the flame *o*, which should appear at *b*, appears at *a*.

displaced to *a* instead of *b*; — the true base-apex line being *o a*, though the prism is marked as if it were *o b*; hence *a o b* is the angle of error in setting the prism. At twelve feet distant the flame would appear more than two and a half inches higher than it really is.* Now it is well known that

*The unsuspected vertical deflection of a ray of light by a prism whose base-apex line is supposed to be horizontal, or the unsuspected horizontal deflection by a prism whose base-vertical diplopia greatly embarrasses the neuromotor apparatus, and in some persons it cannot be overcome at all when greater than one degree, so the prism in the previous experiment may be put down with the verdict that it is too strong to be overcome, when really it is the concomitant accidental *vertical* diplopia created by it which cannot be overcome, or at least the effect of which vitiates the experiment.

If any surgeon will take the trouble to test the marks upon his own prisms he will find how frequently they are misplaced; the test can be easily made by the following simple device. Draw upon a sheet of paper two fine straight lines intersecting each other exactly at right angles as in *Fig.* 14, and hold the prism vertically above them so that on closing one eye the supposed apex apparently coincides with the point of intersection of the lines, and the prism only appears to touch the horizontal line at that point, and does not in the least

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apex line is supposed to be vertical, may be found in any particular case, by the following formula, $\sin. x = \sin. D + \sin. r$; where x is the angle required, D is the deviating angle of the prism, and r the angle of accidental rotation from exact rectitude.

overlap it on either side. If the prism is correctly marked, the vertical line appears unbroken as in *Fig.* 14, but if not, the part of the line seen through the prism appears

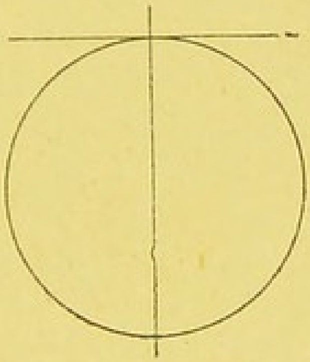

Fig. 14. Mode described for testing the apex of a prism.

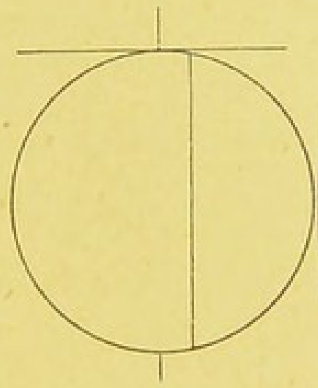

Fig. 15. Appearance with a badly marked prism.

disjointed from the rest, and displaced as in *Fig.* 15, towards the side of the real apex. It only remains to rotate the prism till the unbroken appearance of *Fig.* 14 is gained; then the point on the prism's edge in apparent coincidence with the point of intersection of the lines may be regarded with confidence as the real apex. The cross lines can be permanently provided on a large card suspended upon the wall of the consulting room in connection with that for testing the deviating angle, and they will be found useful for many purposes. For opticians it is suggested to have a diamond half embedded in a plate of glass fixed horizontally above cross-lines similar to those already employed, or merely above one vertical line if the horizontal one be graven on the glass. The diamond would be brought in correspondence with the point of intersection of the lines, so that after finding the apex a slight push of the prism would mark its true position.

A still better form of the apparatus would be one with two shoulders cemented on the glass plate, to grip the edges of the prism instead of using a horizontal line, and to have the diamond held in a sliding arm to make a perfectly straight scratch. Greater distance of the prism from the vertical line magnifies the phenomenon, and makes the test more delicate. The true base of a prism can be found and marked in just the same way as the apex, and if prisms thus manufactured come into use, one of the many causes of experimental inaccuracy will be removed.

C.—PRISMETRY.*

For measuring the refracting angle of a prism (that is, it will be remembered, the angle by which its refracting surfaces are parted), several instruments exist already, named Goniometers,† of which it is easy to make

* This name will be given to the measurement of the deviating angle of prisms ; that of Goniometry being already applied to the measurement of their physical angles.

† A home-made Goniometer for clinical prisms can be easily made by mounting a prism-holder (a lens-holder will do) by a pivot on the centre of a small circular dial of wood ; a long-hand of a clock is fixed to the upright pivot of the prism-holder, and the dial is graduated with degrees, or simply fitted with a common protractor as found in any box of mathematical instruments. The procedure is as follows : Place the prism to be tested in the holder, with base-apex line horizontal, and support the whole instrument on a table or stand opposite the window. Now set the indicating clock-hand at zero of the scale, and rotate the dial itself till a vertical sash of the window, as seen reflected from one face of the prism, appears (to an eye placed between the prism and the window, but lower than the former,) exactly to coincide with a chosen spot or line on the opposite wall. Now, leave the dial *in statu quo*, but rotate the clock-hand till the same window-sash is seen reflected from the other face of the prism, and is brought in line as before with the other two points. The index-hand will now be found pointing to the degree on the scale which describes the refracting angle. The only precaution necessary is to be sure that the observer's eye occupies the same position in making the two observations. Another way to measure the refracting angle is to adapt the legs of a pair of compasses.

an adaptation suitable for ophthalmological prisms. But these acquaint us only with the geometrical—not with the optical properties of prisms; what the surgeon needs alone to know is not their refracting angle, but their deviating power over a beam of light. It has been noticed already that this "angle of deviation" is in each case about half the angle of refraction—with weak prisms rather less, and with strong ones rather more, than half (DONDERS),—but apart from this difference, and from the uncertainty of always in practice ensuring the exact position of minimum deviation, the refractive index of

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to the two faces of the prism, then either use a protractor, or measure the distance between the points of the legs, by placing them on a millimetre rule. If the length of the legs is known, the angle required is found by dividing the length of the legs by half the distance between their points, and doubling the angle of which this is the sine. But the dial mode first described, or that with the protractor, needs no calculation. Having thus, by one or other way, measured the refracting angle *A*, we may measure the deviating angle *D*, by one of the modes given in the text, and then ascertain the refractive index of the glass of which the prism is composed by dividing the sine of half the sum of the two angles by the sine of half the refracting angle.

Thus :
$$\mu = \frac{\sin. \frac{A + D}{2}}{\sin. \frac{A}{2}}$$

different specimens of crown glass varies so much that, as Donders* truly observed of the angles of deviation, "If we wish to know these accurately, it is necessary to determine the deviations for each glass separately." To do this with certainty and ease two simple methods were contrived some years ago, one most suitable for the student or surgeon, the other for the optician. The first can be made without expense, and employed without artificial light. It consists simply of a strip of cardboard suspended horizontally near the right-hand corner of a consulting-room wall, and at such a height from the floor as to be about level with the eyes of the observer. On the wall adjacent to that on which the cardboard is hung, and which enters into its right-hand corner, a permanent mark is made at the distance most generally convenient for making the observations. The card itself is marked, as in *Fig.* 16, in degrees† for this

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* "Accommodation and Refraction of the Eye" (Sydenham Society, p. 132).

† Really, of course, in tangents of degrees. A paper scale of this kind was affixed in May, 1886, to the wall of Messrs. Pickard and Curry's workshop, having been sent them by the author for measuring the deviating angles of their prisms.

distance. All that is necessary to measure

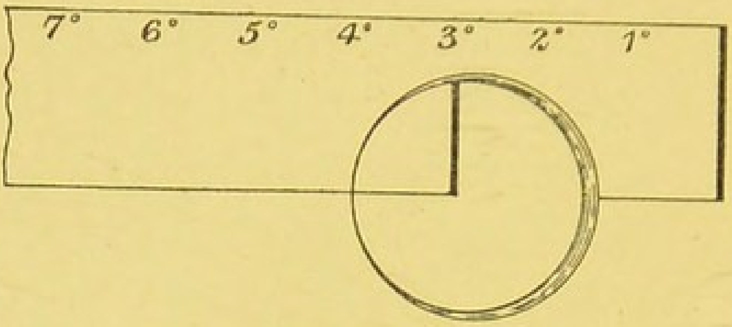

Fig. 16. The author's first mode of prismetry.

the deviating power of a prism is to hold it opposite the already mentioned mark on the wall* with its apex to the left, and so that its upper border appears just beneath the line of degrees as in the figure. The vertical border of the card appears necessarily displaced towards the edge, and points upwards to the number which expresses in degrees, at once and without calculation, the required deflecting angle of the prism. In the figure this is seen to be 3°. One precaution alone needs to be observed ; if the lower edge of the cardboard seen through the prism appears disjointed from the level of the rest, as in *Fig.* 17, the apex of the prism is not pointing exactly to the left, but is either too high or too low, according as that part of the broken line seen through

* The distance of the observer's eye behind the prism does not affect the result in any way.

the prism is above or below the remainder.

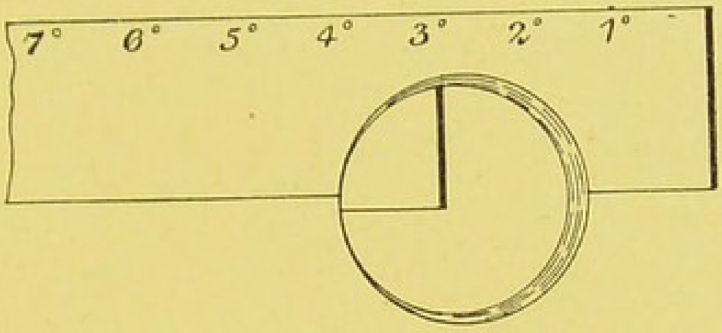

Fig. 17. A prism not held truly.

A slight rotation is therefore necessary to correct this, till the lower border of the card-board appears at one level, as in *Fig.* 16.

The distances between the degrees of the card depend, of course, on the chosen distance at which it is found most convenient to hold the prism, and this would depend on the size of the room and other conditions. The distance of the observer's eye from the prism is of no consequence ; any student can easily mark a piece of cardboard for himself from the accompanying table which gives the distances from the right-hand border of the card at which the several degrees are to be marked upon it, assuming the prism to be held at a uniform distance of six feet (first column), or two metres (second column).

TABLE I.

For marking a card in tangents of degrees at 6 ft. (column A); or 2 metres (column B).

	A	B		A	B
1°	1·25 in.	3·49 cm.	9°	11·4 in.	31·29 cm.
2°	2·5 "	6·98 "	10°	12·6 "	34·73 "
3°	3·7 "	10·467 "	11°	14·0 "	38·16 "
4°	5·0 "	13·95 "	12°	15·3 "	41·58 "
5°	6·3 "	17·43 "	13°	16·6 "	44·99 "
6°	7·57 "	20·9 "	14°	17·9 "	48·38 "
7°	8·84 "	24·37 "	15°	19·3 "	51·76 "
8°	10·12 "	27·83 "	16°	20·64 "	55·13 "

For a different range, the measurements would of course differ in proportion; thus, should it be decided to always hold the prism at 3 feet, the distances would be half as great as in the table; if at 12 feet, twice as great. It is clearly an advantage, when a patient enters with prismatic spectacles, for the surgeon to be able to ascertain their strength without calculation or artificial light; and such spectacles will no doubt come into more frequent use, since convergence is becoming more precisely studied.

The second method affords a much prettier *demonstration* of the deviating angle of prisms, but needs a more definite illumination than diffused daylight. It consists of a strip of wood, as in *Fig.* 18, laid flat on a table or coun-

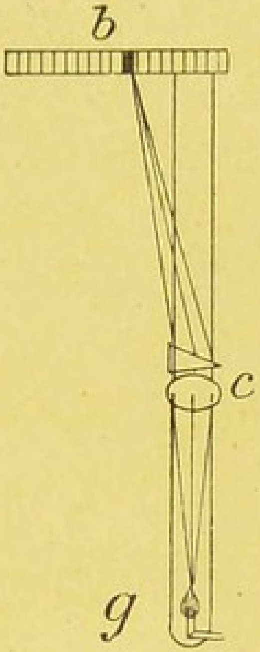

Fig. 18. Second mode of prismetry.

ter with a shorter strip *b*, fixed at right angles to its further end in such wise that while horizontal in its length its plane is vertical. Upon the longer strip a cylindrical lens *c*, is fixed erect, with its axis vertical, so as to throw a line of light from the gas flame *g* upon the strip *b*, which is marked in degrees* so that a prism held before the cylinder *c*, with its base-apex line horizontal, at once makes the bright line move to that degree which indicates the deviating angle. The flame can either be fixed to the main strip or be quite separate, and it is well, if the light is

* Strictly speaking, "in tangents of degrees."

poor, to combine with the cylindrical lens a spherical one of such strength that the source of light shall be at its principal focus.*

An important proposal has been made by Dr. Edward Jackson, of Philadelphia, that all ophthalmological prisms should be *marked* with the angle by which they deviate rays of light, and, in consequence, it was recommended by a committee of the American Ophthalmological Society in September of the year 1888, that :

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* A modification in this method was suggested by Messrs. Pickard and Curry (to whom it was given about the same time as the other), viz. : to curve the graduated scale into an arc, in order to save the calculation of tangents in its manufacture. The following footnote appeared in an essay at the time : "Since the only clinical use of prisms is to deflect the rays of light which traverse them, and since the index of refraction varies with the different specimens of glass, the usual method of marking prisms is not very satisfactory for exact purposes. After consultation with Messrs. Pickard and Curry, they have now a quick method of testing the declinating angle of their prisms" (Journal of Anatomy and Phys., Maddox, Oct., 1886, p. 32).

It will be seen, however, from this extract, that it was only for "exact" (*i.e.* physiological and experimental) purposes that the need was thus expressed for the marking of prisms with their deviating angles. Dr. Jackson's subsequent proposal has prominence given to it in the text, because it embraces all prisms used in ophthalmology : its acceptance by Messrs. Pickard and Curry was due to the energy of Dr. Landolt, last year.

(1,) Prisms ought to be designated by the number of degrees, "minimum deviation," they produce.

(2,) Where intervals of less than one degree are desired, half degrees and quarter degrees should be used.

(3,) To indicate that degrees of deviation are meant, the letter *d* should be used; thus prism 2°*d* will indicate a prism that produces a minimum of two degrees.

The committee consisted of Drs. E. Jackson, S. M. Burnett, and H. D. Noyes, and their decision was conveyed by Dr. Landolt to the Heidelberg Congress in the same year.

It is almost certain, therefore, that prisms thus marked will soon come into general use. and they will greatly simplify calculation.

Possibly, however, if I may be allowed to suggest it, a still better plan would be to have all prisms marked with metre angles and their fractions, so as to correspond with lenses in the trial case, a metre angle being the chosen unit of convergence just as a dioptre is that of accommodation. The only disadvantage is that the metre angle is an inconstant quantity. It is the angle by which each eye has converged from direct parallelism while fixing a point in the median line at the distance of one metre. Its size, therefore, depends on the distance of the centre of rotation of the eye from the median plane, for it is this line which subtends the angle. Its average in adults is taken by Nagel as 1° 50′. It is useful to have a scale, as in *Fig.* 16, marked in metre angles according to this average, as well as a scale marked in degrees, so that by holding any prism up to view, its strength in either unit can be seen without calculation.

In Table II the measurements are given by which such a scale can be made by anyone for himself, on a strip of paper or cardboard.

TABLE II.

For marking a card to be used at the distance of two metres, for telling the strength of a prism in metre angles.

Metre Angles.		Metre Angles.	
0·5 m. a.	3·2 cm.	5·0	32·3 cm.
1·0 „	6·4 „	5·5	35·6 „
1·5 „	9·6 „	6·0	38·9 „
2·0 „	12·8 „	6·5	42·2 „
2·5 „	16·0 „	7·0	45·6 „
3·0 „	19·3 „	7·5	49·0 „
3·5 „	22·5 „	8·0	52·3 „
4·0 „	25·7 „	8·5	55·8
4·5 „	29·0 „	9·0	59·3 „

D.—PLANENESS OF SURFACE.

Little need be said of this, though in buying prisms it is well to examine the planeness of the important " refracting surfaces"; it is often very defective, and this slightly contributes to the difficulties of using prisms. Moreover, since plane faces are rarely ground with the same accuracy as spherical ones, it is better when combinations of lenses and prisms are prescribed to have both surfaces spherical instead of one spherical and the other plane, except when very strong lenses are employed, in which case they are better sometimes plano-convex to diminish spherical aberration.

E.—ADJUSTMENT OF PRISMS IN THE TRIAL-FRAME.

If the apex and base of a circular prism are correctly marked, there is no difficulty in setting it with the base-apex line either exactly vertical or horizontal. But if there should be any doubt about their precise position, the following simple expedient will at once enable us to detect and correct any malposition. If the base-apex line is wished to be horizontal as with the right hand prism of *Fig.* 19, hold the trial-frame a few inches

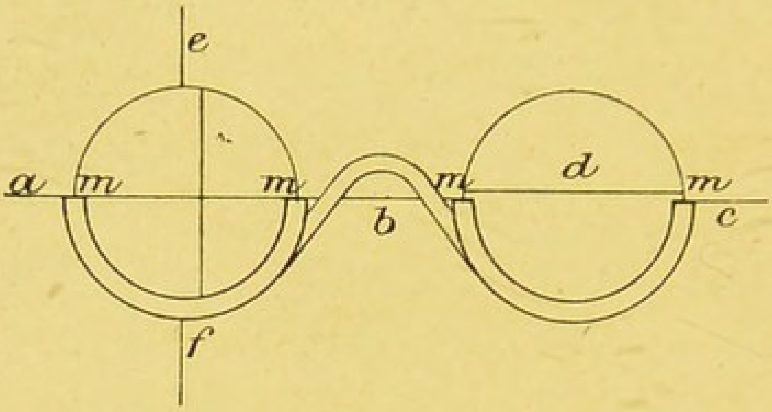

Fig. 19. Two prisms in a trial-frame.

from the eyes, so that, as represented in the figure, the upper extremities *m m m m*, of its sockets coincide to all appearance with a horizontal line *a b c*, upon the wall: if this line upon the wall appears continuous, the prism is correctly set, but if that part of it visible through the prism appears disjointed from the rest as *d* in *Fig.* 19, the apex is either too high or too low, according as the apparent disjointment is upwards or downwards. In the figure the apex is too high and the correction is therefore easily made by rotating the prism so as to depress the apex till the line appears continuous. If the base-apex line is wished to be vertical, as with the left hand prism of the same figure the horizontal line on the wall must be supplemented by another at right angles to it, as *e f* in the figure: again adjusting the frame as before to the horizontal line of sight, the rectitude of the prism is now indicated by the appearance of the *vertical* line. If *its* course appears undeviating the setting is faultless, but if, as in the figure, the part seen through the prism is dissociated from the rest, the apex is shewn to be too much to the same side, and it therefore needs readjustment.

F.—TEMPORARY TRIALS.

Before prescribing prisms or their combinations, it is well, when practicable, to let the patient wear a trial pair at home for a few evenings first, for sustained action alone affords a true indication of whether they will suit. Prisms and lenses can be bound in an ordinary trial-frame by a strip of gutta-percha,

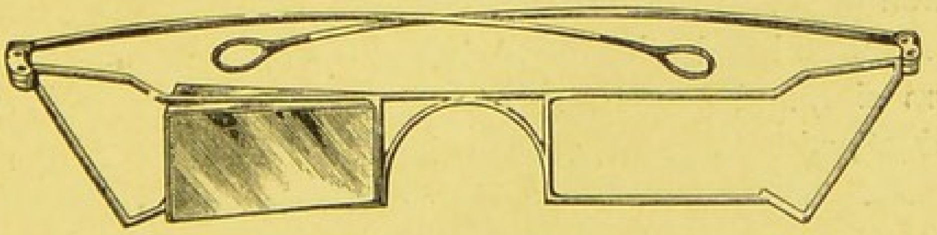

Fig. 20. Rectangular prisms in a frame as suggested in the text. This frame may be obtained from Messrs. Pickard and Curry.

but as accidental rotation is very apt to occur, some other contrivance is desirable when prisms alone are in question. *Fig.* 20 represents a device I once suggested* for the purpose of holding *rectangular* prisms, which I find can be made quite as cheaply as circular ones. The small size of the prisms, while yet allowing sufficient lateral range of movement for the eyeballs, would contribute to the manifest desideratum of lightness. No time is wasted in exact adjustment of the prisms, as their shape not only secures a correct position at once, but removes any possibility of subsequent displacement. Each prism has a longitudinal groove in its upper and lower surface, so that it need only be pushed in between the wires till caught by the elbow.

So light a frame as this could be worn *together* with an ordinary pair of spectacles,

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* I find since that Mr. Chas. Wray, F.R.C.S., of Croydon, has had a somewhat similar frame made with the addition of a spirit level. Dr. Stevens says, " It is my custom to keep on hand a large number of spectacle frames of uniform size, and a quantity of plain prism glasses of 1°, 2°, and 3°, which can be, without loss of time, slipped into the frames. With these I am able, in a few moments, to arrange temporary prisms for a patient."—(Archives of Oph., June, 1888, p. 184.)

when it is desired to try for a few evenings the joint effect of prismatic and spherical glasses.

These prisms would also be exceedingly useful for those cases of paralytic strabismus in which partial or complete recovery may be expected, and for which prismatic spectacles are prescribed. The necessity, if this treatment of such cases is to be successful, of prescribing weaker prisms as the case improves (for without this they actually retard recovery), makes it desirable to have a set of test prisms, a pair of which can be worn for a few days or weeks, and be exchanged for another pair if they cause discomfort, or when they need to be weakened owing to progressive recovery.

Part II.

DECENTERING OF LENSES;

AND COMBINATIONS OF PRISMS WITH LENSES.

Instead of combining a prism and a lens, where it is wished to obtain the effect of both, it is very frequently possible to get the same result by simply decentering the lens, a process which, though already well known, may be simply explained.

The "optical centre" of a lens is that point in it traversed by all rays which, after entering the lens, emerge from it in a direction parallel to their former course. * All rays which do *not* traverse the optical centre are bent from their former course to a degree which depends on the distance from this point, at which they pass through the lens—the greater the distance the greater the deflection. In other words, a lens, in every part other than the optical centre, has the effect of a prism upon any

* This one "property" is all that is necessary for our present purpose, hence it is mentioned, instead of giving a correct definition. See footnote, p. 45.

single ray of light,—the effect of a weak prism near the optical centre, and of a stronger and yet stronger one with every further removal from it, and this equally with concave as with convex lenses. It is evident, therefore, that by shifting a lens so as to bring a more peripheral part into use, a prismatic effect can be obtained just as much as if a prism had been cemented to the lens in its former unshifted position. Such displacement of the optical centre can be effected in one of two ways, the prismatic equivalent of which is identical, but each of which possesses an advantage of its own. First, the lens may simply be *displaced* as it is, rim and all, by lengthening or shortening the spectacle-frame; or, secondly, the frame remaining unchanged, the lens can be *decentred* in its rim as shewn in *Fig.* 21.

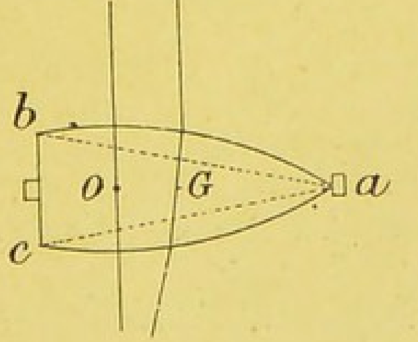

Fig. 21. A decentred lens.

The dioptric strength, or refraction-correcting power, of this lens is exactly the same as that shewn in *Fig.* 22, inasmuch as their surfaces

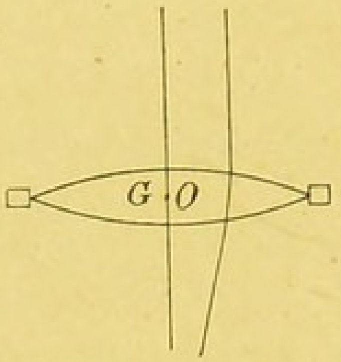

Fig. 22. A lens normally centred.

have the same radius of curvature, but it is as though it were cut peripherally, as shewn in *Fig.* 23, from a larger lens *c d*, so that its optical *O*, and geometrical *G*, centres do not coincide as in an ordinary lens. A brief study of *Fig.* 21, which gives the lens *a b*, of *Fig.* 23

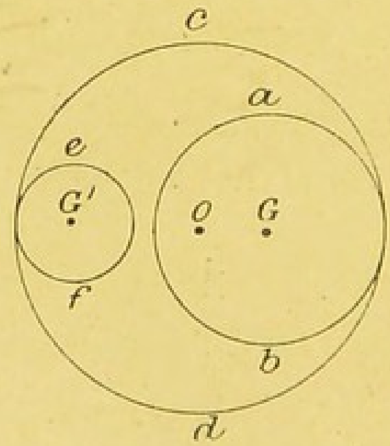

Fig. 23. Peripheric lenses cut out of a larger one.

in section, will show that the effect of cutting it eccentrically out of a larger lens is exactly the same as if a smaller lens of the same strength had been split to admit a prism between its two halves. Without altering its dioptric power then, a prism has been virtually introduced. The *geometrical* centre of a lens is the point midway between all edges, as *G* in *Figs.* 21, 22 and 23. The *optical* centre on the other hand, lies between all points* on the two opposite surfaces of a lens which are parallel to each other and which therefore have no more prismatic or deviating effect on a ray of light entering by one and emerging by the other than a plate of glass would have. It is needless to say that it lies in the thickest part of a convex lens and the thinnest part of a concave one.† For determining its position in any particular lens, an apparatus will be described further on. A lens is said to be normally centred when the optical and geometrical centres coincide as in *Fig.* 22; but to be decentred when, as in *Fig.* 21,

* Strictly, of course, points cannot be parallel, but only the tangents to the curve at the points. But the text will be easily understood.

† It lies in the principal axis of a lens,—the line joining the two centres of curvature; and divides the line of centres in the ratio of the radii of curvature.

the optical centre *O*, and the geometrical centre *G*, are apart, the amount of decentration depending on their distance apart. The two points may be so far removed from each other that the optical centre may come to lie outside the lens altogether. Such would evidently be the case with the small lens *e f* in *Fig.* 23, since the optical centre is at *O*. *Fig.* 24 shews this small lens in section, and

Fig. 24. A lens with its optical centre *O*, far outside itself.

it is evident at a glance that opposite surfaces are nowhere parallel, and that one or both of the surfaces would need to be prolonged considerably before any point could be found in the one parallel to a point in the other; were this done a line uniting the points would pass through the optical centre *O*. We have seen that the effect of decentering a biconvex lens is equivalent to splitting it into two halves, and inserting a prism between them (*b a c* in *Fig.* 21). The strength of this virtually interpolated prism depends on, first the amount of decentration, and second the dioptric strength of the lens. A strong lens needs decentering to a less extent than a weak one to produce the same effect. Table III. not only illustrates this but enables us to find the exact prismatic effect of decentering any lens. All that is required is to fix on the number of millimetres (in the highest horizontal row of figures) by which a lens is known to be decentred, and the prismatic effect is found in the column beneath, opposite the dioptric strength of the lens. Conversely, should it be required to know how much to decentre a given lens in order to combine with it the effect of a certain prism, the eye runs along the horizontal line of angles opposite the known strength of lens till that angle is found nearest to the strength of prism required, when the number of mm. at the head of the column will indicate the decentering necessary.

The word "decentering" is generally applied to the removal of the optical centre away from the geometrical centre of the lens, but we have already said that the prismatic effect is the same if the whole lens, rim and all, be simply *displaced*, as by lengthening or

TABLE III..

	1 mm.	2 mm.	3 mm.	4 mm.	5 mm.	6 mm.	7 mm.	8 mm.	9 mm.	10 mm.	11 mm.	12 mm.	13 mm.	14 mm.	15 mm.	16 mm.	18 mm.	20 mm.	22 mm.	24 mm.	26 mm.	28 mm.	30 mm.	32 mm.
·5D	1'43"	3'26"	5'	7'	8'25"	10'	12'	14'	15'28"	17'	19'	20'37"	22'27"	24'	26'	27'30"	31'	35'	38'	41'	45'	48'	52'	55'
·75D	2'30"	5'	8'	10'	13'	15'28"	18'	20'37"	23'	26'	28'	31'	33'	36'	38'	41'	46'	52'	57'	1°2'	1°6'	1°12'	1°17'	1°22'
1D	3'26"	7'	10'	14'	17'	20'37"	24'	27'30"	31'	35'	38'	41'	45'	48'	52'	55'	1°2'	1°9'	1°16'	1°23'	1°29'	1°36'	1°43'	1°50'
1·5D	5'	10'	15'28"	20'37"	26'	31'	36'	41'	46'	52'	57'	1°2'	1°6'	1°12'	1°17'	1°22'	1°32'	1°43'	1°53'	2°3'	2°13'	2°24'	2°34'	2°44'
2D	7'	14'	20'37"	27'30"	35'	41'	48'	55'	1°2'	1°9'	1°16'	1°23'	1°29'	1°36'	1°43'	1°50'	2°4'	2°18'	2°32'	2°46'	2°58'	3°12'	3°26'	3°40'
3D	10'	15'28"	31'	41'	52'	1°2'	1°12'	1°22'	1°32'	1°43'	1°53'	2°3'	2°13'	2°24'	2°34'	2°44'	3°6'	3°26'	3°46'	4°7'	4°27'	4°48'	5°9'	5°29'
4D	14'	27'30"	41'	55'	1°10'	1°22'	1°36'	1°50'	2°4'	2°18'	2°32'	2°46'	2°58'	3°12'	3°26'	3°40'	4°8'	4°35'	5°2'	5°29'	5°56'	6°24'	6°50'	7°18'
5D	17'	35'	52'	1°9'	1°26'	1°43'	2°	2°18'	2°35'	2°52'	3°9'	3°26'	3°43'	4°1'	4°17'	4°35'	5°9'	5°44'	6°17'	6°51'	7°24'	7°58'	8°32'	9°6'
6D	20'37"	41'	1°2'	1°23'	1°43'	2°4'	2°24'	2°45'	3°5'	3°26'	3°46'	4°7'	4°27'	4°48'	5°9'	5°29'	6°10'	6°51'	7°31'	8°12'	8°52'	9°32'	10°12'	10°52'
7D	24'	48'	1°12'	1°36'	2°	2°24'	2°48'	3°12'	3°37'	4°1'	4°24'	4°48'	5°12'	5°36'	6°	6°24'	7°11'	7°58'	8°45'	9°32'	10°19'	11°5'	11°52'	12°38'
8D	28'	56'	1°22'	1°50'	2°18'	2°46'	3°12'	3°40'	4°8'	4°35'	5°2'	5°29'	5°56'	6°21'	6°50'	7°18'	8°12'	9°6'	9°59'	10°52'	11°45'	12°38'	13°30'	14°22'
9D	31'	1°2'	1°32'	2°4'	2°35'	3°6'	3°37'	4°8'	4°38'	5°9'	5°39'	6°10'	6°40'	7°11'	7°41'	8°12'	9°12'	10°12'	11°12'	12°11'	13°10'	14°9'	15°7'	16°4'
10D	35'	1°9'	1°43'	2°18'	2°52'	5°26'	4°1'	4°35'	5°9'	5°44'	6°17'	6°51'	7°24'	7°58'	8°32'	9°6'	10°12'	11°19'	12°25'	13°30'	14°34'	15°39'	16°42'	17°45'
12D	41'	1°23'	2°4'	2°45'	3°26'	4°7'	4°48'	5°29'	6°10'	6°51'	7°31'	8°12'	8°52'	9°32'	10°12'	10°52'	12°11'	13°30'	14°47'	16°4'	17°20'	18°31'	19°48'	21°
14D	48'	1°36'	2°24'	3°12'	4°1'	4°48'	5°36'	6°24'	7°11'	7°58'	8°45'	9°32'	10°19'	11°5'	11°52'	12°38'	14°9'	15°39'	17°7'	18°34'	20°	21°24'	22°47'	24°8'
16D	56'	1°50'	2°46'	3°40'	4°35'	5°29'	6°23'	7°19'	8°12'	9°6'	9°59'	10°52'	11°45'	12°38'	13°30'	14°22'	16°4'	17°45'	19°24'	21°	22°7'	24°8'	25°38'	27°7'
18D	1°2'	2°4'	3°6'	4°8'	5°9'	6°10'	7°11'	8°12'	9°12'	10°12'	11°12'	12°11'	13°10'	14°9'	15°7'	16°4'	17°57'	19°48'	21°36'	23°22'	25°5'	26°45'	28°22'	29°57'
20D	1°9'	2°18'	3°26'	4°35'	5°44'	6°51'	7°58'	9°6'	10°12'	11°19'	12°25'	13°30'	14°34'	15°35'	16°42'	17°45'	19°48'	21°48'	23°45'	25°38'	27°29'	29°15'	30°58'	32°37'

TABLE III.* Shewing the prismatic effect of decentering any lens.

Procedure.—Find the dioptric strength of the lens in the left-hand column, the prismatic effect is then found opposite, under the number of mm. of decentering.

* This table is adapted from a thesis in 1884, where it appeared under another title ("Journal of Anal. and Phys.," Vol. XXI., p. 32). It was made from the simple formula: $\tan x = \frac{d}{f}$

x, being the deviating angle of the virtual prism; d, the decentering in millimetres; f, the focal length of the lens in millimetres.

shortening the spectacle frame; in other words, it makes no prismatic difference, so long as the optical centre is moved, whether the geometrical one remains in *statu quo*, or whether it is shifted equally itself. How are we then to decide between these rival modes, in any given case? Decentering of any kind has the disadvantage of being attended with proportionate increase of weight, as much as if a prism were inserted: the lens of *Fig.* 21 is very evidently heavier than that of *Fig.* 22. This fault is entirely avoided by the alternative of displacing the entire lens (instead of only decentering the optical centre *in* the lens), but, on the other hand, such displacing entails, beyond certain limits, a limitation of the field of binocular fixation. It may therefore be laid down as a practical rule that the dislocation of the optical centre should be effected by displacing the whole lens, rim and all, as much as can be done without interfering with the field of binocular fixation,* leaving only the remainder (should any more be required) to be obtained by decentration proper, that is by decentering the lens *in* its rim.

* *i.e.* The range of lateral binocular vision.

To take an example, let us suppose it is desired to prescribe spectacles such that each optical centre is 10 mm. nearer to the middle line than the centre of the eye, and we have found by the localiser that the centre of each eye is 32 mm. from the median (sagittal) plane. The effect of limitation of the field of binocular fixation must be considered for each case, for its inconvenience or otherwise depends on the distance of the patient's occupation; but, say that on consideration, 5 mm. of *displacing* for each lens is all that is advisable; that will make each geometrical centre 27 mm. from the middle line, and leave 5 mm. for *decentering*.

In prescribing the spectacles, therefore, some such form as the following would be used.

	R.	L.
Spherical.	+ 4 D	+ 4 D
Cylindrical.		
Geometrical centre.	27 mm	27 mm.
Decentration.	5 mm. inwards.	5 mm. inwards.

To make such a pair of lenses the optician *might* first make two larger lenses of +4 dioptres, and 10 mm. (*i.e.* twice the decentration) wider than the lenses required, which would then be cut out peripherically as in *Fig.* 23. But this would involve a serious waste of time and labour, since precisely the same result may be attained by the simpler plan of finding from Table III. the prismatic equivalent of the decentering, and then proceeding as he is accustomed to do when ordered to combine a prism of that *deviating* power, with a lens. He would cut the prism required, and then impart to its surfaces the required sphericity. Lest any confusion should arise here between the deviating and refracting angles it will be well to repeat, that the angle of refraction by which the two surfaces of a prism are separated, and by which the workman first cuts a prism, is twice the angle of deviation which is given in the table, and marked on the prismeters. In the example we have taken, in which lenses of +4 D are decentred 5 mm., a reference to Table III. shews that the prismatic equivalent is 1° 10′, but this being the deviating angle must be doubled to get the angle of refraction, which will therefore be 2° 20′. Two prisms, each with their plane surfaces at an angle of 2° 20′ will now be made, and a sphericity of + 4 D be given to each surface. Having thus shaped the decentred lenses, the workman would next place them in a frame made with the centre of each rim 27 mm. from the middle of the bridge. The effect of such a pair of spectacles on a patient with the centre of each pupil 32 mm. distant from the middle line, would be the same as if normal lenses of + 4 dioptres, each combined with a prism of 2° 18′d were placed exactly in front of the two eyes; as may be easily seen from the table; for 5 mm. of *decentering* + 5 mm. (*i.e.* 32 − 27) of *displacing*, give a total of 10 mm. for the alteration in position of the optical centre. Under the heading of 10 mm. in the table, opposite 4 D, is found the *combined* prismatic effect, viz. 2° 18′. With this, of course, the optician has nothing to do.

Though it was thought well in passing, to give an instance of how a decentred lens may be prescribed, a better plan will be to mention, not the decentering, but the prism equivalent to it. This will save the optician all calculation, with the attendant possibility of a mistake.

It will be a simple proceeding for the surgeon, after finding the total prismatic effect it is desirable to produce, to deduct from it the proportion to be attained by displacing and set down the rest in the form of a prism whose surfaces are to receive the needed sphericity. To take a varied illustration, we will suppose the lenses to be sphero-cylindrical. If the axis be vertical, the effect of a cylinder on convergence is precisely the same as that of a spherical lens of the same curvature, but with each departure from the vertical it acts like a weaker spherical lens till with axis horizontal its effect is *nil.* A lens, therefore, of + 3 D sph., + 2 D cyl. axis *vertical*, would affect convergence like a + 5 D sph. : with axis *horizontal* it would affect convergence like a + 3 D sph. Let us take for an example such lenses of + 3 D sph. and + 2 D cyl., axis vertical, the total effect on convergence being that of a spherical lens of + 5 D. Suppose it is wished to relieve the convergence of each eye by 2° for an occupation distance of 15 inches. It is decided, let us suppose, that 7 mm. of displacing can be allowed without interfering with the required field of fixation. But 2 mm. out of these 7 mm. must be deducted as useless for the purpose, since they only go to counteract the *excess* of convergence, which lenses placed precisely in front of the centres of the eyes would occasion in near vision, for it is clear that the lines of fixation would then traverse the lenses internal to their optical centres. With habitual vision for 15 inches, we have to allow 2 mm. for this reason, and with vision for 10 inches we have to allow 3 mm. since only if the lenses were 2 mm. or 3 mm. respectively, internal to the centre of the eyes, would they have no effect on convergence, for then only the visual axes would traverse the optical centres. This position therefore forms the zero, by departing from which in either direction the convergence is affected. To return to our example, after deducting these

2 mm., 5 mm. of *effective* displacing remain. By Table III. we find the prismatic equivalent of 5 mm. of displacing to be exactly 2°. This is all we desired, and there is therefore no need for decentering. Had it been desired to afford greater relief to convergence, say 4°, then the remaining 2° should be prescribed as prismatic combination. If the centre of each eye be 32 mm. from the middle line, then this, less the total 7 mm. of displacing, would make the geometrical centre 25 mm. from the middle of the bridge, and it would stand thus :—

	R.	L.
Spherical.	+ 3 D	+ 3 D
Cylindrical.	+ 2 D axis vert.	+ 2 D axis vert.
Geometrical centre.	25 mm.	25 mm.
Prismatic.	4° (2° d) edge out.	4° (2° d) edge out.

The optician should understand that the new marking is intended whenever the letter "d" is appended. In this case, therefore, he would cut two prisms, each with an angle of refraction of 4°, and impart to one surface a sphericity of + 3 D, and to the other a cylindricity of + 2 D, setting them in a frame with the centre of each rim 25 mm. from the middle of the bridge.

To relieve convergence, prisms should be "edge out;" while convex lenses should be displaced inwards, and concave lenses outwards.

To meet excessive convergence, prisms should be "edge in;" convex lenses displaced outwards (only slightly practicable owing to limitation of near binocular fixation), and concave lenses inwards. It is with strong lenses, such as those for aphakia and high myopia, that care in the position of the enses is of chief importance.

"Orthoscopic Spectacles" as described by Dr. Scheffler, have been so long known that they must not altogether escape mention. In these, accommodation and convergence are affected in equal amount. The two lenses have but one optical centre common to both, just as though they were cut from opposite edges of one large lens. The proof of their correct manufacture is that they throw a *single* distinct image of a flame upon a wall. They have generally been prescribed in a few standard strengths, but they can be made for any patient by combining with each of his lenses a prism, whose deviating angle is found in Table III., opposite the description of lens, and under the number of millimetres by which the optical centre of each eye is distant from the middle line. These spectacles undoubtedly may have their place, but it is better to ascertain the conditions of convergence in each case and prescribe accordingly, rather than to adhere to any fixed combinations.

Part III.—LOCALISATION.

LOCALISING THE EYES.

It will be at once evident from the preceding section, that it is impossible to prescribe spectacles of any kind with a view to produce a definite prismatic effect without first knowing the precise distance of the centre of each eye from the middle line, and in clinical work the need must have been often felt for a quick yet reliable objective test. Many subjective tests are in existence already for the purpose of telling, not the distance of *each* from the middle line, but the mutual distance between the centres of the two eyes, ("interocular" or "intercentral" distance); such as Smee's "visuometer" as used by Donders, Landolt's chiasmometer, Snellen's frame, or Dr. Johnstone's trial frame with the short tubes in the two discs. But an objective test is more desirable, and especially one for each eye, and though it is true that single points have already been placed before each pupil, such as, for example, the intersection of cross wires, with a view to obtain this information, yet the very principle of such a *single* "sight" or "bearing" is fallacious. It affords no guide or guarantee for the position of the observing eye, which is therefore left to guess-work. For a test to be true in principle, not only must the visual lines of the observing and observed eye coincide, but the line so composed must be exactly at right angles to the line uniting the centres of the two eyes, or at least if one eye be examined with any angle of inclination, the inclination must be the same in the examination of the other.* It need hardly be said that this cannot be ensured when only a single point is used for a bearing. To overcome this difficulty the writer has had a little device made (*Fig.* 25), with two sights

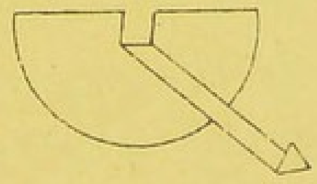

Fig. 25.

so disposed as to always be in a line at right angles to any trial-frame in which it is placed. One pupil is localised at a time, all that is

* On the principle of the parallelogram.

necessary being to increase or diminish the breadth of the frame till the two sights and the centre of the pupil are in line as in *Fig.* 26; the patient meanwhile is bidden to be

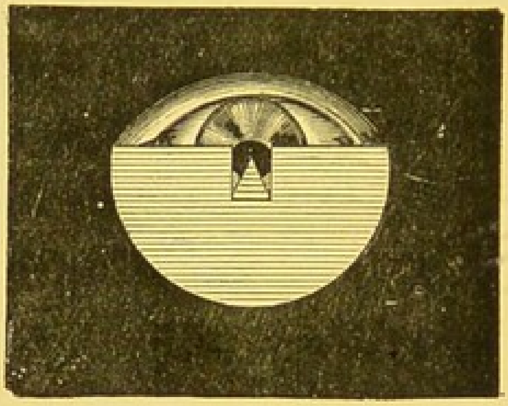

Fig. 26.

looking at the pupil of the surgeon's observing eye, by doing which the two visual lines (*i.e.*, that of the observing and that of the observed eye), come to practically coincide. If the patient is a child it is quite easy to excite its interest in its own miniature reflection in the surgeon's pupil while taking the observation, adeptness in which needs a few trials to become familiar with the parallactic motion. The instrument is then placed in the other rim of the frame, and the observation repeated for the other eye.

By this method we comply with the two afore-named conditions of accuracy; the visual lines of the observing and observed eyes coincide, and of necessity they are both at right angles to the trial-frame. The frame must of course be one movable by a screw, and marked in millimetres, so that the record can be read off after localising each pupil. The distance of the centre of each eye from the middle line is in each case *half* what is registered by the frame. It is true that the present methods are considered sufficiently exact for practical purposes, but there is, nevertheless, a pleasure in working on correct principles, and a number of small inaccuracies in the different steps of testing and prescribing may amount together to a considerable error. The frequent and careful use of this principle will shew how many an unsuspected difference exists in the position of the two eyes, and will train the surgeon who uses it to a quicker appreciation of asymmetry and its amount. When ordinary spectacles are prescribed for eyes placed unsymmetrically, the prismatic effect is greater for one than the other, which may (or may not) be deleterious, or even advantageous, according to the nature of each case which, therefore, needs individual investigation.

Part IV.

ANALYSIS OF SPECTACLES.

So far we have dealt with the synthetical part of our subject, how to combine lenses and (virtual) prisms. The analytical part must now be considered. When a patient comes to us with a pair of spectacles already in use, but which cause discomfort, how are we to analyse their prismatic effect, and find how the glasses are centred ? One thing is clear, that we must set ourselves to discover with all possible accuracy the cause of the discomfort. It *may* be due to the irritability of the patient's nervous apparatus, but before deciding this we must exclude the other alternative, that the spectacles are not the best in every way that could be given. The focal length of the lenses is easily determined by the plans given on page 16. The next thing is to measure the distance between their optical centres, or, preferably, the distance of each from the centre of the bridge, and this may be done in several ways. If sunlight is procurable the spectacles may be held at their focal distance from a card exactly parallel to the two lenses, then the distance between corresponding points of the two spots of light on the card gives the required distance between the optical centres. If artificial light be used, the distance between the spots of light (more strictly, between corresponding points in them), must be multipled by the distance of the light from the spectacles, and divided by that of the light from the card. In this experiment care must be taken that the light and the bridge of the spectacles are in a line perpendicular to the lenses and the card. A modification of the Phakometer could easily be adapted for this purpose. But inconvenience attaches to the use of either direct sunlight or artificial light, and if they can be dispensed with the better. *Fig.* 27 illustrates

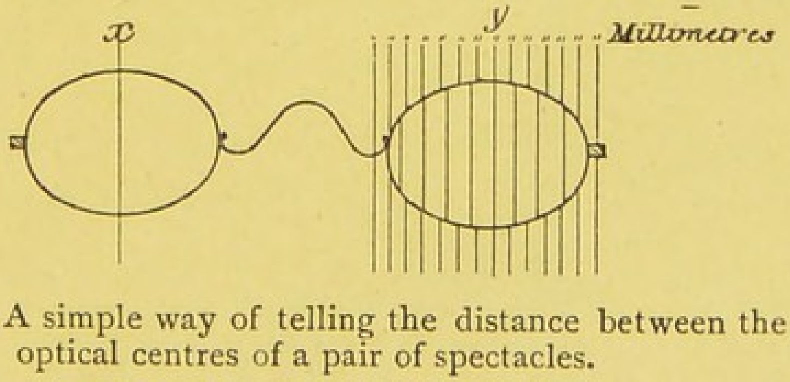

Fig. 27. A simple way of telling the distance between the optical centres of a pair of spectacles.

a rough mode of telling the distance between the optical centres. The spectacles are held horizontally, and some inches above a card marked to one side with a vertical line *x*, and towards the other side with parallel lines *y*, at different measured distances from the single one. The observer, holding his left eye about a foot above, and as nearly vertically over the left lens as he can judge, closes the right eye, and moves the spectacle frame from side to side till the line *x*, appears unbroken by the left lens. Now, without moving the head, the right eye is opened and the left closed, and that line which appears to be least displaced by the right lens is the line nearest its optical centre, and the number above it furnishes a rough estimate of the required distance between the two optical centres. To ascertain whether each optical centre is midway between the upper and lower border of its rim, each lens must be held lengthwise over the left hand line till it appears to run continuously. The principle (though not new) of this test is so simple, yet its imperfections so many,* that I have

* Besides its want of accuracy, it only gives the mutual distance between the optical centres, and not the distance of each from the middle of the bridge, and it is not available when the optical centre lies outside the lens.

constructed an "Analyser" to secure the former, without the latter; it is shewn in *Fig.* 28. The two essential conditions are that the lenses should be parallel

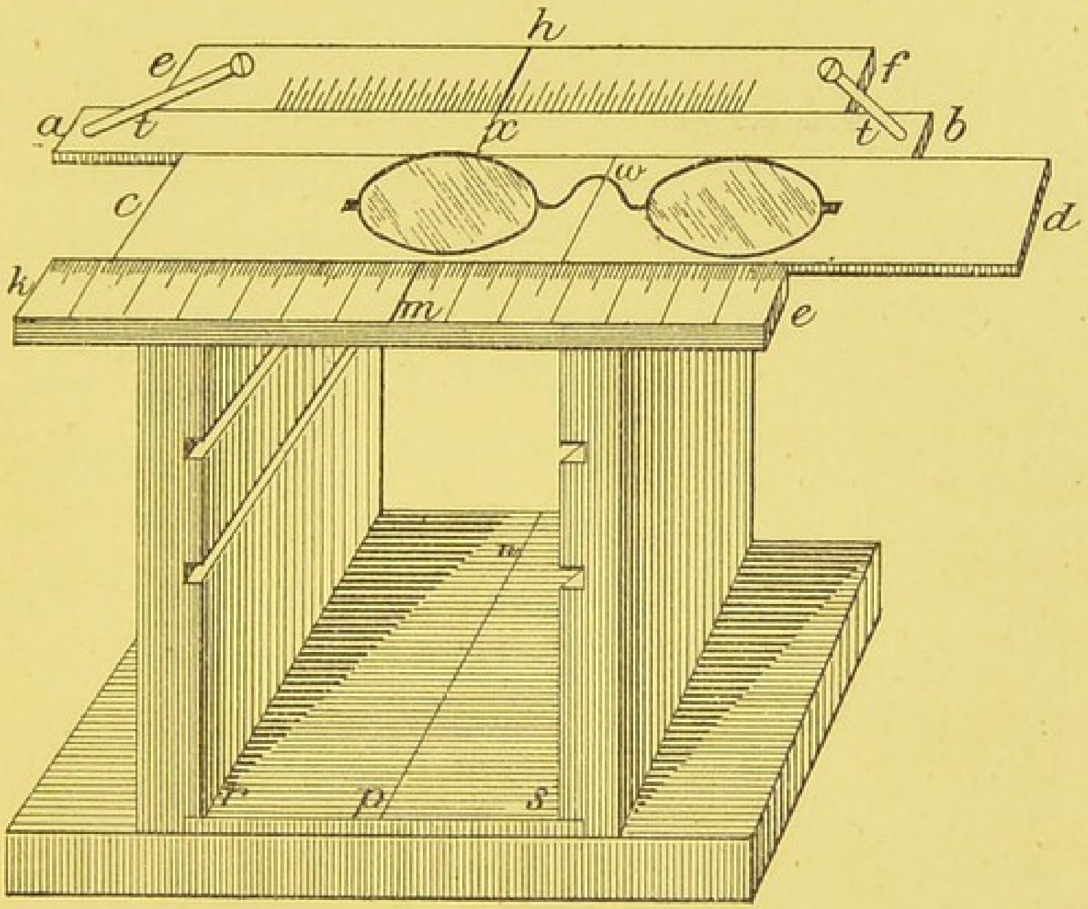

Fig. 28. The first form of analyser.

to the card, and that the line of vision in looking through each lens should be exactly vertical. The first is secured by laying the spectacles on the plate of glass *c d* which is movable from side to side; and the second by keeping the eye so that the line *x* is maintained in apparent coincidence with the line *n p*. The letters *a b* indicate the narrower strip, also movable, marked exactly across the middle, with a transverse line *x*. On either side of the slides is a millimetre scale with the zero in the centre. The broad slide has a long line *w* right across it opposite the zero of its scale. The *card r s* has only one line upon it, exactly beneath the central lines of the glass strips, and it can be placed either in the bottom of the apparatus as as in the figure, or in the grooves higher up, for lenses whose focal length is shorter than the height of the glass plates above the lowest grooves. The card is generally used in its lowest position, because distance of the line upon it from the lenses, as we have already seen with prisms, magnifies the phenomenon, and makes the experiment more delicate. The height of the upper surface of the glass plates from the card in the lowest grooves is about $4\frac{1}{2}$ inches.

To analyse a pair of spectacles, lay the centre of the bridge on the line *w*, and place the observing eye so that the lines *x* and *n p* appear to coincide. Now move the broad slide bearing the spectacles till the line *n p* appears undeviating through one lens; then *w* points to the distance between the optical centre of that lens and the centre of the bridge. Repeat in the same way for the other lens.

The *geometrical* measurements, as for the breadth of frame and the rims, are made by laying the spectacles still lengthwise, but half on the broad slide and half on the narrow. By keeping the line *x* at zero, and placing any required point of the spectacles over it, then drawing out the line *w* to the other point, the latter line indicates the required distance, on the scale *k e*. It is well to have the narrow strip fixed by strong pieces of watch spring *t t*, like those for microscope slides, or by a little screw at one corner of the frame.

Lastly, by laying the geometrical centre of a lens opposite the zero of the scale *k e*, the line *n p* will, if it be a decentered lens, appear displaced through it. How great is the apparent displacement? By answering this we tell the prismatic equivalent of the decentering without recourse to any table.

We must use another sight* fixed to the narrow slide perpendicularly beneath its line *x*, then by holding the eye so as to keep them both in apparent coincidence (thus ensuring a vertical line of vision) and moving them till they appear exactly abreast of the apparent displacement of the line *n p* as seen through the lens, the prismatic equivalent of the decentering is indicated by the degree on the scale *e f* to which *x* points. The special applicability of this mode is when the optical centre lies outside the lens. The principle would, of course, be the same if instead of moving the glass slide, the analyser were so made as to let the card at the foot be moved alongside a metric scale. When the lenses under test are of shorter focal distance than the height of the analyser, the card must be placed in one of the other two pairs of grooves : then, though the use of the scale *k e* is unchanged, it must be remembered that when the card is in the grooves half way up, each figure in the scale *e f* must be multiplied

* Another way is to use a plane mirror instead of the card *r s* and keep the line *x* in line with its reflection—a little difficult sometimes.

by two, and when the card is in the highest grooves, as for cataract lenses, each must be multiplied by four.*

ANOTHER FORM OF ANALYSER.—The instrument already described is, perhaps, most appropriate for surgeons, since no artificial light is needed, and it is small and portable. For opticians, however, who use large numbers of spectacles and wish to classify them, another kind is recommended, which permits both the focal length and the position of the optical centres to be tested at one and the same time.

A plan of it is shewn in *Fig.* 29. Upon a horizontal strip of wood *k l*, is fixed an equatorial portion of a large lens (preferably plano-convex, as in *Fig.* 31, to lessen spherical

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*For the guidance of opticians it may be said that the scale *e f* can be marked either in millimetres or in degrees; if the latter then the height of the lenses above the card must be 53·3 mm. or some multiple of that number, for the degrees to be one millimetre from each other, or some multiple of a millimetre. But if marked in millimetres the height of the lenses above the card should be 100 mm., so that by a table of tangents affixed to the analyser the degree can be found. This is the most exact method, especially for strongly prismatic lenses, but being rather less simple is not mentioned in the text.

aberration). *Fig. 30* represents in miniature how this rectangular piece is cut from the

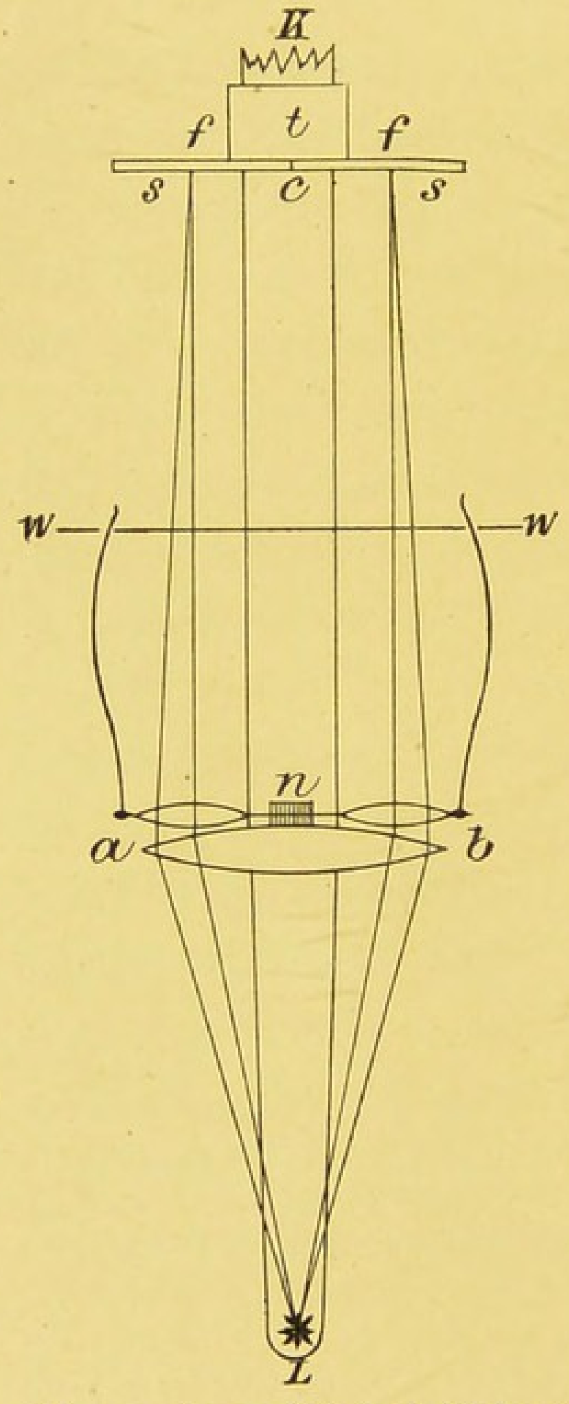

Fig. 29.—Second kind of Analyser.

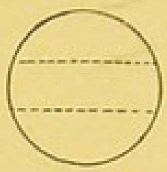

Fig. 30.—A lens, with the equatorial zone marked by dotted lines.

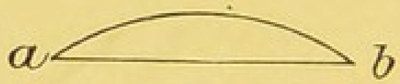

Fig. 31.—Plano-convex lens.

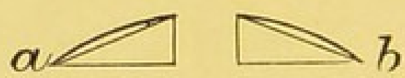

Fig. 32.—An Analyser made with a trial-frame.

equatorial band or zone of the large lens: it should be as long as the broadest spectacles used. At its focal distance is placed a flame *L*, so that parallel rays of light are thrown upon a screen *s s*, which is fixed to the traveller *t*, and is provided with a metric scale, running right and left from the central zero at *c*. A small wooden nose *n* is provided to support the bridge of the spectacles, and two wires *w w*, fixed to the under surface of the strip of wood, so as not to interfere with the movements of the traveller, support its limbs or temple-pieces. Two movable stenopæic slits, (in default of which, the large lens should be blackened except in two vertical stripes,) greatly increase the definition of the focal points *f f*, which indicate upon the metric scale the distance of each optical centre from the middle of the bridge. After laying a pair of spectacles in position, the traveller is moved till distinct images are thrown on the screen; then the dioptric strength or focal length is read off from the flat strip which is marked both in dioptres and inches, and the position of the optical centres is read off from the screen. *Fig.* 32 is to shew how a temporary style of the instrument can be made by placing in each side of a common adjustable trial-frame a lens in conjunction with a prism.* But rectangular reading glasses can often be obtained in shops, and the portions not to be used can be covered with asphalt or with black silk plaister.

THE EFFECT ON CONVERGENCE OF DISPLACED OR DECENTRED LENSES.

This study will cause embarrassment if allowed in any way to be confused with those of previous pages, and, perhaps, for that reason, the less said on it the better. It must be clearly borne in mind that the prismatic equivalent of decentering a lens, and the effect of that decentred lens on convergence

* The lenses chosen should have a focal length equal to the most convenient distance of the flame, then by Table II., prisms should be selected nearest to the strength indicated opposite the dioptric description of the lens in or near the columns headed by 28 mm. or 30 mm. After setting them in position with the apices of the prisms exactly outwards the final correction is made by adding to each couple a vertical stenopæic slit, and holding the whole combination exactly athwart direct sunlight, so as to throw two fine images upon a card held at the focal distance of the lenses. The trial-frame is then adjusted so that the two images exactly coincide. Their action now is the same as that of the large lens.

are two distinct things, though at first sight they appear the same. Suppose we decentre a lens, or what is the same thing, suppose we place a normally centred lens precisely before one eye and associate a prism with it. We might anticipate that the angle of deviation of this prism would exactly express the effect on convergence. But it is not so. *Fig.* 33,

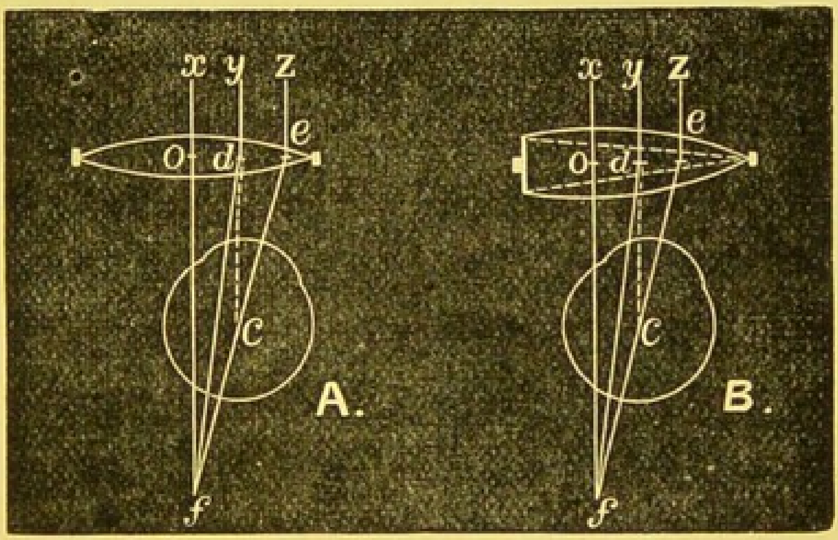

Fig. 33.—A. The right eye is looking at a distant object through a lens *displaced* inwards, *rim and all*, by a distance *o d*; *d c e* is the effect on convergence. B is the same eye looking through a lens of the same focal length, but *decentred in* its rim by the same distance *o d*. The dotted lines indicate the prism that would be equivalent to the decentering, and the effect on convergence is the same as with A.

B, represents a decentred lens, the action of which is precisely similar to a prism and lens, for, as said before, it is as if the lens were split in two, and the prism shewn in dotted outline were inserted between the two halves.

Now it will be evident at a glance, that the angle *c d f* is the deviating angle of the virtual prism, while the greater angle, *d c e* is that which represents the effect on convergence. It makes no difference to the effect on convergence whether a lens is decentred, or displaced to the same amount as in *Fig.* A.

There is one exception to the discrepancy between the prismatic equivalent and the effect on convergence, and that is when the lenses are *convex* and the object of fixation is at their focal length. Within that distance the effect on convergence is less, and beyond it more, than the prismatic equivalent. But with *concave* lenses it is always *less.*

Part V.

A BRIEF OUTLINE OF THE CHIEF CLINICAL APPLICATIONS OF PRISMS.

There are seven uses of prisms in the consulting room which may be described first; then five more uses as worn by patients will follow, making in all twelve clinical applications.* Prisms are—

A.—OF SERVICE IN THE CONSULTING ROOM.

1.—To measure *the absolute minimum of convergence* (r^c). This is generally a negative quantity, and then the minimum of convergence of the visual axes is identical with their maximum of divergence. Its measure is therefore taken by finding the strongest pair of prisms, with their edge outwards, compatible with single vision of some distant object, as

* In working with prisms, we are happily not concerned with the angle alpha, either in testing or prescribing.

shewn in *Fig.* 34. The *deviating* angle of

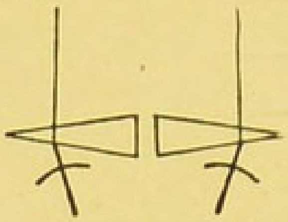

Fig. 34.—The absolute minimum of convergence.

each prism expresses the "absolute minimum of convergence" for each eye. The figure also makes clear that the visual axes meet behind the head during the experiment, and their point of intersection is still called "the far point of convergence," though its position is negative instead of positive. If a *single* prism be used, since its effect is distributed between the two eyes, its angle of deviation must be mentally halved for each. Remoteness of the point of fixation during the experiment is an important consideration if it is desired to reach the *absolute* minimum, for the knowledge of the object being at a great distance favours the evolution of diverging energy, and in normal eyes the sympathy of convergence with the very beginnings of accommodation (even for instance for six metres) is very great.* If

* Investigations, &c., Maddox, "Jour. Anal. & Phys.," Vol. XX., p. 574.

lenses are worn in the trial frame, for ametropia, of sufficient strength, the experiment can be made by separating them if concave, or approximating them if convex, till double vision occurs, and then the prismatic effect can be calculated from Table III.

Thus, if the distance between the optical centres of lenses of -4 D be increased till it is 16 mm. greater than the distance between the centres of motion of the eyes, we divide the 16 mm. between the two eyes, for clearly each lens is displaced 8 mm., and therefore by the table there is $1°50'$ of divergence for each eye, or just one metre angle. It is expressed by saying that the absolute minimum of convergence is $-1°50'$. Dr. Stevens finds that with vision for six metres, the normal power of the abducting muscles is measured by a prism of 8°, or, possibly, 9°. He first corrects any existing ametropia, but does not appear to calculate for the prismatic effect of the lenses during the experiment.—(Archives of Oph., June, 1888, p. 163.) Schweigger also gives 8° as the average strength of prism in *E.*, and quotes Schuurman as giving 5·6° as the average prism in *H.*, and

11·6° in *M.* In making this test with M, refraction should first be corrected, and the effect of the lenses on the direction of the visual lines calculated for by Table III. In *H.*, the test should be made both with and without lenses.

2.—To measure the *absolute maximum of convergence* (p^c). Find the strongest adducting prisms, as in *Fig.* 35, compatible with

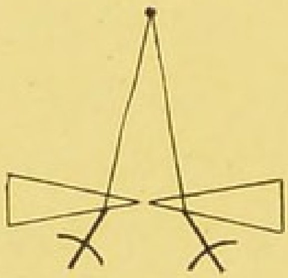

Fig. 35.—The absolute maximum of convergence.

single vision of a test type or printed page held as close to the eyes as accommodation will permit.

This test, though described for completeness, is not easily enough made with ordinary prisms to be much used, or to replace in practice the old established custom of advancing a finger towards the root of the nose till one eye deviates outwards, or the use of Dr. Landolt's Dynamometer in which the finger is replaced by a line of light. The two last tests, however, it may be suggested, do not give the "*absolute* maximum of convergence," for as soon as the point of fixation passes within the binocular near point of accommodation, diffusion circles appear on the retinæ, and increase rapidly in size with every approach till the eyes resign the impossible task of accommodation —then the ciliary muscle relaxes, and with it the convergence.

Just as in absolute hypermetropia, efforts of accommodation cease as soon as the impossibility of obtaining sufficient definition is realised. These tests discover only, I believe, the point of *the resignation of ciliary effort.* Even were the accommodative efforts to persist, it is scarcely to be expected that two pictures on their respective retinæ, each composed of a mass of diffusion circles, should excite the desire for fusion in its full strength, as clearly defined pictures would. At first sight the highest adducting prisms compatible with single vision of a test type held at the absolute near point of accommodation *would* seem to give the true "absolute maximum" of convergence; but here there is a new difficulty, for the chromatic dispersion of the prisms spoils the definition of the pictures on the retinæ, though truly it might be avoided by using a monochromatic light.* By adding the result of this test to the already ascertained "negative convergence," we get the "absolute range (amplitude) of convergence" (a^c), of which, according to Dr. Landolt, not more than one third or one fourth can be continuously in exercise for comfortable vision.

3.—To measure the "*relative range of convergence*" (a_1^c). For this we find the strongest pair of abducting prisms, as shewn

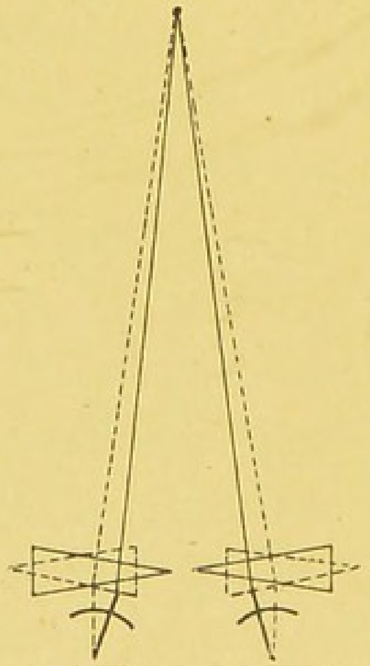

Fig. 36.—The relative range of convergence.

* Such light may be obtained of a pure yellow by placing common salt, or of a pure red by placing some salt of strontium, upon the wick of a spirit lamp of which the flame is kept steady by incombustible gauze.

in dotted outline in *Fig.* 36, and then the strongest pair of adducting prisms, as shewn in continuous outline, compatible with single distinct vision of an object or type at some chosen distance. The distance most suitable is that at which the patient's daily work is done (occupation distance), and for which spectacles are most required.

The abducting prisms measure the negative part of the range (r_1^c), and the adducting prisms its positive part (p_1^c). This test would probably be the most valuable of any, if the best ratio between the negative and positive parts were well worked out for different distances of vision; meanwhile it may be gathered in large part from *Fig.* 57 of Donders' "Anomalies, etc." At twelve inches, for instance, the subject of his experiments had a relative range of nearly seven metre angles, the negative and positive parts being equal. At eight inches the relative range is slightly greater, but its parts are still equal. At six inches the positive part exceeds the negative. For distances greater than twelve inches the chart is incomplete on the negative side, but the positive part is at 24 inches, 3 full metre angles, and at 72 inches about $2\frac{1}{2}$ metre angles.

Since the relations between convergence and accommodation become temporarily altered by prolonged efforts to overcome strong prisms, all observations should be taken as quickly as possible; hence the rectangular trial-frame of *Fig.* 20 would be better than an ordinary one, since no time is wasted in setting a prism.

The principle of "rotating prisms," as introduced in America some years ago, should be a valuable one;* but as I have not yet tried them, more cannot be said now.

In testing the ranges of convergence it is undoubtedly best to use *pairs* instead of single prisms; then the deviating angle of each gives the result for each eye. Should, however, a single prism be used, its deviating angle must be halved for each eye; and should the pair be an odd one, that is, with one prism stronger than the other, half the sum of their deviating angles must be taken for each eye. The prismatic relief found

* These prisms are cogged edge to edge so as to rotate, ne before each eye, in opposite directions at equal rates.

desirable to give by any of these plans would of course apply to each lens in the spectacle frame.

4.—To *dissociate convergence and accommodation.* This is done by placing a weak prism with its edge upwards or downwards before one eye. One of 4° (2°d) is generally strong enough to create vertical diplopia which cannot be overcome in distant vision; but for near vision, a stronger prism must be used. Graefe's was 15°.

In this way the stimulus to convergence is suppressed, and the eyes take that position, relatively to each other, which is due to the central association (in the nerve centres) between convergence and accommodation. Accommodation is in normal exercise and creates a definite proportion of associated or sympathetic convergence, which it is the purpose of the test to estimate. To give a simple illustration, we may compare the centres for convergence and accommodation to the two legs of a tuning fork; the slightest vibration in one provokes vibration in the other. It is a perfect instance of irradiation, which appears to be a necessary accompaniment of all nerve-cell energy, but which is here economically gathered into a mutual channel between two confederate functions which are always associated in daily work. If the two images in this test appear in the same vertical line, the associated convergence is just equal to the accommodation ; if they are not in the same vertical line the diplopia is of course either homonymous or heteronymous. In the former case convergence is in excess of accommodation, and we say there is " relative convergence" ; and in the latter there is a deficit of convergence, and we say there is " relative divergence."*

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* By an easy paper experiment communicated to the " Roy. Soc., Ed." (Proc. 1883-4, p. 433), for the author by Prof. Crum Brown, any one may convince himself that with dissociated distant vision some convergence of the visual axes is generally, though not always present. This was called "the initial convergence." With accommodation for nearer distances, "associated or accommodative convergence" is added to it till the "point of coincidence," where accommodation and convergence are abreast. For distances nearer than this there is generally relative divergence, which, after gradually reaching its maximum, again declines to a second point of coincidence near the near point of accommodation, and speedily gives way towards the absolute near point to relative convergence. These and kindred points will be found worked out in the "Jour. of Anat. and Phys.," vols. xx. and xxi, in papers already referred to. The results

The point of fixation may be, according to Von Graefe's suggestions, either a distant flame, or a vertical line with a dot situated upon it on a card. In the latter a fallacy has been shewn, from the fact that the reduplicated line still creates a desire for single vision of those portions which overlap.* When a light is made the point of fixation, a double prism, like that in *Fig.* 37, makes it much easier to detect the condition present

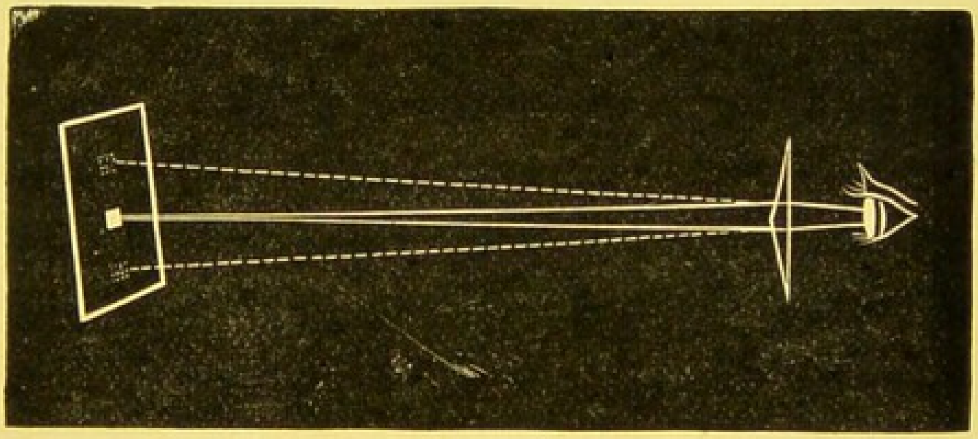

Fig. 37.—A double prism. From "Jour. Anat. & Phys.," Vol. XX., p. 496.

by observing whether the central image, which is seen by the unclad eye, appears to

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were obtained by the "visual camera"; and to obtain similar ones it is essential to employ a method of the same kind which takes note of the tiniest aberrations, and allows them full time to occur in a field entirely dark but for the two points of light.

* Noyes, "Treatise on Diseases of the Eye," New York, 1882, p. 88.

the right or left of the imaginary line between the other two, which are false images seen through the prism. The degree of deviation can be measured by finding the additional prism, edge in or out, required to bring the images into a vertical line, as suggested by Graefe ; or the first prism may be rotated till the images are vertical, and then from the strength of the prism and the degree of turning, a calculation can be made of the deviation.*

For near vision the double prism may also be used, as in the figure, or with a device marked on a card, which measures the deviation at the same time ; but I have come to prefer a single prism, mounted with its edge upwards on one end of a strip of wood along which a

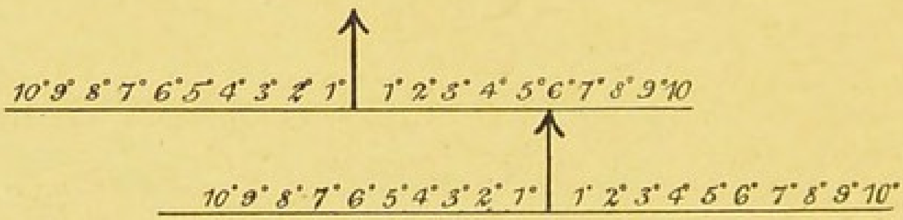

Fig. 38.—A metric device for a single prism. The lower row is marked on a card, and the upper is its false image.

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* The sine of the angle through which the false image was displaced, is the multiple of the sines of the angle through which the prism has been rotated, and the angle by which it deflects rays of light. Sin. x = sin. Δ sin. r.

traveller bears the same device, which now appears only doubled as in *Fig.* 38 instead of trebled. It is of course desirable to make this test at the occupation distance of different patients, and if the scales are marked in degrees or metre angles a different one is necessary for each distance; if marked in mm., and provided with an indicator capable of being lengthened or shortened, one is sufficient, but a calculation is necessary.

What is the due significance to attach to this test? It clearly does not decide the strength of one rectus, for convergence is a single function affecting both eyes equally. It is true that each rectus is a link in the chain of convergence, and *may* be the weak link, but that would shew itself best in testing the lateral movements of the eyes. Neither does it afford a pure test of the strength of convergence; for the converging innervation might respond in power to its *proper* stimulus and yet fall short of this test from its central communication with accommodation being abnormal or affected by disease. Neither does it entirely test the freedom of communication between the centres; for that might be perfect, and yet the test exhibit failure from some imperfect link in the chain of convergence. It really tests all in a joint way, so that its full value only comes out when it is made for both near and distant vision, and is conjoined with some of the previous tests to interpret the exact import of its revelations: the way in which these vary slightly according to the time of day, the state of the sympathetic system, and other conditions, has been described elsewhere.*

5.—To disclose any *tendency to vertical diplopia* (hyperphoria). Accommodation and convergence are dissociated for this purpose by a prism with its edge *outwards*, and slightly stronger than can be overcome—say one of 6°d. In this test especially, precision in the setting of the prism is essential, since imperfect setting can produce in a normal patient an apparent difference in the height of the two images. This is shewn in *Fig.* 13.

Interesting cases of latent vertical diplopia, with very successful correction, have been recorded by many, especially in America.

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* "Investigations," &c., J. A. P., vol. xx., p. 568.

In making the test, the object should be a flame at the distance of 6 metres, and the full prismatic correction should then be given.

Instead of a single prism, a double prism with its axis horizontal, like that in *Fig.* 37, may be used, and it is not difficult for the patient to tell whether the central of the three images is equi-distant between the other two. Better still is a stronger double prism with each refracting angle of 10°: this is used with its axis vertical instead of horizontal so that the three images appear in one horizontal line, and the patient is asked to say whether the central one is higher or lower than the line between the other two.

Yet a fourth, and perhaps easiest way of making the test is to use an ordinary stereoscope,* marked before one eye with a vertical line graduated in degrees up and down from a central zero point, and before the other eye with a horizontal line exactly level with the zero point just mentioned. On looking into the instrument, the horizontal line appears to

* "Ophthalmic Review," An Abstract, &c., Dec. 1886, p. 348.

lie across the vertical one; if it crosses it at zero there is shewn to be no tendency to vertical diplopia; but if otherwise, the latter is present, and its amount is expressed by the figure which the horizontal line crosses, and which the patient is asked to read off. The stereoscope must be held horizontally and with care.

All these are "diplopia tests," or "equilibrium tests," since they depend on the dissociation of the eyes by the artificial creation of diplopia. But Stevens has shewn the desirability in these cases of also finding the highest prism, edge up, compatible with single vision, and the highest prism, edge down.*

6.—Prisms have sometimes been used to measure strabismus, or to measure the degree of any existing diplopia, but for this they are useless.

Not so, however, when the purpose is to ascertain *by what proportion diplopia must be lessened* to place its entire correction just within the control of the innervation con-

* "Archives d'Ophthalmologie," XVI; 6; p. 544.

cerned in the preservation of single vision. It suffices to find the weakest prism, with its base-apex line parallel to the line between the two images, which enables single vision to be effected. The deviating angle of this prism informs us of the proportion of the diplopia which is *beyond* control, and when this proportion is deducted from the whole diplopia, the remainder is the proportion which can be brought *under* control. It is sometimes advisable to prescribe prisms just strong enough to bring the diplopia well under the control of "the fusion innervation" (as it is sometimes named) but no stronger, so as to exercise the neuro-motor mechanism till its strength is regained. Compare p. 41. For homonymous diplopia the edge of the prisms must be directed inwards, and for heteronymous (crossed) diplopia, outwards, or, in simpler words, "place its apex in the same direction as that in which the eye deviates; thus, if the eye turns outwards, the apex of the prism must be turned outwards; if the eye turns in, the apex must be inwards also."—(Juler).

7.—To decide *the presence of binocular* *vision.* The fact that a prism before an eye deflects the line of fixation has been turned to account by Graefe, in cases of suspected malingering, to see whether an eye *has such a thing* as a line of fixation, or in other words whether it is a seeing eye. The following is perhaps the fullest plan. After fixing the patient's attention, we may first place a strong prism, say of 30°, (edge in or out) before the *sound* eye. If, while doing this, the other betray no associated movement, vision is almost certainly binocular, for nothing but fixation could preserve it from accompanying the deflection of its fellow, except in paralytic cases. Should it move, however, nothing is proved beyond the expected fact that its fixation power is less perfect than that of the other.

The same prism is now similarly placed before the *doubtful* eye; if while doing so the other display an associated movement, vision is not only binocular, but the impugned eye is the best of the two, at least for the distance of vision employed at the time: but if there be no associated movement nothing is proved.

Lastly, on placing a prism of about 10°

before the doubtful eye, and *quickly* withdrawing the prism, we closely watch the eye from which it is taken ; for a corrective movement, if detected, at once tells us that its line of fixation has been deflected by the prism, and that it *has* therefore a line of fixation and is a seeing eye.

The subjective test, in which the patient's statements have to be relied on, is, for obvious reasons, often unsatisfactory, though it possesses the peculiar advantage of convincing a by-stander from the patient's own mouth, and of thus relieving the surgeon from the sole responsibility. It consists in placing a prism first before the unsound eye, and asking whether any object, preferably a flame, appears double. The reply is almost certainly negative. The prism is next placed before the sound eye, and the question repeated, "Do you now?" If incautious, the patient may admit that though he sees nothing with the bad eye, he sees double when the prism is held before the good one. A refinement has been introduced in America by first placing the edge of the prism partly over the pupil of the sound eye, to shew the patient that vision may be double with that eye alone, when the other is covered by the hand. A stereoscope, however, with a circle on one side, and a cross on the other; or Snellen's coloured test-types, afford better subjective tests than any with prisms.

B.—PRISMS MAY BE WORN IN SPECTACLES.

1.—To relieve any *strain between convergence and accommodation* (esophoria or exophoria). The existence and nature of the strain must, if possible, be first made out. An ideal investigation would include, after the usual study of accommodation: (1,) The total range and region of convergence; (2,) Its relative range, with vision for occupation distance; (3,) The effect of dissociating the two functions with both near and distant vision. But with present methods, to attempt all these makes too great a demand on time, except for a few cases in order to form a groundwork for others; and in general, those tests must be selected which are most suitable for the case. How, when refraction also needs correction, to apportion the desired relief between displacing on the one hand, and decentering or the addition of a prism on the other, has been shewn in the previous section on "Decentering of lenses." There is little to be gained from prisms stronger than 2°d.

Dr. Noyes' plan is to "first decide the proper working distance, and the correcting glass which for this point is required, and with it ascertain the muscular error," by dissociation, &c. He adds, "To give prisms equal to one half the amount of error is usually sufficient," and says, further, "We must sometimes order prisms for permanent wear, either with or without a refractive correction, and this is indicated when a muscular error has been detected in testing for the distance of 20 ft. Here the correction of weakness of the externi, or of vertical diplopia, is of the utmost importance, and the full correction must be prescribed. . . . . It is sometimes extraordinarily gratifying to see what relief is obtained by suitably-chosen glasses." What he terms "insufficiency of externi for distance, and of interni for near vision," implies, he says, general muscular weakness, and indicates constitutional treatment, and Dr. Dyer's "invigorant plan." This consists in giving the patient four squared prisms, of about $2\frac{1}{2}^{\circ}$, 5°, 10°, and 15° respectively: twice a day for ten minutes he is to fix a flame or door-knob at 20 ft., and exercise abduction and adduction (really relative divergence and convergence), beginning with the weakest prism, and mounting the ladder to the strongest. Dr. Noyes' following remarks are so apposite that we conclude this subject with them: "The true purpose of prisms for constant wear, or for working, is found in those cases in which the difficulty lies in want of balance between opposing groups by which one set predominates too much over the other, not in those cases where the muscular power as a whole is below standard. Weakness of all the muscles is seen in that tremor or jerkiness which the eyeballs show when fixed in some extreme position, or in the sudden jump which the globe makes on reaching a certain point, as the eyes follow the finger slowly from one side to the other. The jump comes when another combination of muscles is required by the change of fixation, and means that all do not conspire to an equable and smooth action."—(Noyes, *op. cit.*, p. 94.)

2.—To relieve any *tendency to vertical diplopia* (hyperphoria). The existence and amount of the latent diplopia may be determined by one of the methods on p. 88. Then a prism whose deviating angle equals, or nearly equals, the angle of diplopia may be ordered. Since the degree is generally small, it is not often worth while to distribute the correction between two prisms. If the image seen by the right eye appears highest, a prism should be worn before that eye with its edge downwards, just strong enough to bring the highest image to a level with the other; or the same prism with its edge upwards before the left eye would amount to the same thing.

Oblique tendencies (hyperesophoria and hyperexophoria) are best resolved into their component horizontal and vertical elements, to allow the first to be studied in connection with convergence, and the second to be studied independently; but instead of prescribing separately the required horizontal and vertical prisms, a single prism is to be ordered of such a strength and so intermediate in the direction of its apex as to have their combined effect. For formulæ, see p. 112.

3.—To *correct persistent and incurable diplopia*, if of sufficiently small degree. This is done by letting the patient wear a prism whose angle of deviation is equal to the angle of the diplopia, and whose edge is in a direction contrary to the displacement of that false image which is seen by the eye before which it is worn.

4.—To train the neuro-motor fusion-apparatus to *overcome by degrees a curable diplopia*, as in paralytic strabismus, or diphtheritic, or other pareses. Thus Donders wrote, "We may further, in paresis of a a muscle, so far meet the disease by means of a prism, that in order to make the double images which have been brought near one another run together, the muscles will become powerfully tense which, for the alleviation of the paresis, appears to be no matter of indifference".* If one rectus alone be paralysed, the prism should be worn before the eye of

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* "Anomalies," &c., p. 134.

that side, but if a conjugate innervation be affected, each eye should be supplied with a prism. In either case their strength should be such as to relieve that proportion of the diplopia which is beyond the control of the fusion function, but not strong enough to let the whole diplopia be overcome without a slight and harmless effort. At regular intervals the diplopia should be measured, to note its gradual decrease, and to order weaker prisms accordingly, which will still stimulate the paretic structures, till they regain control of the diplopia altogether, without the further need of prisms.

An undoubted difficulty in this treatment consists in the variations of the relative positions of the images in the different parts of the field of fixation. Schweigger seems to go a little too far in saying, "The correction of diplopia by prisms is indicated only when there exists secondary contraction of the antagonistic muscle, and, as a consequence of that, diplopia throughout the entire field of vision," and "the prisms should be chosen of such a strength as to correct only that part of the diplopia which is due to this contraction of the antagonist." —("Handbook of Ophthalmology," trans. by Farley, 1878.) See the Appendix, p. 110.

5.—To *relieve convergence for near work in some cases of short sight*, where it is impracticable to remove the occupation distance, by concave lenses alone, far enough to avoid excessive converging effort. But this application of prisms is very limited, owing to the weight, to the illusory properties, and to the chromatic aberration of the prismatic combinations. Any tendency to divergent strabismus would be aggravated by this method, and even without that tendency being noted, such spectacles should be very carefully guarded from any attempt to employ them in distant vision, even if necessary by surrounding the desk or other scene of work by a light screen at such a distance that the visual axes can never become divergent. For the same reason distant vision spectacles should have their optical centres no further apart than the centres of rotation of the eyes; otherwise they cause actual divergence of the axes, the muscular strain of which is perhaps as detrimental to the coats of the eyes as that of excessive convergence. I have seen a myopic patient, in whom spectacles prescribed by one of universally recognised skill caused discomfort for years, and were then improved upon by a pair selected at random by himself from a common store ; no doubt the refraction was perfect, but the optician had received no intimation of the position of the lenses, and for myopic *children* especially, spectacles are very apt to be too wide. In some patients, the movements of the elongated eyeballs are so hampered, that convergent strabismus appears in distant vision, and divergent strabismus in near vision. In such cases, if the two kinds of strabismus are not too extensive, the distant vision spectacles may well have their lenses decentred (not displaced) outwards, and those for near vision be displaced (and, if necessary, decentred also) inwards. Displacing is, for distant vision, less advantageous than decentering, since it interferes with the binocular field of fixation which it is here important to preserve. Schweigger says of prismatic spectacles for the muscular asthenopia of myopia that "They may be used with special advantage when it is possible to employ a working distance of at least 10 or 12 inches."—(*Op. cit.*, p. 172.)

There are other applications of prisms, such as to wear a pair with their edges inwards to enable hypermetropes to accommodate more easily (a sure way to develop convergent strabismus), and Culbertson's Prisoptometer, in which a double prism is used to reveal anomalies of refraction, but they need not detain us. Another interesting use of prisms is to make manifest the presence of what Dr. Stevens calls "habitual unconscious diplopia." The suppressed picture of a flame, as has been long known, becomes often manifest on placing a weak prism before the eye, even though it be in the direction of correcting the diplopia. In other directions, however, it *might* be acting by creating diplopia. Lastly, it may again be mentioned that prisms should never be prescribed without a fair preliminary trial.

APPENDIX.

Till attention was kindly called to it by Mr. Charles Wray, F.R.C.S., I was not acquainted with the work of Dr. Stevens of New York, whose thoughtful papers in the "Archives d'Ophthalmologie" (vi. 6), and the "Archives of Ophthalmology" (vols. xvi. and xvii.), well repay perusal. They deal with the subject of faulty tendencies of the ocular muscles, not so much from the optical standpoint, as with a view to afford surgical relief by a modified form of tenotomy. He has introduced a new nomenclature, as follows :—

I.—GENERIC TERMS.

Orthophoria.—Tendency of the visual lines to parallelism.

Heterophoria.—Tendency of these lines in some other direction.

II.—SPECIFIC TERMS.

Heterophoria can be divided into—

1.—*Esophoria.*—Tendency of the visual lines inward.

2.—*Exophoria.*—Tendency of the lines outward.

3.—*Hyperphoria* (*right* or *left*).—Tendency of the right or left visual line to place itself in a direction above that of the opposite side. "This term does not imply that the line alluded to is too high, but only higher than the other, without indicating which of the two is defective."

III.—COMPOUND TERMS.

Tendencies in oblique directions can be expressed in the following manner:—

1.—*Hyperesophoria.*—Tendency upward and inward.

2.—*Hyperexophoria.*—Tendency upward and outward. The designations *right* and *left* must be added to these terms. He says, "In registering the respective elements of these compound expressions, I employ the sign ∟. For example, if we wish to indicate that the right visual line tends above its partner by 3°, and that it has a tendency inward of 4°, these facts are inscribed as follows: Right hyperesophoria: 3° ∟ 4°."—

(" Archives d'Ophthalmologie," vi. 6, p. 542.) The *tendencies* of the visual lines thus classified must not be confused with actual *deviations*, as in strabismus. In strabismus, to which he gives the name of *heterotropia* (τροπος, a turning), there is habitual (conscious or unconscious) diplopia, but in *heterophoria* (φορος, a tending,) the visual lines only *tend* to deviate, and are restrained from doing so by extraordinary fusion effort, so that binocular vision is habitually maintained, but at the expense, often, of headaches and other nervous symptoms. These faulty tendencies are, in short, what have long been known as "dynamic (or potential) squint," (Von Graefe), or "latent squint" (Alfred Graefe).

Dr. Stevens retains the old expressions abduction and adduction in their usual sense, as representing the diverging and converging action of an eye, by which it overcomes a prism with its edge out and in respectively, and contributes the new term "sursumduction" for the overcoming of a prism with its edge up or down, and says, " It often happens that the images can be united when a prism is placed before an eye with its base up or down, but that diplopia occurs if the prism is inverted, or if it is placed in its first position before the other eye." The standard distance at which he makes his tests is 20 feet, with the head in the primary position, and any error of refraction corrected, though it does not appear whether the effect of the lenses is accounted for. He says, "The usual power of the abducting muscles in orthophoria is measured by a prism of about 8°, or, possibly, 9°," and of the adducting muscles by one of 50°, while the powers of sursumduction are normally measured by a prism of 3°. In manifest strabismus, diplopia is generally difficult to demonstrate, owing to habitual suppression of one of the images, but a red glass before one eye, or a weak prism, may make it evident.

Dr. Stevens believes that hyperphoria rarely exceeds 4°, and if any case appears an exception to this, hypertropia is to be suspected, and the suspicion is made almost a certainty if combined with it there is a lateral deviation of more than 6°. Esophoria of more than 10°, or exophoria of more than 8° is not likely to be found with maintenance of binocular vision. ("Archives of Ophth.," June, 1888, p. 163.) His experiments are made with an apparatus called a "Phorometer." It consists of a vertical standard, supported by a tripod, and adjustable for differences of stature. It bears a hinged arm, which may be horizontal, or be used at any inclination notified by a scale of degrees, or it may be folded down altogether. At the hinged extremity it is provided with a spirit level, and in a groove along its upper surface, carriers bearing prisms can either slide or be removed at will. Instead of simple rectangular prisms, two discs can be used, each consisting of six prisms united at their apices, so that on rotation, prisms of increasing strength come before the two visual apertures. A tablet, marked with a small cross on one side, and a larger one on the other, is held by a rod at the distance of half a metre from the prisms, or at any other desirable distance. He first places the patient in the primary position, 6 metres distant from a flame, with the ocular muscles relaxed, and any refractive anomaly corrected; and then tests for hyperphoria by a prism, edge out, stronger than can be overcome. If the two images are at different heights, hyperphoria is demonstrated and is measured by that prism which, with edge up or down, brings them to the same level. He next tests for esophoria or exophoria by a prism, edge up or down, too strong to be overcome, and measures the amount of deviation by the prism which, with edge in or out, makes the images vertical. Eyes, therefore, are characterised as eso- or exophoric, etc., when they are shewn to be so by tests made at the standard distance of 20 feet, and for the results of near-vision tests, Dr. Stevens proposes to speak of "exophoria *in accommodation*," etc., but this is scarcely precise enough, and it will be better to mention the exact distance of the test, and speak of exophoria at 20 feet, esophoria at 10 inches, and so on.

I have drawn up the following series of prismatic tests, for cases of suspected nerve trouble from heterophoria.

A.—WITH FLAME AT 20 FEET.

1.—With prism of 10°, edge out, or a stereoscope, test for hyperphoria (p. 88).

2.—With prism of 4°, edge up, test for esophoria or exophoria (p. 83).

3.—Find highest prism, edge out, compatible with single vision (p. 75).

4.—Find highest prism, edge in, compatible with single vision. (Rarely necessary.) (p. 106).

5.—Find highest prism, edge upwards, compatible with single vision (pp. 105, 106).

6.—Find highest prism, edge downwards, before the same eye, compatible with single vision (pp. 105, 106).

B.—WITH FIXATION FOR "OCCUPATION DISTANCE."

1.—Find highest pair of prisms, edge out, compatible with single vision (p. 80).

2.—Find highest pair of prisms, edge in, compatible with single vision (p. 81).

3.—With a prism of 10°, edge up, test for esophoria or exophoria at working distance, using a device to measure the amount, as in Fig. 38 (p. 86).

C.—WITH FIXATION FOR THE ABSOLUTE NEAR POINT OF ACCOMMODATION.

Find the highest prisms, edge in, compatible with single vision of test-types, or use Landolt's dynamometer (p. 78). (The usual "finger test," the "cover test," the lateral movements of the eyes, and the distance of each eye from the middle line, are observations which should not be omitted.)

As to prescribing prisms for recent paralytic strabismus, Dr. Noyes puts the matter well in the following quotation: "Double vision which concerns fixation 10° above, and for all the field below the horizontal meridian, or which concerns the median region of fixation, is the most distressing, and calls loudly for aid. The office of prisms is usually confined to these regions, namely, on the median line, or for parts on or below the horizon. In fact, to extend their influence over the whole field is impossible, because the relations of the double images become entirely different in its different parts, and it is impracticable to adapt the prisms to these changes."—(*Op. cit.*) Dr. Stevens makes an important observation to the effect that slight vertical tendencies (hyperphoria) may modify the adducting or abducting power considerably, and mentions cases in which marked esophoria in distant vision, and exophoria, or even diplopia, in near vision, disappeared after some co-existing hyperphoria had been remedied by a slight tenotomy. We have seen that Dr. Noyes had attributed these conditions to general weakness of the ocular muscles, and it is well to bear both causes in mind. Dr. Stevens finds that the whole of a faulty tendency is rarely revealed by a test with prisms, and that part still remains latent, which indeed might have been expected; and says that "instances of even approximate balancing of the eye muscles in anisometropia are rather exceptional," and also that hyperphoria is generally associated with monocular amblyopia, which he attributes to mental suppression of one image during occasional periods of diplopia. This reason appears scarcely valid, for however legitimate it may be to speak of "amblyopia ex anopsiā" in cases of complete and long-standing strabismus, we can scarcely suppose that intermittent diplopia could bring it about. Yet were the diplopia persistent, the case would not be one of hyperphoria, but of hypertropia. The cause is more probably to be found in the same unilateral defect of development as that to which the anisometropia and the hyperphoria itself are due. Dr. Stevens prefers to perform a very delicate tenotomy for cases of heterophoria rather than to prescribe prisms. Dr. Webster, following in his footsteps, also performs tenotomy, but only when all other means have failed and the nervous consequences of the anomaly are serious. He places the eye under the influence of cocaine, and tests the muscular equilibrium by prisms at intervals through the operation.—("Oph. Review," vii. 363).

An account of some ingenious devices for testing the conjugate tendencies of the eyes will be found in papers by Dr. Ward A. Holden, of Cincinnati, in the "Archives of Ophthalmology," Sept. 1887, p. 295, and Dec. 1887, p. 403.

Resultant Prisms, as recommended on p. 98, are prescribed as follows. Let R be the deviating angle of the prism required to combine the effects of a vertical and horizontal prism: let V be the deviating angle of the vertical prism, and H that of the horizontal one ; then $\text{Sin. R} = \sqrt{\text{Sin.}^2\text{ V} + \text{Sin.}^2\text{ H}}$; and if r be the angle of rotation from the vertical,

$$\text{Sin. } r = \frac{\text{Sin. H}}{\text{Sin. R}}.$$

We thus obtain both the strength and position of a prism whose effect will be the resultant of the other two, and an ordinary table of logarithmic sines makes the calculation a very brief one.

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