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THE STEREOSCOPE IN THEORY AND PRACTICE, ALSO A NEW PRECISION TYPE STEREOSCOPE

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ONE of the unfortunate aspects of stereoscopic investigation is that the practitioner is confronted with advanced optical principles and calculations which are not simplified or interpreted for practical adaptation. The stereoscope, because of generalities and ambiguities, has been made to appear, in spite of its increasing popularity, an undignified *modus operandi*. The author has attempted to interpret the optical principles underlying the use of the stereoscope so that the reader may better appreciate the operation and value of a calibrated stereoscope.

The considerations in this paper may be grouped under two main headings—theoretical and practical—as follows :—

1. THEORETICAL—STEREOSCOPIC OPTICS.

(a) *Perspective.*

Visual and Geometric Axes.

The Simple Stereoscope, and its Relation to the Visual and Geometric Axes.

(b) The Metre Angle and Convergence.

The Metre Angle in Stereoscopy.

- (c) Variations in Convergence induced by Ametropia in Relation to Stereoscopy.
- (d) Terms used to express Fusional Status with use of Stereoscope.
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Divergence Insufficiency. (Esophoria or Esotropia for far).

Perspective

In the fields of topography and art, perspective represents the projection of parallel rays to a vanishing point. In the field of ophthalmology perspective points to a condition identified with depth perception, but beyond this we find no attempt to analyse the basis for that phenomenon. A little reflection should reveal the folly of employing both terms synonymously. If by perspective we refer to angulation of parallel lines as registered by means of a lens on a ground glass, then a short-focus photographic lens should provide enhanced perspective. If by perspective we mean long-range three-dimensional stereo-power, then a long focus photographic lens or a binocular should fill these requirements, inasmuch as the stereo-power is directly proportional to the numerical magnification of the lens system employed.

For practical purposes, let us take the case of the railroad track and the subject standing midway with his eyes in the primary position and gazing into infinity. In relation to our eyes, the tracks diverge proximally and converge with distance (Fig. 1, 2, and 3). That the tracks are not parallel we call an optical illusion. If the tracks were endowed with eyes, they might say that our eyes

FIG. 1.

Eyes in primary position and their visual axes in relation to parallel railroad tracks which we shall call geometric axes. In relation to tracks, the eyes are in a state of relative convergence. In relation to visual axes tracks are in a state of relative divergence. Points O and O' represent juncture or vanishing points of both geometric and visual axes.

FIG. 2.

Theoretical representation of divergences of visual axes required to fuse images of tracks at variable distances. In actual state, parallelism represents the limit of divergence of the visual axes.

converge when they diverge; and that we diverge when they converge, even though our eyes are perfectly straight. We may regard this as a case of optical relativity. And so if we should reconstruct the visual projection lines in relation to the parallel tracks which to our senses appear convergent (for far), we have

FIG. 3.

Showing relation of visual and geometric axes as applied to stereoscope. S and S' represent apparent variable positions of a stereogram at and within infinity ranges respectively, but with their separations unaltered, in relation to visual axes OC and O'C'. Whereas the stereogram centres actually remain fixed when moved along the parallel axes OC and O'C' they appear distinctly divergent at S' (as in the case of the tracks), because of the relative convergence of the visual axes.

FIG. 4.

Illustrating the progressive convergences of the visual axes as applied to the stereoscope, but with the geometric axes (tracks) shifted to their actual state of parallelism.

(Disproportion in inter-ocular separations should be discounted). Whereas in the last diagram, the visual axes are represented as relatively convergent to the geometric axes, here we find them to correspond to their actual state—with the geometric and visual axes meeting only with the eyes directed for infinity as in last diagram. S1, S2, S3, S4 show the changeable positions which stereogram (and its central dots) would have to assume to meet the visual axes with changing accommodations. The lines CO and C'O' formed by joining these projection points we shall call the visual vergence axes.

a relationship such as is depicted in Fig. 4, in which our eyes would have to diverge considerably for near, and progressively less with receding distance in order to translate to our senses a parallel arrangement. This raises the interesting problem as to what arrangement the tracks would have to assume in order to appear parallel to our eyes when looking into infinity, but I shall not involve myself in such intricacies in this article, except to state that such projecting lines (of parallel tracks) imply gradations in the sizes of retinal images with receding distance.

If we could preserve the same size of retinal image with projection in space, then the element of converging lines is destroyed, even though other elements of depth perception such as light and shade and atmospheric haze will register in us an appreciation of stereoscopic sense.

Nor is this problem essentially a binocular one, for monocularly the same effect is registered by shifting one eye to either direction so as to emulate the divergence and convergence properties of binocular function. In either instance this shifting of the eyes to gauge distance through perspective we call parallax.

By juggling the two sets of lines so as to nullify the element of perspective or convergence in these railroad tracks to their state of actuality, and shifting the visual lines accordingly, we find our eyes in a state of relative convergence for near which diminishes with receding distance. By bearing this analogy in mind, it becomes easier to understand the phenomena associated with stereoscopic perception through a stereoscope.

A stereoscope in its simplest form consists of two lenses whose optical centres correspond to the average pupillary separation of, say 60 mm. and which are in direct geometrical relationship with the corresponding points on two split charts of a stereogram of equivalent separation. Whether we move the stereogram away from or towards the lenses will not alter the parallelism of the geometric axes. If now in place of, or in addition to these stereoscopic lenses we employ two human lenses (as in Fig. 4), we find their axial relationships to these pictures to vary as the charts are moved away from or towards the eyes, as in the case of the tracks. In other words, the visual axes and the geometrical axes do not correspond (except at infinity range), and, as will be shown later, this discordance between visual and geometric axes varies depending on the focal lengths of the lenses employed in the stereoscopic eyepiece, and on the viewing distance.

However, our eyes may converge or diverge, we are not usually mindful of these alterations in a subjective sense, but always think of positions of objects in space in relation to our own eyes which we unconsciously assume to be straight. If we should shift the visual axes back to a position of parallelism (as in Fig. 3), and move the geometric axes accordingly, we now observe that the geometric axes which were formerly parallel (Fig. 4), are now distinctly divergent (within infinity), in relation to the visual axes which have now been rendered parallel. This apparent divergence is most marked nearer to the eyes, and diminishes with receding distance. It also explains why two vertical lines on a stereogram that are readily fused at the far point of the corrected lens system, lose this power, and become distinctly and increasingly divergent when brought closer to the eyes.

The Metre Angle and Convergence

The term "metre angle" usually refers to the angle of convergence which each eye must bring into play when focusing on to a single point at a fixed distance from both eyes. It also may be represented as one-half the amount of deviation produced by both eyes. Whether the eyes be hyperopic or myopic does not matter so long as that fixed point is seen binocularly. We may also think of the metre-angle as the amount of convergence required to displace the visual axes of each eye from a position of parallelism

FIG. 5.

- A. Variations in amount of convergence required to displace visual axis of each eye through the same extent (30 mm.) at different viewing distances.
 B. Values of some of the multiples of the metre-angle corresponding to an inter-ocular distance of 60 mm. in terms of degrees and prism dioptres.

From W. S. Duke-Elder, "THE PRACTICE OF REFRACTION"

METRE ANGLES			DEGREES			PRISM DIOPTRIS (Approximate)	
1	...	...	1°	43'	15"	...	3'00
2	...	...	3°	26'	39"	...	6'00
3	...	...	5°	9'	82"	...	9'0
4	...	...	6°	53'	53"	...	12'0
5	...	...	8°	37'	62"	...	15'1
6	...	...	10°	22'	19"	...	18'2
7	...	...	12°	7'	34"	...	21'5
8	...	...	13°	53'	19"	...	24'8
9	...	...	15°	39'	86"	...	28
10	...	...	17°	27'	46"	...	31
11	...	...	19°	16'	13"	...	35
12	...	...	21°	6'	00"	...	38'5
13	...	...	22°	57'	27"	...	42'3
14	...	...	24°	54'	08"	...	46
15	...	...	26°	44'	62"	...	50
16	...	...	28°	41'	12"	...	54'5

to a medial axis; and for a pupillary separation of 60 mm. it would mean a convergence of each axis medially to the extent of 30 mm. As shown in Fig. 5, the number of metre-angles varies with the viewing distance. Also, variations in the amount of pupillary separation exercise slight but appreciable differences in the value of the metre-angle. The greater the separation, the greater the value of that angle, and *vice versa*.

In looking through a stereoscope, we determine aberrations of convergence in terms of prism dioptres (or metre-angles) not in relation to a single fixed central point, but through the incorporation of suitable plus spheres in relation to calculated projection points.

Variations in Convergence induced by Ametropia

Just as refractive errors are theoretically apt to alter the directions of the visual axes at infinity range, so may they induce characteristic changes within infinity range.

In hyperopia, we may theoretically expect a medial displacement of the visual vergence axes at all ranges (as compared to emmetropia) due to the superadded accommodative convergence. In actual practice, however, the results are variable.

In myopia, we may theoretically expect a lateral displacement of the visual vergence axes at all ranges (as compared to emmetropia) due to diminished accommodative effort. Here, too, the actual results often vary.

Terms used to express Fusional Status

If a Wells B2 or B3 Phoria or Dobson's Index chart be inserted in the stereoscope, say at infinity range, the eyes will select a line crossing or a numbered ball corresponding to the most comfortable position of both eyes at that range. If the subject chooses the No. 6 ball (60 mm. separation) corresponding to a like lenticular separation, we say that he is orthophoric for infinity in the primary position. We speak of this as the *selective or passive fusion*, inasmuch as it is effortless; for were the subject confronted with but two vertical lines or two balls at different separations, say 50 mm. or 70 mm., he would most likely fuse them too. In the latter instance we speak of *active fusion*.

The *phoria point* is the selective fusion point in relation to the calculated vergence points which the patient fuses. The calculated vergence point for infinity range corresponds to the primary position of the eyes, and if the subject selects the 60 mm. crossing with the Wells B3 chart, we say there is no phoria point. For further confirmation we may insert a base-down prism over either eye, and repeat the operation; and then after the eyes have come

to rest on a particular number, repeat our reading. If at that distance the patient selects the 30 mm. crossing, his phoria is 30 mm. less than his orthophoria (60 mm.), and by referring to the proper table we can express this esophoria in terms of a definite number of prism dioptres. If the 90 mm. crossing be selected, we may for the present state that there are 30 mm. of exophoria for far. The *tropia point* is an exaggerated phoria point, and may be represented as that amount of separation of a split stereogram which the eyes can approximate or superimpose.

A modified phoria chart may also be extended to include the testing of vertical phoria. In the absence of any hyperphoria, one would expect the arrow to cross the vertical rule at the "O" or horizontal level. If the horizontal rule crosses the vertical rule above the "O" it points to a left hyperphoria; if it crosses below the "O," to a right hyperphoria. These vertical displacements may then be translated in terms of prism dioptres of right or left hyperphoria.

The *range of fusion* (or fusional reserve or fusion amplitude) is, as its name implies, the range of linear separations of the split

FIG. 6.

Author's Modified Phoria Charts for fixed stereogram holders.

halves of a stereogram which the eyes can successfully fuse. If the extent of such fusion at infinity range be represented at from 50 mm. to 70 mm., we may for the present state that there are 20 mm. of fusion amplitude at that viewing distance.

As we bring the Wells B2 or B3 stereogram closer to the eyes, well within infinity range, we find that the emmetrope no longer selects the No. 6 (60 mm. separation) ball, but one of a lesser separation, say the No. 2 or No. 3 ball. This represents the positive convergence which the eyes automatically bring into play with accommodation, and must not be confused with the phoria point, but should be regarded as the normal selective fusional point for the particular range chosen. We term this the *relative normal fusional stereovergence* (or accommodative convergence), and forms part of the visual vergence axis (Fig. 4). And just as the phoria point is calculated in relation to the No. 6 ball at infinity range, so will the phoria point be determined in relation to, say No. 3 ball at a particular accommodative range.

Relative Normal Fusional Stereovergence

The relative normal stereovergence depends on :—

- (a) The position of the geometric axes.
 - (b) The strength of the viewing lenses.
 - (c) The viewing distance.
- (a) The geometric axes maintain their parallelism in the simple, non-prismatic stereoscope.
 - (b) The greater the strength of the plus lenses used in viewer, the less will be the accommodation and convergence (or visual vergence axis displacement) at a fixed distance, and *vice versa*.
 - (c) It has already been established that the selective fusion for near with a phoria chart will yield, say 30 mm. instead of 60 mm. separation. We are now in a position to calculate beforehand what separation (or No. ball) the emmetrope should select on the basis of the position of the geometric axes, the viewing distance, and also on the strength of the lenses used in viewer.

For our introductory study of relative normal fusional stereovergence, let us take the case of an emmetrope using a simple stereoscope with an inter-lenticular separation of 60 mm. From such an arrangement, we can base our calculations in relation to the parallel geometric axes, and to the midline (septal partition). To demonstrate the changeable normal accommodative vergences with such a simple arrangement, not only in relation to viewing distance, but also in relation to the dioptric strength of the lenses employed, the author presents three charts, representing the findings with plus 2 D., 3 D., and 5 D. lenses respectively. As may

FIG. 6A.—VISUAL VERGENCE CHART NO. 1. FOR PLUS 3D. SPHERES (33 cm. Focal Length).
INTER-LENTICULAR SEPARATION=60 mm. ORTHOPHORIC CALCULATIONS.
C O L U M N N U M B E R S.

-1- VIEWING DISTANCE	-2- DIOPTRIC OF ACCOMMOD. AND EQUIV. METRE EACH EYE	-3- DIOPTRIC OF ACCOMMOD. AND EQUIV. METRE EACH EYE	-4A- -4B- FUSIONAL STEREO- VERGENCE ONE EYE (Prism Dioptres)	-4A- -4B- FUSIONAL STEREO- VERGENCE BOTH EYES (Prism Dioptres)	-5- LINEAR VALUE OF 1 PRISM DIOPTRE	-6A- -6B- FUSIONAL STEREO- VERGENCE IN MM. FROM GEOM. AXIS	-7- WELLS B3 VISUAL AXIS SEPARATION	-8- WELLS B2 VISUAL BALL NO.	-9- DIVERGENCE TO USE NO. 6 BALL (Prism Dioptres)	-10- PRISM VALUE OF 1 MM.
10 cm.	7.	21.	42.	21.	1. mm.	9.	18.	2	42.	1.
11 cm.	6.1	18.3	36.6	20.1	1.1 "	9.9	19.8	2	36.6	.91
12 cm.	5.3	16.5	33.	19.8	1.2 "	10.2	20.4	2	33.	.83
13 cm.	4.7	14.1	28.2	18.3	1.3 "	11.7	23.4	2	28.2	.77
14 cm.	4.1	12.3	24.6	17.2	1.4 "	12.8	25.6	2-3	24.6	.71
15 cm.	3.7	11.1	22.2	16.5	1.5 "	13.5	27.	3	22.2	.67
16 cm.	3.2	9.6	19.2	15.5	1.6 "	14.5	29.	3	19.2	.625
17 cm.	2.9	8.7	17.4	14.8	1.7 "	15.2	30.4	3	17.4	.59
18 cm.	2.6	7.8	15.6	14.	1.8 "	16.	32.	3	15.6	.56
19 cm.	2.3	6.9	13.8	13.	1.9 "	17.	34.	3-4	13.8	.53
20 cm.	2.	6.	12.	12.	2.0 "	18.	36.	3-4	12.	.5
21 cm.	1.8	5.4	10.8	11.3	2.1 "	18.7	37.4	4	10.8	.48
22 cm.	1.5	4.5	9.	10.	2.2 "	20.	40.	4	9.	.445
23 cm.	1.3	4.	8.	9.2	2.3 "	20.8	41.6	4	8.	.435
24 cm.	1.2	3.6	7.2	8.5	2.4 "	21.5	43	4	7.2	.42
25 cm.	1.	3.	6.	7.5	2.5 "	22.5	45.	4-5	6.	.4
26 cm.	.85	2.55	5.1	6.6	2.6 "	23.4	46.8	4-5	5.1	.39
27 cm.	.71	2.13	4.26	5.8	2.7 "	24.2	48.4	5	4.26	.37
28 cm.	.57	1.71	3.42	4.8	2.8 "	25.2	50.4	5	3.42	.36
29 cm.	.44	1.32	2.64	4.	2.9 "	26.	52.	5	2.64	.345
30 cm.	.33	1.	2.	3.	3.0 "	27.	54.	5-6	2.	.333
31 cm.	.23	.7	1.4	2.2	3.1 "	27.8	55.6	5-6	1.4	.32
32 cm.	.13	.42	.84	1.34	3.2 "	28.7	57.4	6	.84	.31
33 cm.	0	0	0	0	3.3 "	30.	60.	6	0	.3

be expected, the far points for these different lens systems will vary; in the case of the 2 D., being 50 cm.; the 3 D. 33 cm. and with the 5 D., 20 cm.

The dots in this diagram are plotted according to column 6B of visual vergence chart (Fig. 6A). They also indicate the positions through which the stereogram centres would have to be shifted in relation to upper fixed rule to correspond to easiest fusion

FIG. 6B.

Explanatory diagram of visual vergence chart applied to author's stereoscope at viewing distance of 22 cm. using plus 3 D. spheres.

for these various viewing distances. By joining these numerous dots, we obtain a straight diagonal line which we shall call the *visual vergence axis*, which demarcates the zone of excessive convergence on one side, and the relative divergence (or accommodative convergence) on the other. As will be noted, the prismatic value for this excessive convergence remains constant irrespective of the viewing distance or its linear extent, for the displacement of the prism dioptre changes with distance. The

FIG. 6C.

Illustrating application of aforementioned visual vergence chart to stereoscopic readings.

range of relative divergence (or accommodative convergence), however, registers gradually increasing prismatic readings.

Note: If we were to reconstruct the visual vergence chart for plus 5 D. viewing lenses, the excessive convergence range would be increased to 30 prism dioptres with a 60 mm. interlenticular separation, and to 40 prism dioptres with an 80 mm. interlenticular separation. The excessive convergence range (for far) may be further increased to almost 70 prism dioptres by using plus 8 D. viewing lenses with an 80 mm. separation (Fig. 9).

FIG. 7.—VISUAL VERGENCE CHART NO. 2. FOR PLUS 2 D. SPHERES (50 cm. Focal Length).
INTER-LENTICULAR SEPARATION=60 mm. ORTHOPHORIC CALCULATIONS.
C O L U M N N U M B E R S.

-1- VIEWING DISTANCE	-2- DIOPTRIC OF ACCOMMOD. AND EQUIV. METRE-A EACH EYE	-3- DIOPTRIC OF ACCOMMOD. AND EQUIV. METRE-A EACH EYE	-4A- -4B- FUSIONAL STEREO- VERGENCE PRISM DIOPTRIC ONE EYE	-4A- -4B- FUSIONAL STEREO- VERGENCE PRISM DIOPTRIC BOTH EYES	-5- LINEAR VALUE OF 1 PRISM DIOPTRIC IN MM.	-6A- -6B- FUSIONAL STEREO- VERGENCE IN MM. FROM GROM. AXIS	-7- WELLS B3 VISUAL SEPARATION MM.	-8- WELLS B2 BALL NO.	-9- DIVERGENCE TO FUSE NO. 6 BALL PRISM DIOPTRIC	-10- PRISM VALUE OF 1 MM.
10 cm.	8	4.67	24'	48'	1'	24	12	1	48	1' Prism
15 cm.	3	3	14'	28'	1.5	21	18	2	28	.67 Dioptre
20 cm.	2	2	9'	18'	2'	18	12	2-3	18	.5
25 cm.	1.33	1.33	6'	12'	2.5	15	9	3	12	.4
30 cm.	.857	.857	4'	8'	3'	12	6	3-4	8	.33
35 cm.	.5	.5	2.55	5.1	3.5	9	4.2	4	5	.286
40 cm.	.22	.22	1.5	3	4'	6	48	5	3	.25
45 cm.	0	0	.66	1.32	4.5	3	54	5-6	1.2	.22
50 cm.			0	0	5.0	0	60	6	6	.2

FIG. 8.—VISUAL VERGENCE CHART NO. 3. FOR PLUS 5 D. SPHERES (20 cm. Focal Length).
INTER-LENTICULAR SEPARATION=60 mm. ORTHOPHORIC CALCULATIONS.

10 cm.	11 cm.	12 cm.	13 cm.	14 cm.	15 cm.	16 cm.	17 cm.	18 cm.	19 cm.	20 cm.
5'	4.9	3.3	2.7	2.1	1.67	1.25	.88	.555	.263	0
15'	12.27	10.1	8	6.3	5	3.75	2.65	1.67	.79	0
30'	24.5	20.2	16	12.6	10	7.50	5.3	3.35	1.58	0
15'	15'	13.53	12'	10.4	7.5	6'	4.5	3'	1.5	0
15'	16.5	18	19.6	21.2	22.5	24	25.5	27.2	28.5	30
30'	33	36	39	42	45	48	51	54	57	60
3	3	3-4	4	4	4-5	5	5	5-6	6	6
30'	24.5	20.2	18	12.6	10.1	7.5	5.3	3.35	1.58	0
1'	.91	.83	.77	.71	.67	.625	.59	.56	.53	.5

Each chart (visual vergence chart) is tabulated under the following headings (or column numbers):—

1. *Viewing distance.*
2. *Dioptres of accommodation* for viewing distance, or the calculated accommodation for that distance minus the dioptric strength of the lenses employed. For example, the accommodation at a distance of 10 cm. with plus 5 D. lenses in viewer would be 10 D. minus 5 D. or 5 dioptres.
3. *Equivalent metre-angles.*—Which has the same value as the calculated accommodation. It indicates the fusional or accommodative stereovergence.
4. *Prismatic equivalent or metre-angle reading.*—For a lenticular separation of 60 mm., one metre-angle is equivalent to three prism dioptres; for 70 mm., one metre-angle equals 3.5 prism dioptres; and for 80 mm., four prism dioptres.
5. *Lateral displacement per prism dioptre.*—While a prism dioptre indicates a lateral deflection of a ray to the extent of 1 cm. at a distance of 100 cm., it also means a proportionately decreasing displacement with decreasing distance. So that at 20 cm. the deviating effect would be 2 mm., and at 10 cm. only 1 mm. irrespective of the strength of the viewing lenses.
6. *Displacement of visual axis in relation to geometric axis and to midline.*—This is determined by multiplying the number of prism dioptres by the linear value of the prism dioptre for the particular range desired. By referring to visual vergence chart No. 1, we note that the fusional stereovergence for each eye at a range of 20 cm. is 6 prism dioptres (Col. 4A), which means that the visual axis of each eye has been displaced medially from each geometrical axis by 12 mm. (Col. 6A). And if we set our geometrical reading at 30 mm. from the midline, the pointer would fall 12 mm. medial to the 30 mm. line, or 18 mm. from the midline (Col. 6B).
7. *Separation of the visual axes* (Wells B3 reading).—If, in the above instance, the vergence reading for each eye is 18 mm. from the septum, then the visual axes are 36 mm. apart.
8. *Reading with Wells B2 chart.*—This roughly corresponds to the separation of the visual axes in millimetres.
9. *Divergence required to select the No. 6 ball.*—Or the amount required to nullify the accommodative convergence (as in Col. 4B).
10. *Prism value of 1 mm. displacement of visual axes for each eye.*—Transpose the reading in column 5.

Computation Problems

With the aid of visual vergence chart No. 1, we may ask ourselves such simple practical questions as :

1. How much accommodative convergence will the orthophoric find easiest at a distance of 16 cm.? Answer—19.2 prism dioptres (Col. 4B) with 3.2 D. accommodation.

2. How shall we set our split charts to correspond to such a convergence? Answer—each chart centre should be 14.5 mm. from septum (6B).

3. To what number ball with Wells B2 chart would normal fusional stereovergence correspond to at that distance? Answer—No. 3 ball.

4. If the patient selects the No. 2 ball with this arrangement of the stereoscope at (16 cm.), what would you conclude? Answer—that he has about 10 mm. of esophoria, or, according to column 10, $10 \times .62$ prism dioptres or 6.2 prism dioptres of esophoria for near. The Wells B2 is a very rough method of determining the approximate phoria. The Wells B3 with the horizontal rule calibrated in millimetres would be the desirable method of making our calibrations.

5. If the patient selected the No. 6 ball at that distance what would you conclude? Answer—that he has a convergence insufficiency to the amount of 18 prism dioptres (column 10, 30 mm. $\times .625$ or 18.75).

6. If he selected the 20 mm. crossing at the infinity range of the plus 3 D. viewing lenses? Answer—divergence insufficiency, equivalent to 60 minus 20 or 40 mm., or according to column 10, 12 prism dioptres ($40 \times .3$) of esophoria for far.

7. If he selected the 90 mm. crossing at infinity range with these lenses? Answer—divergence excess equal to the difference between 90 mm. and 60 mm. or 30 mm. By again consulting column 10 of said chart we derive a reading of 9 prism dioptres of exophoria for far ($30 \times .3$).

8. Supposing the patient is known to have 10 prism dioptres of exophoria at a distance of 20 cm., what would be the most comfortable inter-stereogram separation for such a divergence? Answer—At 20 cm. distance, the most comfortable inter-stereogram separation would be 36 mm. (Col. 7). Ten prism dioptres of exophoria would imply an additional separation of 2 mm. for each prism dioptre (Col. 5), or, 20 mm. in addition to the orthophoric 36 mm. reading, making a total of 56 mm.

9. How much excessive convergence would be required to fuse two upright pencils 20 mm. apart at a distance of 20 cm. with these lenses? Answer—according to column 7, the normal fusional stereovergence at that distance would correspond to a visual axes separation of 36 mm. The extra 16 mm. of convergence would amount to $16 \times .5$ or 8 prism dioptres of excessive convergence (Col. 10).

FIG. 9.—PRISMATIC EQUIVALENT CHART NO. 4.
Prismatic equivalent per unit displacement on movable rule.

Viewing Distance	DISPLACEMENT IN MILLIMETRES.							
	5 mm.	10 mm.	15 mm.	20 mm.	25 mm.	30 mm.	35 mm.	40 mm.
	PRISM DIOPETRES							
40 cm.	2·5	5	7·5	10	12·5	15	17·5	20
33 cm.	3	6	9	12	15	18	21	24
32 cm.	3·1	6·2	9·3	12·4	15·5	18·6	21·7	24·8
31 cm.	3·2	6·4	9·6	12·8	16	19·2	22·4	25·6
30 cm.	3·3	6·6	10	13	16·5	20	23	26
29 cm.	3·4	6·8	10·2	13·6	17	20·4	23·8	27·2
28 cm.	3·6	7·2	10·8	14·4	18	21·6	25·2	28·8
27 cm.	3·7	7·4	11·1	14·8	18·5	22·2	25·9	29·6
26 cm.	3·9	7·8	11·7	15·6	19·5	23·4	27·3	31·2
25 cm.	4	8	12	16	20	24	28	32
24 cm.	4·2	8·4	12·6	16·8	21	25·2	29·4	33·6
23 cm.	4·3	8·6	12·9	17·2	21·5	25·8	30·1	34·4
22 cm.	4·5	9	13·5	18	22·5	27	31·5	36
21 cm.	4·8	9·6	14·4	19·2	24	28·8	33·6	38·4
20 cm.	5	10	15	20	25	30	35	40
19 cm.	5·3	10·6	15·9	21·2	26·5	31·8	37·1	42·4
18 cm.	5·6	11·2	16·8	22·4	28	33·6	39·2	44·8
17 cm.	5·9	11·8	17·7	23·6	29·5	35·4	41·3	47·2
16 cm.	6·2	12·4	18·6	24·8	31	37·2	43·4	49·6
15 cm.	6·6	13	20	26·4	33	40	46	53
14 cm.	7·1	14·2	21·3	28·4	35·5	42·6	49·7	56·8
13 cm.	7·7	15·4	23	30·5	38	45·5	53	61
12 cm.	8·3	16·6	24·9	33·2	41·5	49·8	58·1	68·4
11 cm.	9·1	18·2	27·3	36·4	45·5	54·6	63·7	72·8
10 cm.	10	20	30	40	50	60	70	80

FIG. 10.

Comparative visual vergences with plus 2 D., 3 D., and 5 D. spheres respectively.

The Angle of View and the Field of View

The angle of view with the stereoscope is, as its name implies, the angle which the halved stereogram subtends on the eye. There are certain factors which govern the size of this angle :

1. The viewing distance.
2. Diameter of viewing lens.
3. Strength of viewing lens.
4. Conformations and restrictions offered by viewing frame.
5. Size of stereogram.
6. Lenticular Separation.

The viewing angle (for each eye) may in turn be subdivided into two component angles (Fig 11)—one nasal, and one temporal. Viewed monocularly these components may be said to be equal.

The field of view represents the area on the stereogram which can be perceived by the eye. It is obvious from a cursory inspection of Fig. 11 that as we bring the chart nearer to the eye, the area or field of view becomes proportionately less, even though the angle remains the same. The area may be represented as varying directly as the square of the distance from the eyes. For example, if at a distance of 10 cm. the area perceived be 9 sq. cm., then at a distance of 20 cm. it would be 36 sq. cm. From the standpoint of stereoscope diagnosis and precision, we are concerned with the linear range of view, or the distance between the lateral margins of the halved stereograms. By multiplying the two adjacent lengths we ascertain the field of view.

FIG. 11.

Angle of view in relation to field of view

FIG. 12.

Visual axes in relation to angle of view. At the infinity range for viewing lenses we should, in normal orthophoric state, expect the eyes to be in primary position—and with the Wells B2 chart to select the ball to correspond to such a normal state—in this instance, the No. 6 ball.

Within infinity range, the visual axes converge, and the orthophoric will select a smaller number ball corresponding to a lesser separation of these axes, in this case the No. 5 ball. We here observe two things:

First—The convergence of the visual axes bisects the stereogram into two unequal portions—a smaller nasal and a larger temporal. This is important in realizing that as we converge, the relative range of active convergence becomes less and less in proportion to the range of divergence.

Second—It serves to remind us that the field of view becomes progressively less as the viewing distance becomes less. On the other hand, this increasing limitation in lateral displacement is compensated for by the greater prismatic value of unit deviation with proximity.

The relation between the angle of view and the visual axis may be further clarified by referring to Figs. 11 and 12. In viewing a stereogram monocularly, if the subject selects the No. 6 ball (Wells B2) as the centre of the halved stereogram, that ball should normally remain centralized, however, we move the chart back or forth. When viewed binocularly the viewing angles as well as the visual axes appear to converge.

We can readily prove to our satisfaction that the field of view lessens with increasing proximity to the eyes by the following simple experiment:

Look through the stereoscope at, say, the Wells B2 chart with one eye closed, and note which number ball is at each periphery. Then draw chart closer and observe the peripheral balls gradually disappearing from view.

The angle of view (with stereoscope) may be enlarged by:

1. Increasing the diameter of viewing lenses.
2. Bringing the eyes nearer to the viewing lenses.
3. Reducing restrictions in viewing frame to a minimum.

The best that may be expected with such an arrangement as the above is to produce enlarged angles that overlap unless a suitable partition be inserted; but then we would find the angles to be considerably reduced. In order, therefore, to produce two enlarged independent stereoscopic viewing angles which shall not encroach on each other, we must resort to:

1. Insertion of base-out prisms (equivalent to decentering spheres outwards)—Fig. 13. With increasing prism strength, the

FIG. 13.—Showing method of increasing angle of view.

FIG. 13A.

Simple non-prismatic stereoscope. Visual axes parallel—small angle of view.

FIG. 13C.

By means of base-out prisms (or decentered spheres).

FIG. 13B.

Simple stereoscope—visual axes divergent—larger angle of view—impractical

FIG. 13D.

Effect of too strong base-out prisms—distortion.

angle of view may be progressively increased up to a certain limit, beyond which further increase leads to an annoying prismatic distortion as in Fig. 13D. In order to utilize successfully such an increasing angle, the reflecting principle must be employed through such means as :

separation?" A little reflection will assure the examiner that no attention need be paid to pupillary separation, but only to the interlenticular separation reading. A little study of Fig. 14 will help to explain why the pupillary reading is of no importance for purposes of stereoscopic study.

If we set the stereoscope to correspond to a pupillary separation of 60 mm. as in E^1 , it is readily conceivable that the visual axes assume a straight continuous course to strike the chart centre C^1 . But supposing with this stereoscopic arrangement we examine a subject whose pupillary separation is less, say 50 mm. as in E^2 , the eyes will still prefer an inter-stereogram separation of 60 mm. and the visual axis of one will still remain parallel with that of its fellow eye in order to see the chart centre C^1 projected to C^2 . Another way of expressing this compensating effect caused by this decentration of the viewing lenses would be to state that if we could conceive of a lens that had no prismatic effect in its peripheral portions, then the more narrowly separated eye E^2 would diverge in order to fuse chart centre C^1 , but by the interposition of a base-out prism, as in decentering the viewing lens outward, this divergent eye is made straight so as to require no effort to see chart centre C^1 projected straight ahead to C^2 . In the same way, the more widely separated eye E^3 would converge in order to fuse chart centre C^1 unless a base-in prism of sufficient strength were interposed to neutralize this convergent effect and cause its image to be projected straight ahead to C^3 . So that *whether we are dealing with a narrower or a wider pupillary separation, the eyes will remain straight provided the interlenticular separation corresponds to the inter-stereogram separation*. Any truly divergent or convergent effect of the eyes from the primary position will be induced by disturbing this lens-chart relationship (visual vergence points), such as through shifting of split charts or by adding prisms to that required to disturb ocular equilibrium. This leads us to think of a prismatic stereoscope not necessarily as one containing a prism but of one containing sufficient prism or its equivalent (through shifting of pictures) to upset the calculated parallelism of the visual axes for far, or its calibrated convergences with changing accommodations. And vice versa, it leads us to think of a simple stereoscope as one containing sufficient sphere or sphero-prism (as in decentration) to maintain such parallelism of the visual axes for infinity. Contrary to supposed notions, therefore, a Holmes stereoscope or the American Telebinocular, with its fixed stereograms, does not produce a convergent effect because of its decentered spheres (or equivalent added prisms) but merely serves to adapt them to pictures that are more widely separated than the average pupillary diameter.

For those who wish to think in terms of figures in order to clarify

this problem, let us insert, for example, plus 5 D. spheres in viewer, as in Fig. 8 which is calculated for an interlenticular separation of 60 mm. Given a subject with a pupillary separation of 50 mm., it is readily conceivable that such a combined decentration of 10 mm. for plus 5 D. spheres would be equivalent to a base-out prism of 5 dioptries, and by referring to Col. 5, we readily note that at infinity range (20 cm.) 5 prism dioptries would displace the visual axes medially by 5×2 or 10 mm. so as to make an interstereogram separation of 60 mm. appear best for that pupillary separation wearing decentered spheres. In the same way, we can prove to our satisfaction that for any range of accommodation such variations in pupillary separation have no bearing whatsoever on the lenticular separation provided the latter is determined in relation to its visual vergence or primary position points on the stereogram for the particular accommodative range chosen.

(h) APPARATUS CONVERGENCE.

One of the major criticisms to stereoscopic investigation has been what some have termed apparatus or psychic convergence to indicate an inevitable tendency to convergence with the stereoscope even though accommodation be completely relaxed with suitable plus spheres. And so, phoria readings obtained with the stereoscope have been discounted by some because they were made at such a close range.

Without involving myself in the question as to whether such a reading is or is not correct, we must admit that the accepted practice of determining phoria by inducing an amblyopia in one eye (with red glass) also cannot be proved to be thoroughly reliable. Whatever the merits of such a phoria reading with the stereoscope may be, the author is satisfied that apparatus proximity does not explain "apparatus convergence." This fact may be readily proved by respectively inserting lenses of long and short focal lengths in the viewer, and making readings at the same accommodative range, say at infinity. Whether the viewing distance be long or short, the phoria readings at the infinity planes of the respective viewing lenses will be the same.

If comparative studies be made of lateral phorias with the red glass and prism method, and then with the stereoscope, there will be differences in the phoria readings. Some instances of exophoria will register esophoria with the stereoscope; and vice versa, in fewer instances, cases of esophoria will indicate exophoria with the stereoscope. We cannot prove that such variations indicate error in one or the other method, but merely serve to show that apparatus or psychic convergence does not tell the story. It would be preferable to speak of stereoscopic esophoria or stereoscopic exophoria.

In one method, the phoria readings are determined in relation to a point source of light which is artificially broken into two lights; in another, both eyes are made to function independently through the interposition of a septum.

The phoria readings made with the stereoscope are sufficiently constant to serve as a basis for subsequent comparative studies. Phoria readings in themselves have not proved as significant to the author as duction readings; for by whatever method one employs, a good phoria with poor duction (either abduction or adduction) is far worse than a poor phoria with good duction.

And finally, apparatus convergence would suggest that the range of abduction obtained with the stereoscope or synoptophore would be distinctly less than with the prism divergence method. As a matter of fact, it compares quite favourably with any of the older routine methods.

Author's Phorometric Stereoscope

In describing this modified type of stereoscope, the writer is quite mindful of the splendid progress made in orthoptic instruments in recent years, especially in England. These developments in precision machines appear to have been confined to improving the amblyoscope rather than the stereoscope. And so we have the elaborate synoptophore, with its Maddox accommodative convergence test attachment which may be expected to perform admirably. The element of precision does not seem to have invaded in like manner the interpretation of stereoscopic readings. I have been at a loss in aiming to answer for myself such questions as I have advanced in the previous chapter (under Problems in Computation). Some of the questions may be enumerated as follows:

1. What interpretation are we to make with stereoscopic readings?
2. Can we translate the linear separation between charts at variable ranges with changing accommodations in terms of prism dioptres of convergence or divergence?
3. Can we measure the fusion reserve at any particular range with any fair degree of accuracy with the aid of the stereoscope?
4. Can we record with an improved stereoscope the visual status of an amblyopic eye, and determine from subsequent examinations the amount of improvement in that eye?
5. Can we determine the presence and amount of convergence excess and insufficiency; and divergence excess and insufficiency with the stereoscope?
6. Can we record the findings with a stereoscope as a basis of determining progress in the individual case?

Practically all these problems may be solved with the complete synoptophore, but in favour of an improved stereoscope there are:—

- (a) Simplicity of construction.
- (b) Dispenses with the use of auxiliary lenses for determining fusional status and fusional reserve at any desired accommodative range.
- (c) Accommodation convergence may be varied at will by merely varying viewing distance; also the infinity plane may be varied at will by inserting lenses of desired focal length.
- (d) Not only may transparencies be used, but also opaque paper prints, photographs, and solid objects. Moreover, by the use of adapters, different sizes of transparencies or opaque prints may be employed.
- (e) Offers the examiner a more ideal method for prescribing home training exercises with the stereoscope.

For excessive degrees of squint, the synoptophore may be expected to serve better, for there is a limit to the strength of prism that may be incorporated in the stereoscope without causing distortion.

While the ordinary stereoscope may be depended upon to serve the purposes of a home-training instrument, there is no element of precision in recording the status of the eyes before or after exercises. And the so-called professional stereoscope is but a glorified home-training stereoscope.

Rather than describe the detailed mechanical features of my stereoscope, it may be better to distinguish it from the already familiar Brewster or Holmes stereoscope to which it is as intimately related as the synoptophore is to Worth's original amblyoscope:

1. The viewing head of the familiar stereoscope has been replaced by a simple, sturdy trial frame with compartments for two sets of trial lenses as well as multiple spring-holders for the *free insertion of supplementary square prisms*. This frame may be readily adjustable to a *lenticular separation that could be varied* from 52 mm. to 90 mm. so as to be made to correspond to equivalent selective separations of the viewing boxes. The *lens holders are calibrated* to permit the study of plus or minus cyclophoria, as well as to indicate the position of a cylinder when an *ametropic correction be added in the frame*.

2. The connecting rod between the viewing boxes and the viewing head has been marked off in centimetres, and not in accommodation equivalents, so that the *examiner may feel free to employ whatever strength lenses he chooses* in the trial frame. The viewing distance may be readily varied by a rack and pinion screw

from 12 cm. to 40 cm. so as to permit flexibility in the choice of lenses for different requirements.

3. The viewing boxes or carriers are designed to receive *transparencies* and *solid objects as well as opaque prints*. Whereas in the familiar stereoscope fixed stereograms are in the main relied upon, in my instrument I employ split pictures which permit *flexibility in movement and control* in operation through a two-way thread device which shifts both boxes simultaneously by turning a handle which is conveniently placed within reach. The thread chosen is such that each complete turn of the handle moves each picture through a distance of 1 mm. Thus the operator is saved frequent inspections of the viewing scale.

4. For purposes of precision, the *position and lateral movements* of the split pictures or objects *may be readily noted* by means of an adjustable pointer which intersects two millimetre-rules: one that is fixed; and an upper one that moves with the movement of the boxes after its "O" position is set for the centre or selective point of whatever size picture is employed. *For testing vertical phorias and ductions, suitable adapters may be readily*

FIG. 15.

inserted and manipulated in relation to laterally placed vertical rules.

5. It offers both the examiner and his patient a *variety in the choice of stereoscopic material*. Due provision for pictures of five different sizes by the use of suitable adapters has been made— 45×45 mm.; 60×60 mm.; 75×75 mm.; 82×82 mm. (synoptophore slides); as well as an adapter which holds both the Sattler and Guibor split charts. The advantage of the smaller picture lies in its greater range of movement for both convergence and divergence. The larger picture is more appealing for its wider field of view. Moreover, the first three sizes were also chosen to correspond to the more popular-sized stereoscopic cameras so as to enable the examiner to make his own pictures, if he so desires.

6. Each picture is illuminated by an independent lighting unit which operates both the lamp on the top of the viewing for opaque prints as well as the lamp within the box for transparencies. By a simple turn of a switch the *light may be shifted* to one or to the other.

7. One of the shortcomings in most eye examining or training instruments has been that the doctor cannot see the patient's eyes follow the shifting of the pictures. This difficulty has been overcome in my instrument by the incorporation of a *tilted mirror*, whereby *inspection of the patient's eyes* can be made without the patient being conscious that he is being watched. It also obviates unnecessary manipulations by the examiner who faces both the mirror and the viewing boxes with its calibrations.

8. A *collapsible, automatically operating septum* consisting of two opaque cloth curtains extend forward from respective rollers behind each viewing box to be attached to the viewing frame and, at the same time, hug these carriers in such a manner as to guard against the leakage of stray light when separated. This septum may be released from its attachment when desired so as to enable the examiner to insert a *stereo-campimetric attachment* in a specially designed groove in front of the viewing boxes.

9. Appreciating the importance of recording the state of visual acuity in the presence of amblyopia, the author offers the suggestion of supplementing and even incorporating a photo-electric cell unit with the stereoscope, so that metre-readings may guide the observer in recording the condition of the eyes at successive sittings. The importance of such a unit may be understood when we realize that the brilliancy of any lamp does not remain constant; and that the density (light-transmitting or light-reflecting properties) of prints and transparencies vary within wide limits.

As to the deductions to be made with the photo-electric cell, the author has not yet carried out any experiments in relation to the stereoscope, but nevertheless feels convinced as to its ultimate value because of its successful application in collateral fields. For the present, however, we may state that with such an added feature we may wish to determine the minimal brightness required for the subject to note the details of a halved stereogram (as in amblyopia), and to record the metre-reading as the status of visual acuity at that sitting.

One of the shortcomings of the ordinary stereoscope is that it is not suitably adapted to excessive degrees of squint. Such a defect may be corrected to a considerable extent by removing all unnecessary barriers in the viewing frame, by providing a more flexible range to the viewing distance, and by the use of selective lenses in the viewer. Inasmuch as the unit displacement of the visual axis registers a greater prismatic effect for near, we may

adapt the stereoscope to more marked degrees of convergent squint with either lenses of short focal length (stronger plus lenses) for infinity, or lenses of longer focal length for accommodative ranges. If, for example, we choose plus 8 D. spheres in viewer for infinity range (12.5 cm.), the maximum convergence for far which could be accommodated at that range without the use of supplementary prisms would be equivalent to more than 60 prism dioptres. On the other hand, divergence could be carried to a considerably greater extent without the use of supplementary prisms.

Plan of Stereoscopic Investigation with a Phorometric Stereoscope

While a stereoscopic study *per se* can yield valuable information as to the binocular status of the eyes, a preliminary refractive, ocular, and routine muscle study will prove indispensable in evaluating the entire picture. A suggested procedure is as follows:

1. History—rule out hereditary factors; birth injuries; poliomyelitis; diphtheria; whooping cough; encephalitis; syphilis; previous operations; age of onset; general health; muscle exercises; headaches—worse for near work or far; blurring of vision; ocular pains; diplopia; head-tilting.

2. Vision—with and without glasses, including ametropic correction (note with or without cycloplegic).

3. Routine study of eyeball proper.

4. Introductory study of muscles.

(a) *Do eyes appear straight or crossed?* A screen or cover test usually done both at 20 feet and at 13 inches respectively will tell us whether the eyes remain stationary or move out (esophoria or -tropia) or in (exophoria or -tropia) when the cover is removed. If the eyes remain motionless in spite of an apparent deviation they would suggest a positive angle alpha if they gave the appearance of a divergence, and a negative angle alpha if they gave the appearance of a convergence. In either instance, the details are recorded, as well as noting whether the excursion on removal of the cover is slight or considerable. By such a record, the check up with the stereoscopic approach becomes more fascinating. The neutralization of the ocular movements by means of prisms as part of the screen test are not so essential and can be determined much more easily under the calibrated stereoscope.

(b) *If a squint is present, which is the fixing eye and which the squinting eye? Is the squint alternating or monocular, constant or periodic, intermittent or continuous?*

(c) If there is a true deviation, *what is the approximate measure in degrees?* The Hirschberg reflex method has appeared fairly satisfactory, although crude.

(d) Do the eyes converge well for near? *What is the near point of convergence?* There is no uniform method for determining the near point. Whatever method be employed, the author has found it more satisfactory for the subject to follow his own finger than a pencil or other material object, for instinctively it seems to hold the attention of the patient better.

(e) *Do the eyes move equally in the four oblique positions of gaze as well as to the right or left?* If there is a lagging or spasm of either eye in any of these six cardinal fields, what muscle appears to be at fault? For this, the time-honoured methods are resorted to.

For the study of the vertical phorias and vertical ductions, both for far and near, the author finds the stereoscope sufficiently dependable and convenient and precise to dispense with the usual clumsy method of inducing a diplopia with base-in prisms. In the same way, horizontal ductions determined by the familiar prism divergence (abduction) or prism convergence (adduction) tests are dispensed with because they can be measured far more satisfactorily with a calibrated stereoscope or synoptophore.

Before conducting operations with a phorometric or calibrated stereoscope, the examiner should decide upon :

(a) *What strength viewing lenses to select*—For cases suggesting a convergence excess (in-turning for near), lenses of long focal length operated at any selective accommodative range are preferable. For cases pointing to divergence insufficiency (in-turning for far), lenses of shorter focal length such as plus 6 D. or plus 8 D. adjusted to their respective infinity viewing distances are more desirable.

(b) *The Interlenticular Separation*—When a case suggests an in-turning of the eyes, a wider lenticular separation of, say, 80 mm. lends itself to greater degrees of convergence than one of lesser lenticular separation. For such an 80 mm. separation (40 mm. reading on lens frame), the corresponding setting of the split chart at 40 mm. on fixed rule (from septum) yields a primary position reading for infinity as a starting point for the medial shifting of pictures in the adduction phase, and for the lateral shifting in the abduction phase. If a uniform 60 mm. lenticular separation be employed it may necessitate the addition of more supplementary prisms (base-out) to correspond to the added convergence which would otherwise be effected by decentering the spheres outward.

(c) *Viewing Distances*—These depend upon the strength of lenses selected as well as upon the accommodative ranges at which we intend to carry out our tests.

For our introductory study of stereoscopic technique we may, for the present, *discount the above refinements and confine our attention to the more simple operations* of the instrument on the basis of the three afore-mentioned visual vergence charts calibrated for a lenticular separation of 60 mm.

For purposes of practical and ready investigation, Visual Vergence Chart No. 1 (using plus 3 D. spheres) may be reconstructed as follows:—

FIG. 16.
Reconstructed Visual Vergence Charts.

In the same way, the other visual vergence charts may be rearranged for ready reference.

With an elastic stereoscope which permits the free choice as well as separation of the viewing lenses, as well as calibrated shifting of the charts, a set of ready-reference cards may provide added interest and scope to our studies. Such charts may be readily calculated according to afore-mentioned directions for separations of 60 mm., 70 mm., and 80 mm. respectively; as well as for lenses of from plus 1 or 2 D. to plus 8 D. respectively. The author's stereoscope may, if desired, be used for accommodations as high as 8.5 D. without lenses in viewer, and for correspondingly lesser accommodations with spheres of gradually increasing strength.

With the above charts graphically illustrated, the examiner may next proceed to apply it to the particular problems which he wishes to solve. These may be listed in the form of questions as follows:

(a) *If the eyes are crossed, what is the apparent lateral deviation?* The patient fixes a black dot placed in one viewing box. The image of a narrow vertical luminous slit from the other carrier is made to centre on the cornea of the other eye, and reading is then made. Such test is then repeated with the opposite eye fixing the black dot, and the light slit shifted to the fellow eye. The tilted mirror proves indispensable in following the ocular movements.

(b) *Is there simultaneous perception of dissimilar pictures, or of those in which no fusion element is possible? Is the simultaneous perception macular or extra-macular? Is there suspension or suppression?* In cases of squint, unless marked, simultaneous perception is quite possible, but the images are projected falsely or extra-macularly.

FIG. 17.

Showing false projection in relation to stereoscope.

F.P. = False Projection. T.P. = True Projection or True Deviation. M. = Macula.

In cases of convergent squint, the images will be projected laterally (or homonymously) in relation to the actual deviation of the visual axes; in divergent squint, the images will be seen medially (or crossed).

(c) *Is there false or extra-macular projection?* For this test, two dissimilar small sources of light, such as a rounded hole from one carrier, and a lighted cross from the other are selected. After the subject has "fused" or approximated these two sources of light, the lights are alternately flashed, and the patient made to fix first the hole, and then the cross. If motion takes place in this alternate fixation, the projection is false. If the eye turns out to

see the corresponding image there is an esotropia, and the boxes are approximated until alternate flashing and fixation produces stopping of ocular excursion. The rule setting at which such motion stops tells us the amount of true projection or deviation. Here too, with the aid of the tilted mirror, the fine movements of the eyes may be clearly observed by the examiner.

(d) *What is the lateral phoria for far and for near?* In the afore-mentioned theoretical discussion, while the ruled lateral phoria card may be used to test lateral phorias both at infinity and for any selective accommodations, it can hardly hold the attention of the young child who requires a more fascinating and simpler method of approach. With the author's stereoscope and its shifting mechanical arrangement lateral phoria may be tested by the use of two pictures or objects in which no fusion element is possible, and with results that are quite comparable to that obtained with the phoria card.

The "Two-Dog Test" has proved especially gratifying in holding the attention of the young child who looks at two wooden dogs facing each other—one in each carrier—and is asked to tell the examiner when the noses just touch as these boxes are steadily brought together. The position of the movable or slide rule with its "O" beneath the dog's nose in relation to the lower fixed rule with the pointer at the calculated primary position indicates the amount of lateral phoria in millimetres, which is readily translated into prism dioptres of esophoria or exophoria. This test is repeated for any desired accommodative viewing range, the pointer again adjusted, for that viewing range, and the displacement of the movable rule is again interpreted.

For phoria readings with the phoria card, we make our computations according to the visual vergence chart we select.

(e) *What is the range of adduction and of abduction for far and for near? What is the amplitude of fusion?* If we can conceive of adduction as that amount of medial displacement of the split pictures from their primary setting without disturbing single binocular vision; or of abduction as the lateral displacement from the primary position, we can readily understand that the added value of these two displacements is the amplitude or range of fusion. The only additional point to bear in mind is that the primary position (or visual vergence point) does not remain stationary but shifts with changing accommodations.

For testing at infinity, adjust viewing distance and set pointer accordingly. Inasmuch as the range of fusion consists of two phases—adduction and abduction—we first aim to obtain the adduction reading by shifting the pictures medially from their primary setting, and supplementing, if necessary, by the addition of base-out prisms until diplopia results. The pictures are then

returned to the primary position from which we gradually and slowly shift the pictures laterally until there is another "break" in the image. This is our abduction reading in millimetres as measured by the displacement of the slide rule with its "O" beneath the chart centre in relation to the fixed rule with its pointer set at the primary position. Such reading is readily translated into prismatic equivalents by referring to the column at the right in Fig. 16.

For testing at any selective accommodative range, say at 3 dioptres, we set the pointer for that accommodation as outlined in Fig. 16 and repeat our operations both medially and laterally from this altered primary position.

(f) *Is there hyperphoria for far or for near?* The vertical phoria card is helpful, and displacements from the horizontal "O" can be readily translated in terms of prism dioptres of right or left hyperphoria.

In the author's instrument, with the aid of a vertically shifting adapter, it is possible to test vertical displacement of the eyes in hyperphoria and hypertropia both objectively by observing the alternate vertical movements of the eyes with the use of horizontal luminous slits in response to alternate flashing, or subjectively by having the patient level two horizontal lines or slits, and noting displacements, if any, on laterally placed rules. Here too, the tilted mirror proves very helpful.

(g) *What is the range of vertical duction for far and for near?* With a vertical adapter, the range through which two pictures can be made to maintain single binocular vision when shifted vertically is obtained.

(h) *What is the measurement of cyclophoria, if any, for near or far?* The lens frames are calibrated as shown in the illustration to permit the testing of plus and minus cyclophoria with the use of Maddox rods.

(i) *What is the range of cycloduction?* With the use of a calibrated revolving adapter for split pictures, minus and plus cycloduction may be recorded both for far and near.

(j) *What is the status of binocular vision?* This depends on the results of the above tests as well as the added testing with Grade 2 and Grade 3 stereoscopic slides.

For rapid charting, we may plot our readings as follows:

P. = Phoria point. Add. = Adduction. Abd. = Abduction. F.A. = Fusion amplitude. F.P. = False projection. T.P. = True projection or deviation. C.R. = Corneal reflex.

The additional aforementioned tests are not so easily plotted on such a record card, and may therefore be summarized as the examiner sees fit.

The above record refers to a more simple type of case in which at infinity range there is an esophoria of 10 prism dioptres; adduction is 15 dioptres; and abduction, 10 dioptres—making a total of 25 prism dioptres for far. At the 3-dioptre accommodative viewing range, there is an esophoria of 3 prism dioptres in relation to the shifted primary position for that range; the adduction power is 30 dioptres; and the abduction, 20 dioptres, making a total fusion amplitude of 50 prism dioptres for near. The examiner notes at the left hand margin in the particular accommodative range he has selected for his readings.

The rulings on this record card indicate fusion status in terms of prism dioptres rather than in units of length, and may therefore be applied to any of the tables used; for, in the final analysis, no matter what lenses we employ, we are interested in the prismatic equivalents of the readings made.

The Stereoscope in Orthoptic Training

It has been established that the vergence readings (or the visual axes displacement) change with changing accommodations. In order, therefore, to determine the existence or the degree of muscle anomaly, we should first ascertain the normal vergence readings for the particular range of operation. Whatever the disturbances may be, the obvious aim is to train the eyes to fuse an inter-stereogram separation corresponding to the normal calculated vergence readings. Depending on the type of case with which we are dealing, it may mean a gradual lessening of this distance in one case; or a lengthening, if there be an excessive convergence tendency. To be more specific, let us aim to adapt the stereoscope to four well-defined muscle anomalies, as follows:—

1. CONVERGENCE EXCESS. (ESOPHORIA OR ESOTROPIA FOR NEAR).

Operate the stereoscope in the accommodative range. If plus 3 D. lenses are used at a distance of 16 cm., 3 dioptres of accommodational convergence are normally brought into play which according to visual vergence chart No. 1 (Col. 6) displaces each visual axis 15 mm. medially. So that convergence excess implies an added medial displacement that should be accurately noted according to aforementioned directions. After noting the convergence status, proceed very slowly and interruptedly by turning the handle so as to separate these two pictures, always aiming to maintain fusion. If there be a sudden break, approximate the

pictures, and start over again. Note the maximum amount of separation attained at that sitting, and translate this reading in terms of prism dioptres. Before instituting exercises, correct refractive disturbance. If hyperopia, fully correct; if myopia, undercorrect.

2. CONVERGENCE INSUFFICIENCY. (EXOPHORIA OR EXOTROPIA FOR NEAR).

First correct refractive disturbance—if myopia, fully correct; if hyperopia, undercorrect.

Operate stereoscope in the accommodative range, as above. After noting convergence deficiency status, proceed very slowly but in the reverse direction (from convergence excess), and gradually aim to train the eyes to fuse more closely separated pictures; also noting the optimal (least) separation attained at that sitting.

3. DIVERGENCE EXCESS. (EXOPHORIA OR EXOTROPIA FOR FAR).

If myopia, fully correct; if hyperopic, undercorrect.

Set the stereoscope for infinity range; then separate pictures beyond range of divergence, if possible and note on rule the limit of fusion in the divergence range. Then gradually bring the pictures together, and note the optimal (least) separation attained.

4. DIVERGENCE INSUFFICIENCY. (ESOPHORIA OR ESOTROPIA FOR FAR).

Set stereoscope for infinity range.

Exercise eyes to fuse increasingly separated pictures, each time noting the initial (least) and optimal (maximum) separations.

For supplementing home training with the stereoscope, the following details should be explained to the patient at each examination :—

1. Viewing distance—depending on muscle anomaly (as above).
2. Initial and optimal separations of charts to be measured with a millimetre rule and governed by findings of examiner.
3. Length and frequency of exercises-arbitrary.
4. Type of training material—for excessive convergences, the narrower separation limits the size of material.

- 5. Illumination of fusion material—being stronger for amblyopic eye.
- 6. Exercises should be carried out under refractive correction. A daily record by the patient should prove more interesting and valuable to both himself and to the examiner. The following is suggestive:—

DATE	VIEWING DISTANCE	TRAINING MATERIAL	INITIAL SEPARATION	OPTIMAL SEPARATION

Concluding Remarks

- 1. Stereoscopy, as ordinarily practised, is a vague undignified technique.
- 2. An appreciation of the underlying principles of stereoscopic optics is imperative in interpreting stereoscopic manipulations.
- 3. A fixed stereogram (with exception of a phoria card) is an unsatisfactory method of determining the fusion status or for orthoptic training.
- 4. The eyes cannot maintain the same inter-stereogram separation with change in viewing distance.
- 5. As the eyes converge with accommodation, the inter-stereogram separation must be made correspondingly less in order to maintain easy fusion.
- 6. A split stereogram which can be shifted to correspond to changing positions of visual axes with variable accommodations is the only practical method for stereoscopic study.
- 7. A stereogram with a separation fixed for infinity viewing range becomes relatively divergent when brought nearer to the eyes.
- 8. The variable convergences of the eyes with changing accommodations may be accurately calculated and applied to stereoscopic investigation.
- 9. A precision stereoscope enables the examiner to determine the convergence and divergence status in the primary phase both

at infinity and at any desired accommodative range; thus enabling the examiner to diagnose and to classify the type and degree of muscle anomaly; the range of fusion; the amount of phoria; and the progress in terms of prismatic vergence with each sitting.

10. The ordinary professional stereoscope, because of its cramped construction and lenses of fixed focal length, considerably reduces its adaptability to excessive convergence and divergence. The stereoscope, however, may be so modified as to be adaptable to fairly large degrees of ocular convergence by the use of widely separated lenses of selective short focal lengths and supplemented, if necessary, by suitable prisms.

11. Accurate records can be kept with a calibrated stereoscope, and further supplemented with the patient's home-training record for purposes of intelligent co-operation.

12. The incorporation of fixed base-out prisms, as in the ordinary stereoscope is not, as ordinarily supposed, a means of adapting the instrument to greater convergences—but a relic of bygone days for employing larger stereograms (greater field of view) for purposes of parlour entertainment. The addition of selective prisms should be left to the examiner who alone should be in a position to determine the need for supplementing base-in or base-out prisms.

13. The author's stereoscope enables the examiner to determine at a glance the amount of convergence or divergence, with selective accommodations, for fusing split pictures, by incorporating:—

- (a) Viewing lenses of variable separation and of known focal length.
 - (b) Movable calibrated rod.
 - (c) Viewing boxes calibrated to record amount of separation of split pictures, and,
 - (d) Tables to which examiner may refer so as readily to translate these vergence readings.
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