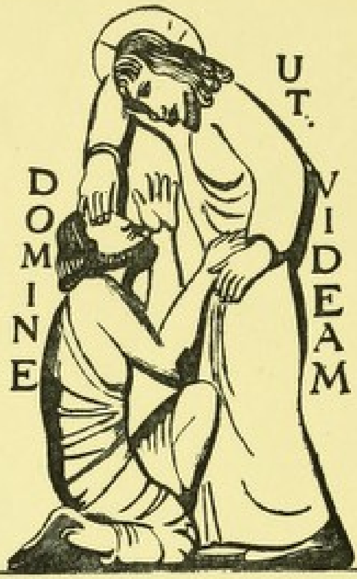
DISTURBANCES OF THE VISUAL FUNCTIONS - -

LOHMANN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DISTURBANCES OF THE VISUAL FUNCTIONS

BY

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With 39 Illustrations in the Text, some in Colours

Calcutta

BUTTERWORTH & CO. (INDIA), LTD., 6, HASTINGS STREET

1913

JOHN BALE, SONS AND DANIELSSON, LTD.,
83-91, GREAT TITCHFIELD STREET, OXFORD STREET,
LONDON, W.

PREFACE TO THE ENGLISH EDITION.

In undertaking an English translation of my book "The Disturbances of the Visual Functions," Mr. Macnab has not only earned my own thanks, but I trust also the gratitude of many of the profession in his own country; for the view of such a collective exposition as it contains is easily dimmed by reading in a foreign language.

May the book gain some friends, and prove a useful guide to the study of pathological optics.

W. Lohmann.

Munich, Easter, 1913.

TRANSLATOR'S PREFACE.

Professor Lohmann's many articles on the psychological problems connected with vision, and the splendid work accomplished in the laboratory at Munich, will at once commend this book to any student of the subject with which it deals.

In undertaking the English translation, I have attempted to keep as close to the original as is consistent with the differences in the two languages, and have been greatly assisted by the fact that Professor Lohmann, who is quite a master of our language, has undertaken to revise the English proofs.

Our literature is so poor in works on this subject, that there is considerable difficulty in finding words which express the meaning; I have been compelled to coin some words the exact meaning of which I trust will be quite clear from the context. I trust that the use especially of the word "librate"—borrowed from the astronomical term—as applied to retinal images, will not be found unjustifiable, and that my choice of psychological technical terms, which has been made with great care, will meet with the approval of the psychologists, to whom this book should strongly appeal.

Interpolations, not appearing in the original and made for greater definiteness of language, are indicated by the letter (T). In the work there are several quotations from English writers, in each of these cases I have referred to and reproduced the original, *e.g.*, the song of the blind flower girl in "The Last Days of Pompeii," and that interesting quotation from Cheselden in Chapter II. Havelock Ellis's translation has been used for the quotation from Heine which appears in Chapter XII, but for the other quotations from this and other authors I have given my own rendering. The inherent difficulties of the subject, entailing as it does a knowledge of ophthalmology, psychology, optics, and the technical language used in each of these subjects, must be the grounds of my apology for the degree which I feel my translation falls short of the original.

Angus Macnab.

London, 1913.

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DISTURBANCES OF THE VISUAL FUNCTIONS.

CHAPTER I.

VISION, AND THE ORGAN OF VISION: THE SIGNIFICATION OF VISION.

Vision: Its Three Elements.—The term "vision" is applied to a complex act, which on close analysis can be divided into three very distinctive phases: A "physical" phase, concerned with the rays of light emanating or reflected from a visible object, their refraction and focussing to form an image on the visual surface; a purely "physiological" phase, consisting in the transformation of the light stimulus into a nerve impulse, and its propagation to the brain. These two factors alone will not induce sight, they must be supplemented by a third and important "psychic" element before percipient vision results.

In fig. 1 the act of vision is schematically represented, the "physical" phase is shown green, the "physiological" red, and the "psychic" represented by black and blue lines.

(1) The Physical Phase in Vision.—Everything relating to the formation on the retina of the image of an outside object, in particular the dioptric properties of the eye, belongs to the physical phase. In order that surrounding rays of light, conveying information to us from illuminated or luminous objects, shall be utilized to their full in exciting vision, a receiving station—the eye—of extremely efficient and appropriate design has been provided.

Critical consideration leads us to the conclusion that primarily a centralized end organ may not have been provided for the perception of light, but that the visual organ in its present form is the result of a gradually increasing adaptation.

To enable a highly complex organism not only to receive impressions of light, but out of the profusion of light around to appreciate differences in position from the reflected light of objects, sensory elements must be developed which are themselves separate and discrete; and, if these elements lie on the surface of the body, each must be connected to the central organ by a nerve-fibre.

Such supposititious percipient elements, being specialized and delicate cells, cannot naturally be scattered over the whole surface of the body. If they were arranged as a flat surface, even though

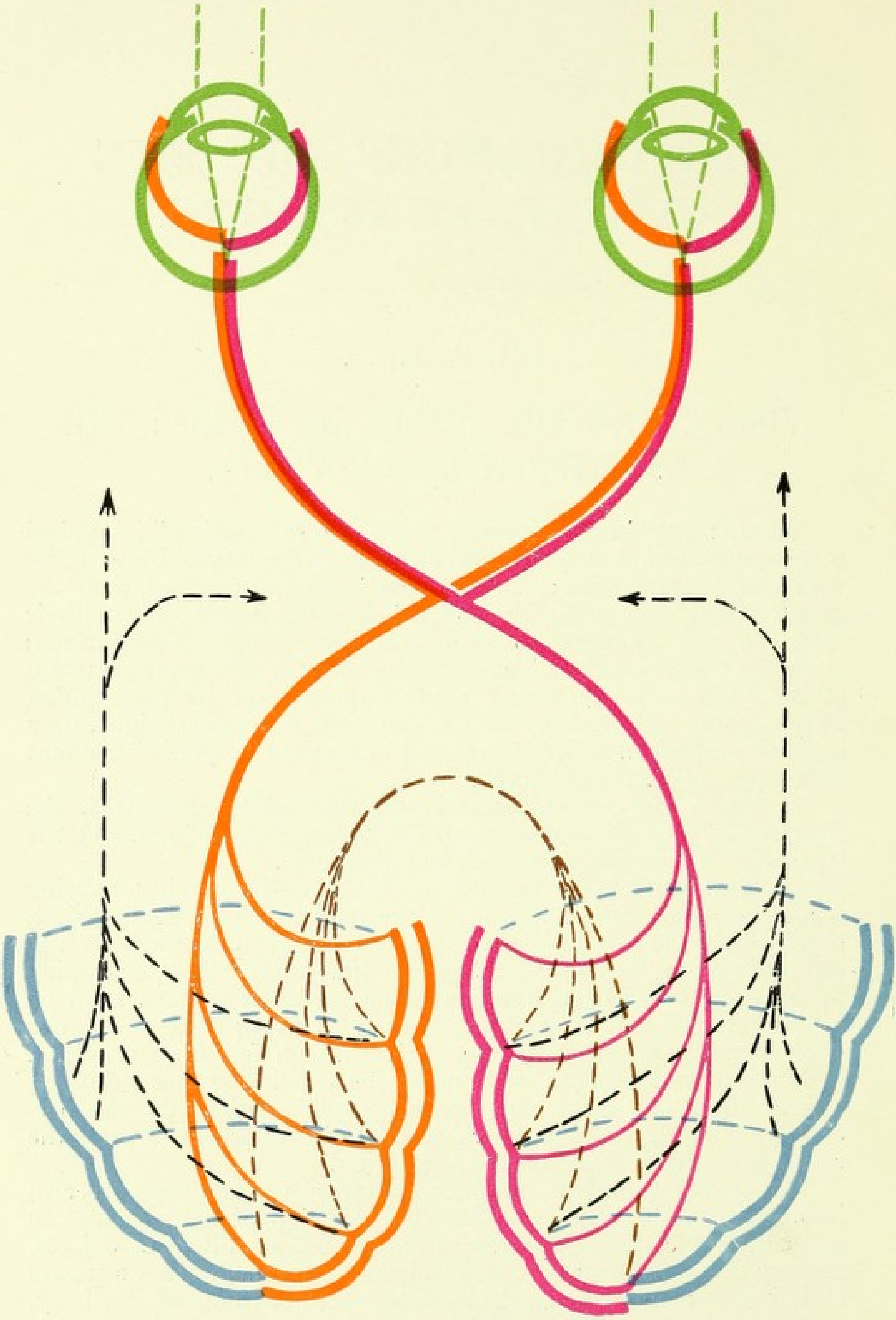

FIG. 1.—Diagram of the act of vision.

Green = "Physical" phase of vision.
Red = Transposition of light stimulus into nerve impulse and its propagation to brain (physiological phase).
Blue = Representation } Psychological phase
Black = Production }

collected at one area, a very limited visual power would result, almost useless for orientation.

Nature, which with sparing hand often achieves so much, here shows the escape from such a dilemma. Consider the complex eye of insects. We see how it is possible, by a convex disposition in the arrangement of the sensory elements, to widen out the visual horizon even of a minute area. When we imagine the radiating cylindrical visual elements to be produced outwards, these diverging lines will in a measure indicate the extent of the field of vision. Such a complex eye is represented in fig. 2 (from EXNER, "Die Physiologie des facettierten Auges").

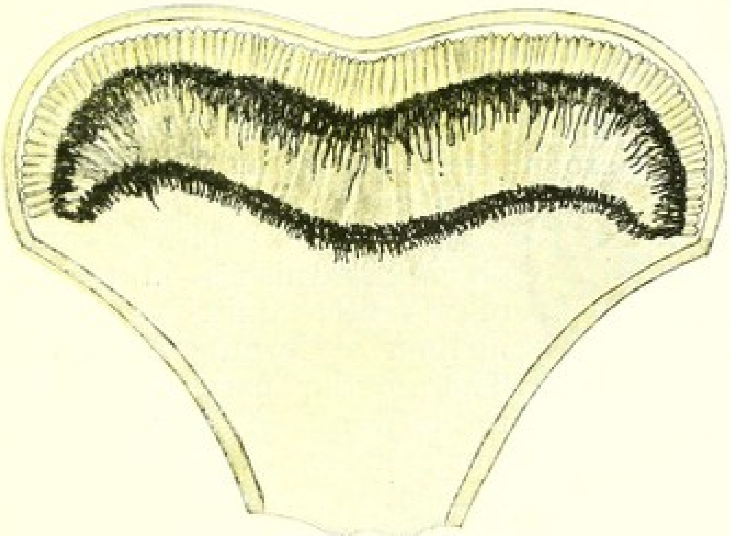

FIG. 2.—Eye of *Squilla mantis* (EXNER).

Amongst the Arthropoda, besides this complex organ, "the facetted eye," just referred to, the so-called "stalked eye" occurs.

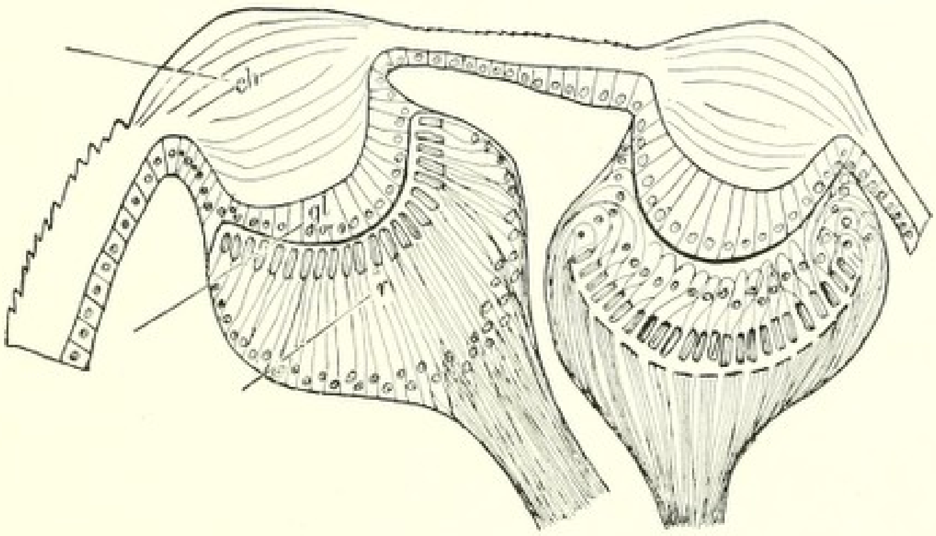

FIG. 3.—Stalked eye (HERTWIG).

Nature thus shows us a second way in which a look-out station with a free view in all directions can be formed in a minimum space.

Fig. 3 is taken from HERTWIG's "Lehrbuch der Zoologie," *ch* is a thickened portion of the chitinous envelope, which has lost its brown colour and acts as a lens; *gl* a number of transparent cells forming a vitreous; *r* the retinal cells which on their peripheral ends carry the rods in contact with the vitreous, and at their other ends pass into nerve-fibres.

The sensory layer in this case is no longer convex, but must be concave, for from the dioptric properties of the eye the refraction is such that the rays collected from the outside are diverging when they fall on the sensory epithelium. These rays can only be uniformly and completely utilized when they are received upon a spherical surface arranged around the nodal point of the dioptric system.

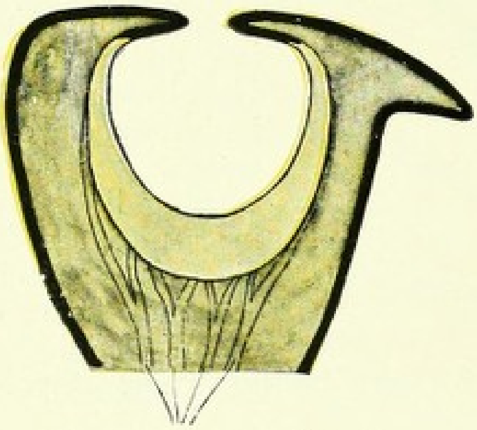

FIG. 4.—The eye of Nautilus (BALFOUR).

The principle of the camera obscura furnishes in the eye of Nautilus quite a different method of forming an image. The anterior part of the eye forms a screen in which is a small aperture; through this rays of light pass to form an inverted image on the opposite side of the interior of the eye (fig. 4).

Let us now glance at a section of the human eye (fig. 5). The various parts are here shown very clearly. The chief innovation, in comparison with the stalked and Nautilus eye, is the circular muscle, the *corpus ciliare*. By its action, through the elasticity of its capsule, the lens is enabled to vary its refractive power, and thus the eye can be focussed either for distant or near objects.

This development of the visual organ has arisen to meet developing needs, but we must not therefore conclude that the evolution of the human eye has taken place along these lines. The Würzburg zoologist, BOVERI, traces the organ of vision up from the single pigmentary visual cells scattered through the neural canal of the whole organism as in *Amphioxus lanceolatus;* just as we have done with the origin of the light sense. Many weighty opinions are opposed to this view.[1] A uniform version of the evolution of the eye throughout the animal world presents great difficulties. PÜTTER[2] takes the opposite view, and sees in the eye a beautiful example of "polyphyletic" development.

The general characteristic—sensitiveness to light—leads to the formation of visual cells. But the supply of connecting links and

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[1] *E.g.*, KEIBEL: "Die Entwicklungsgeschichte des Wirbeltierauges," *Klin. Monatsbl. f. Augenheilk.*, 1906.

[2] PÜTTER: "Organologie des Auges" in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde," 2nd ed.

transition forms between simple cells sensitive to light, and the organs of the human or animal eye is more or less sport for untrammelled fancy.

HISTORICAL.—The philosophical genius of great minds had long striven to elucidate the physics of vision. The explanation of most of its problems was, however, a product of that period of intellectual progress which we call the "Renaissance," the "classical" age of learning.

The ancients held the view that the seat of vision lay in the lens, and in complete agreement with this was their fallacious idea of cataract—a membrane which had sunk down between the iris and the lens; a fluid which had run down, coagulated, and covered up the lens. Hence, too, the name cataract (a waterfall). This ancient view remained until the Middle Ages. The sixteenth century first saw the sun of knowledge shine into this dark region of ignorance, and clear indeed was the light shed by JOHANNES KEPLER's writings.[1]

FRANZISKUS MAUROLYCUS (1494-1577), the learned Abbot of Messina, described in pregnant contrast the lens of the eye (the chrystal) as the collecting lens of Nature; and the glass lens, the spectacle glass, as the chrystal of art. He, however, had no knowledge of the refraction of rays in the eye; he believed that the lens brought the rays together in some way or other to form a truncated visual pyramid, whose basal surface rested upon the outside world, and whose smaller apex lay on the optic nerve extension.

FELIX PLATER (1536-1614), a doctor of Basle, showed clearly that the chrystal of the eye was a lens which formed images of outside objects upon the retina. He was of opinion that the retinal images were thus magnified.

In 1610 JOHANNES KEPLER wrote his great work on the "Dioptrics of the Eye," and provided a scientific basis for the physical phase of vision; he gave the mathematical and physical proof of the path of light rays and the formation of images in the eye.

Our present knowledge, dating from KEPLER, shows that the rays of light which fall upon the eye are, by means of its refractive media (especially cornea and lens), so bent as to form a small inverted image of the outer world upon the retina.

KEPLER's new hypothesis of vision did not displace the ancient view without a struggle, and further proofs were brought forward to support the new doctrine. Well known is the interesting historical demonstration of the inverted retinal image generally attributed to the Jesuit father, SCHEINER.[2]

Pursuing the historical sequence of the facts bearing on the science of vision, we must note a most interesting discovery which,

[1] HIRSCHBERG: "Geschichte der Augenheilkunde" in GRÄFE-SÄMISCH's "Handbuch der Augenheilkunde," 2nd ed., Bd. xiii, S. 294, *et seq.*

[2] *Vide* HIRSCHBERG, *loc. cit.* S.310.

in such a marvellous manner, interrupted the steady advance of knowledge; I refer to the discovery of the blind spot by MARIOTTE (1666).

Blind Fortune did not drop this knowledge as an unearned gift into the lap of the French physicist; it was, indeed, the result of exhaustive research. His anatomical studies had shown MARIOTTE the excentric position of the optic nerve entry, that it was not at the posterior pole, the spot opposite to any point of fixation, but lay laterally in the interior of the eye. MARIOTTE then asked himself what would happen if the image of an object fell directly on the optic nerve head? His investigations established conclusively that this spot was blind. The pioneer then concluded that, if the site of the optic nerve entry, where the nerve-fibres are massed together, be blind, then the fibres themselves cannot be sensitive to light, and the choroid must be the visual layer in the eye.

It was only in recent times that fuller knowledge of the retina, more especially through the exhaustive work of H. MÜLLER, led to the correct view, that excitation must occur in the outer layer of the retina in the rods and cones. MÜLLER in his argument made use of the visible movements of the intra-ocular shadows of the retinal vessels, which occur when a source of light is moved slightly on the sclerotic (1854).

ACCOMMODATION.—The power possessed by the eye of altering its focus, and by which, at will, either a distant scene or a printed page can be sharply reproduced in the eye, is called accommodation. The most diverse views have been advanced to explain this power.[1]

In 1619 SCHEINER first observed the contraction of the pupil in focussing near objects, an action closely associated with convergence, and also, though to a less extent, with accommodation;[2] this was considered by some authors as the primary cause of clear vision at close range (*e.g.*, HALLER, 1743, and MORTON, 1831). But any such elimination of diffusion circles, even by a considerable stopping down of the pupil, is still insufficient to produce sharp vision. HELMHOLTZ conducted an investigation which proved this. If, relaxing the accommodation, we look at a near object through a fine hole made in a card, held close before the eye, the object will appear hazy.

The now classical experiments of YOUNG (1800) opposed a very prevalent view (*e.g.*, BOERHAVE, 1755) that alterations on the surface of the eyeball produced variations in focus. YOUNG placed the cornea under water, and still proved the existence of accommodation just as before; showing that increase in the corneal curvature cannot be a factor. He also showed that the axis of the eye did not elongate to any appreciable degree, as an eye which was fixed at its anterior and posterior pole could accommodate normally. A

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[1] HELMHOLTZ: "Physiologische Optik," § 12.

[2] LOHMANN: "Konvergenz- oder Akkommodationsverengerung der Pupille bei der Naheinstellung?" *Ophth. Gesell.*, 1908.

somewhat prominent eye was directed nasally so that it was possible to fix a small ring between the orbital skeleton and the posterior pole of the eye, the position of the ring being controlled by the appearance of the pressure phosphenes.

SCHEINER (1619) and DESCARTES (1637) had suggested that the accommodative changes took place in the lens, and the experimental work of LANGENBECK, CRAMER and HELMHOLTZ confirmed this. They proved that the lens altered its shape during accommodation, by observing a change in the relative positions of the image reflected from the anterior surface of the lens and that from the cornea, when a light was placed before the eye (PURKINJE-SANSON images).

If the diagram of accommodation (fig. 5) be examined, the theory is at once obvious.

When the ciliary muscle is in a state of rest, the tension of the suspensory ligament (zonule of Zinn) acting on the lens flattens it to such an extent that, provided the refraction of the eye be normal, parallel rays of light falling on the cornea are brought to a focus on the retina (blue lines in diagram). Rays from any nearer point are divergent when they strike the cornea, and the refractive power of the lens at rest is only sufficient to focus them at a point behind the retina (blue dotted line). When, however, the circular muscle contracts, the suspensory ligament relaxes, and the lens, by virtue of the elasticity of its capsule, changes its shape and thereby increases its refractive power. The result of this is that the divergent rays of light (blue dotted) can now be brought to a focus upon the retina (red lines in the diagram).

(2) THE PHYSIOLOGICAL PHASE OF VISION.—The images of surrounding objects formed upon the retina cannot be forthwith passed on to the brain, because the optic nerve is not transparent. The light stimulus must therefore be changed into a nerve impulse. It is extremely difficult to explain how this translation of stimulus occurs, as we naturally cannot observe its occurrence under the microscope. We have information gained by observations on the material alterations in the retina of animals when subjected to light stimuli; but to apply this knowledge to the processes of vision itself naturally yields no definite conclusion as to what extent these occurrences are accidental or essential to the process, and to what particular step in the visual process they are to be related.

CHANGES IN THE RETINA INDUCED BY LIGHT.[1]—It is interesting to note that Goethe[2] in his "Chromatics" (*Farbenlehre*) considered that some kind of movement must take place in the retina under the influence of light. The appearance presented by the bright crescentic moon, of belonging to a circle larger than the faintly visible disc, was explained by Goethe by a contraction of the retina in shadow and an expansion when brightly illumined. We now, of course, explain this phenomenon by "irradiation" of light

[1] S. GARTEN, in Gräfe-Sämisch's "Handbuch der Augenheilkunde," 2nd ed.
[2] GOETHE: "Als Naturforscher," Lecture by Dr. R. Magnus, 1906.

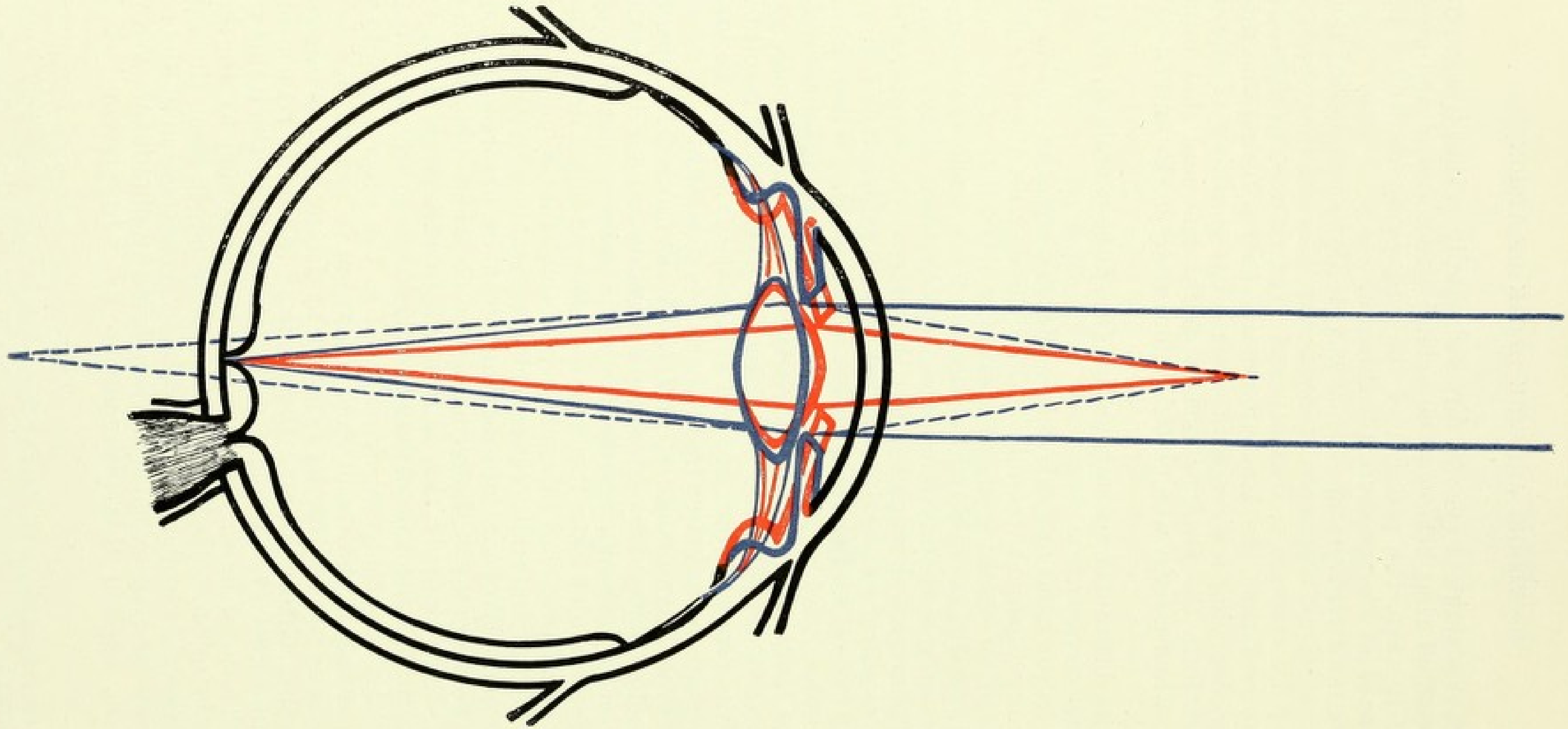

Fig. 5.—Diagram of Accommodation.

beyond the actual image found, but quite recently changes have been shown to occur in the retinal elements under the influence of light.

Van Genderen Stort (1884) first described changes in the cones of the retina as an objective fact. The internal segment of these elements (*myoid*, Engelmann) becomes shorter and thicker when exposed to light. These changes are particularly well seen in those animals whose retinæ have, as well as cones, those other end-organs called rods. In retinæ not containing rods [*e.g.*, the ring snake, *Tropidonotus natrix* (T.)] only very slight changes in the length of the cones can be seen (Engelmann); the rods, on the other hand, elongate under the influence of light, their movement being opposite to that of the cones. This antagonistic action of the two elements of the retina is related to the old idea of M. Schultze, that the cones serve for vision in daylight and the rods in the dusk of twilight. The cones, which apparently are not excited by an illumination of low intensity, give up the field to the rods, which being more adapted for vision in dim light, then take possession.[1]

These movements of the rods and cones are not visible in the higher animals to the same degree as in the lower forms, and it is questionable if they do occur at all in man. Garten was, however, able to demonstrate a definite difference in length between the inner segments of the cones in the periphery of the retina, when adapted for light and for shadow; there seems also to be a very slight difference in the length of the cones at the macula in favour of the dark-adapted eye.

Another change in the retina produced by light, which does occur in man, seems to show that this opposed action in the two end-organs can be assumed to occur in the human eye.

The well-known pinkish appearance of the fresh retina was ascribed by Boll (1876) to a pigment which lost its colour under the influence of light. The so-called "visual purple" is a photochemical substance whose demonstration lends a certain probability to the view that this or some similar substance, which can be disintegrated by light, forms the connecting link between the light stimulus and the nerve impulse. This visual purple is found in the rods; the macula, where vision is most acute and cones alone are present, is free from this pigment. The fovea, the important area for vision in bright light, is therefore inferior for "night vision" (scotopia) to those parts of the retina which contain the rods.

A correspondence can be shown[2] between the rapidity of bleaching of the visual purple by different monochromatic (spectrum) lights, and the "scotopic" value of the retina, *i.e.*, the luminosity value of a faint spectral band which after adaptation appears colourless; and in this we have presumptive evidence for the

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[1] Exner and Januschke: *Ber. d. k. k. akad. der Wissensch., Math. cl.* cxv., Vienna.

[2] Trendelenburg: *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xxxvii.

"duplicity theory" (v. KRIES) which M. SCHULTZE, already quoted, would apply to the human eye (*see* Chapter V.).

Of other changes in the eye due to light we will here only mention the variations in the retinal pigments (BOLL and KÜHNE, 1877). These have been regarded as associated with the regeneration of the visual purple, but apparently in animals they serve for the insulation of the cones (GARTEN).

This short account of the objective changes in the retina due to light leads to the conclusion—naturally not unreserved—that the transference of the light stimulus into a nerve impulse is probably a photo-chemical process; and that the adaptability of the eye to vision in the dark is due to special retinal elements (the rods), while the cones are concerned with vision in bright light.

RÄHLMANN'S[1] hypothesis of colour perception must here be mentioned. It is an attempt to explain the transposition of light stimulus into nerve impulse by definite conditions in the retina showing analogies to LIEPMANN'S colour photography.[2] In this process the interference of undulations in the bromo-silver gelatine film is produced by reflection, and thus a lamellar change in the plate is induced. RÄHLMANN postulates a similar reflection in the rods and cones; coloured light therefore leads to interference undulations, as the outer segments of the rods and cones are lamellar in structure. On the other hand, it can be urged that these lamellæ are artifacts. GREEF[3] states that the interior of these outer segments is perfectly homogeneous in the fresh condition; but he adds that this tendency to break up into discs is so regular that he had no doubt about "the lamellar cuticular structure" of the outer segments, and called to his mind the statement of RAUBER that lamellation presented a great resistance to the incoming rays of light.

GARTEN stated as an objection that the retina reflects less light than does the optic disc, but RÄHLMANN had already attempted to refute this by demonstrating that the reflex, which GARTEN considered so important, was difficult to see, and with the ophthalmoscope only visible in dark-complexioned people; though with the plane mirror it could almost always be seen in the fovea.

The purely physiological phase of vision has not only to deal with the transference and propagation of impulses, but also with adaptation and contrasts; and besides these with the laws of colour blending, which, however, will merely be mentioned here (*see* Chapter VI.). The adjustment of perception which we term adaptation (for scotopia) serves to counteract the variations of illumination (day, evening, night), and has been already alluded to along with the duplicity theory. This is further discussed in Chapter V.

Another form of adaptation occurs when we look through red

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[1] *E.g.*, *Zeitschr. f. Augenheilk.*, XVI.

[2] *Cf.* DR. LEHMANN: "Beiträge zur Theorie u. Praxis der Farbenphotographie," nach L. Freiberg, 1906.

[3] GREEF in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde," 2nd ed.

gelatine spectacles; at first everything is red, but when we are "adapted" to red, we again see surrounding objects in their natural colours. Colour adaptation occurs when we look at a red paper. The red gradually loses its brightness, changes its colour-tone, and becomes yellowish. In a similar way red, orange, and green turn yellow; indigo and violet turn blue.[1] This colour transition even occurs in homogeneous lights. The two colours yellow ($560\mu\mu$) and blue ($460\ \mu\mu$) do not change their tone. The other colours of the spectrum alter in the direction of yellow and blue, and away from green.[2] When the red spectacles are taken off, in the experiment just alluded to, everything appears greenish. When the eye has been exhausted of a colour, this appearance of the complementary colour—the so-called successive contrast—is also seen in the form of simultaneous contrast if colours are in close contact, and is to be looked upon as a physiological element in vision.

(3) PSYCHIC PHASES OF VISION.—While colour perception by the eye is induced from a light stimulus and the essential conditions are generally provided by physiological stimuli, the perception of colour itself is a psychic phenomenon.[3] With the colour impression called forth by the stimulus are associated those representations which HERING calls memory-colours (*Gedächtnisfarben*), and thus the same percept is insured even though surrounding conditions vary. Clothes, whose colour has been recognized by day, are viewed by artificial light, when to a really unprejudiced eye they present quite another appearance, and are seen in their "correct" colours; we also speak of white snow, even when the dusk of twilight has changed it to grey.

The psychic element in vision is very obvious in the following example, which HELMHOLTZ gives in his "Physiological Optics." Imagine oneself to be in a brightly lighted room; impressions are then accompanied by powerful sensations. We find ourselves at dusk in the same room, seeing only the lighter objects, and these indistinctly. Everything which we notice so fuses with our memory-pictures that we can readily find objects looked for. Even in absolute darkness we can find our way in the room by virtue of the memory of previous visual impressions. This example of the reduction of the presentation-image "by an ever increasing elimination of its sense elements to a pure re-presentation image," shows us the intimate connection between the purely sensory and the purely psychic in our concepts and ideas.

In fact our concepts are not induced merely by the visual impressions of the moment, but necessitate the addition to these of re-presentations of sensations; these we inadequately term "factors of experience." It is not always possible to separate the pure sensation from the factor of experience, as the following illustration will show:—

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[1] KOELLNER: "Störungen des Farbensinns.," 1912.

[2] VOESTE: *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xviii.

[3] HERING in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde." "Lehre von Lichtsinn." § 4.

When I look at a portrait, drawn so that the eyes look at me, and then walk about the room, I have the impression that the portrait is always gazing at me. This fixed gaze of the portrait, an easily proved empiricism, is not induced by reflexion, but is the result of an overwhelming sensory impression.

The analysis of the fact that the factor of experience is so important in vision, is by no means simple; it presents a difficult problem to the psychologist.[1] A relatively simple explanation is provided by the hypothesis that the psycho-physical substance as a result of its activity suffers changes, and that residua previously left behind are met with and have a modifying action on a new sense impression.

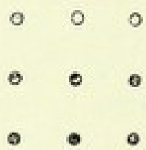
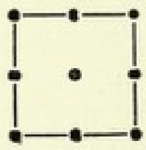
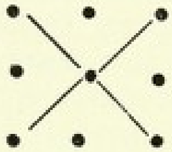
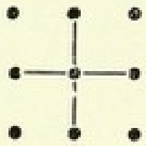
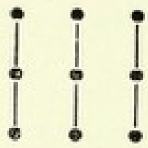
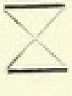
To produce a picture from the individual sensory stimuli of the retina, we must have the component parts built up into a complex percept. WITASEK talks of a "process of production," and his meaning becomes clear when we consider how the same form of stimulus in the same state of the eye can produce different perceptions. For instance, if the arrangement of dots  be looked at various arrangements may be seen, such as  or  or  or . Such a diagram as this  can be "seen" as either a continuous row of  or of .

Fig. 1 is an attempt to represent diagrammatically the psychic in vision; in it the black lines correspond to the "process of production," these meet the fibres associating and knitting together sensory impressions (red) with memory images (blue), thus making the actual conception possible.

IMPORTANCE OF VISION.—In examining the importance of vision, we must take into account the relation of our eye to objects seen, and also the relation of the objects to us. We have to answer two questions: (1) What does sight convey to us regarding external

[1] WITASEK: "Psychologie der Raumwahrnehmung des Auges," Heidelberg, 1910.

objects? (2) What influence has sight on our intellectual life and comfort?

WHAT DOES SIGHT CONVEY TO US?—The first question introduces a much discussed philosophical problem, and ends in the well-known question of objective existence. We either deny a correspondence between our perceptions and the actual objects, and explain all sense perceptions as subjective phenomena and sense delusions not actual realities; or we admit a conformity between the world around as we subjectively find it, and as it objectively exists.

In the latter case we speak of a "pre-established harmony" (EHRHART), and consider that a correlation between mind and matter is shown because the power of mind is derived from the same source as are the forms of energy in the world around. (HUGO WOLF, in his "Psychologie des Erkennens," has recently discussed this idea from the biological standpoint.) I will briefly give IMMANUEL KANT's view of this question. KANT held that the forms of perception (space and time) were *a priori* dogmas of a congenital character, raising the sense impression to quite a new plane, conception itself.

In contrast to such speculative answers to the problem of the relation between vision and the world around, HELMHOLTZ emphasized the practical point, which appears when we consider that surrounding objects, by means of our sense impressions, become to us symbols which, when we have learnt to interpret rightly, make it possible for us to direct our actions so as to bring about desired results. Although the eye is extremely useful practically, it cannot see at all distances, nor perceive all the vibrations of the ether. In the same way we have no guarantee that human intelligence might master everything which can exist or occur.

The common view of simple people that our vision says something about an object, has led to an unfortunate method of expression, which appears when we speak of "red" cinnabar. To a colour-blind eye cinnabar is not red; it is only in the case of a normal eye under ordinary conditions that the rays of light reflected from cinnabar produce that definitely characterized sensation (red).

WHAT IS THE IMPORTANCE OF VISION TO US?—Regarding the second question, the importance of vision to our intellectual life, the view was prevalent amongst the ancients that the many distractions which our visual impressions bring us, prevented an undisturbed development of the soul. CICERO's statement that Democritus had blinded himself in order to reason more clearly would thus be easily understood. We tend, when reasoning, to shut our eyes; but their closing is only temporary against any influence which would interfere with the concentration of the mind. On the other hand, we must recognize that the "hasty glance" will, through visual impressions, advance our quickness of mind, and to a certain extent is a form of mental gymnastics.[1]

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[1] MAGNUS: "Das Auge, in seinen Ästhetischen u. kulturgeschichtlichen Beziehungen," 1876.

The eye is an organ which enables us not only to recognize objects in the vicinity; but also parts of the country, the sea and the starry sky in the far distance. Our visual impressions are closely related to perceptions of space and recognition of time. We will readily be convinced that a spatial sensation of depth is transmitted (extent in height and breadth is conveyed by each eye separately) if we attempt to estimate the position of an object relative to ourselves by monocular vision. It must be admitted that depth is only recognized indirectly with the one eye, in contrast to the immediate and obvious estimation of the position of objects one behind the other which is gained binocularly. Impressions as to succession in time are also conveyed by our visual sense; and I might add, more frequently by this means than by the other sense organs. For the whole field of vision forms the fundamental chord, the continuous impression, in which a movement or an alteration occurs; we see solid objects grouped together constantly changing in their relative positions. It is thus quite obvious what a great intellectual use we make of our visual impressions, so variable in space and time.

I will briefly note that the whole play of our imagination draws freely for material on memory pictures derived from vision, so that visual impressions are the source of a large portion of our inner life.

The true importance of vision to us will be clear if we try to imagine what would remain of our intellectual existence if all visual impressions, and the memory of them, were banished. We must confess with Goethe ("Wahlverwandtschaften," ii, 3):

"Place yourself in what state you will, you will always think of yourself as seeing."

CHAPTER II.

BLINDNESS: THE EDUCATION OF VISION.

Opinions Regarding Blindness.—Blindness is generally considered as a great misfortune. The helplessness of the blind in a strange environment arouses pity, and saddens even the happiest spirit. Poets have poured out their emotions in the song of blindness; to the painter the blind are a gloomy ideal. Think of Piglheim's picture of blindness. What a work! How the blind girl strays through the scarlet blaze of the poppies, knowing nothing of the profusion of colour around! That poem which Bulwer Lytton, in the "Last Days of Pompeii,"[1] puts into the mouth of the blind flower girl:—

> Ye have a world of light,
> Where love in the lov'd rejoices;
> But the blind girl's home is the House of Night,
> And its beings are empty voices.
>
> . . . .
>
> And I thirst the loved forms to see,
> And I stretch my fond arms around,
> And I catch but a shapeless sound,
> For the living are ghosts to me.

If, despite these expressed views, we agree with the speech of Seneca, "*Oculos perdidi; et nox habet suas voluptates,*" we appear to face a contradiction which is even more forcibly impressed upon us when we note the calm and cheery disposition of the blind.

False Ideas on the Condition of the Blind. "Psychology of Blindness."[2]—The importance of sight in life, in intercourse, and in speech, and the way in which it forms the basis of the individual course of life, has often a great influence on the care of the blind and the problem of their education. The conviction that such sense impressions are lost would appear as the announcement that the most important elements in life itself had passed into permanent disuse.

Such a view leads to earnest commiseration with the lot of the blind, but genuine advancement, and real assistance to the blind in escaping from the degrading position of mere recipients

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[1] Book I., Chapter II., "The Blind Flower Girl's Song." (T.).

[2] Recommended studies in "Psychology of Blindness," by Heller, Leipzig, 1904.

of charity, will never arise out of such a view as this alone. This outlook, which is subjective in origin, must give way to another if we intend, without any previously formed prejudices, to make a close objective study of the lives of the blind. The practical aspect of such a blind psychology lies in the problem, Is the method of education of the blind, which, on the HAUYS model, works from pure solicitude, based correctly? The theoretical interest lies in the indirect evidence it affords of the importance of sight, and of the extent to which the eye and the visual sense can be replaced.

PSYCHOLOGY AND EDUCATION OF THE BLIND.[1]—It is much more difficult for the blind to understand speech than for those who see; the individual words and expressions do not have the power of bringing forth in blind people such a wealth of sensory effects and memory pictures as they do in normal individuals. In this respect those blind from early childhood are worse off than those others, blinded in later life, who have carried with them into their unending night of blindness a full treasure store of memory pictures. Instruction in modelling and object lessons assist in enriching the world of their perceptions. The sense of touch will convey to them typical forms and shapes (*e.g.* stuffed animals, models in the flat and relief, &c.) with the impressions and mental pictures associated. Object lessons will convey the ideas of the chief animal and vegetable forms and the chief geometrical shapes; geography is learnt from relief plans, instruction in modelling will then amplify the knowledge thus imparted.

SUBSTITUTED SENSATIONS.—The sense of touch can be made substitute for that of sight to a certain extent, in so far as relates to shape and its derived form-sense. Touch naturally has a much less range than vision. The blind are therefore driven, in representing certain forms and the ideas derived from them, to associate senses other than those employed by seeing persons. The so-called substitute sensations (HITSCHMANN)[2] which answer for all ideas originating in the sensory field of the eye, *e.g.*, colour; or associated with other sensations, *e.g.*, taste, form the outward expression of the limitation of the faculty of perception in the blind. A blind person's conception of a large object not only involves mere impressions of touch, but also the association of an essential idea of movement, for in touching the object to learn it he must move about and stretch out his arms.

Substitute colour vision is derived from hearing, as this exerts an æsthetic influence on the blind. For example, the idea of "red" to a blind person induces the same sensation as a trumpet. From this substitute sensation the mind naturally passes to the phenomena of *audition colorée*, which is also found in the blind (*vide* Chapter IX.). HELLER specially notes that it is not the note of the trumpet which "red" calls up, but the emotion corresponding to

[1] *Vide* VON SCHAIDLER, Inspector of Central Blind Institute in Munich, in WEIGL, "Kurs f. Heilpädagogik und Schulhygiene."

[2] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, iii.

it. The blind are thus readily influenced by the poetry of a seeing poet, for by the help of their substitute sensations, they can feel emotions not far removed from those which the poet wishes to convey, and can quite well fall in with that frame of mind which the poet would induce in seeing persons.

ACCENTUATION OF HEARING AND TOUCH IN THE BLIND?—It used to be said that the sense of touch could entirely replace that of sight; and men spoke of touch filling the breach, vicarious sensation (*Sinnenvikariat—cf.* that part of the account of JUSTINIUS KERNER of "The Seer of Prevorst"). The blind were endowed with the power of recognizing colours by touch—a mere phantasy. It is quite certain that such a refinement of sensation as was alleged to occur in the blind does not exist. Very many tests of the sense of touch (v. RANKE, in the Munich *Zentralblindeninstitut*) have shown that the appreciation of two points as separate was exactly the same in the blind as in the seeing. Hearing also in the blind is not more acute. The functional activity of this sense depends on congenital anatomical grounds; the blind, however, do deduce more from their sensations of touch than do normal people.

This apparent accentuation of sensibility also occurs in people not devoid of sight, when in the evening the veil of darkness is thrown over the world of shapes and colours, then the attention is more keenly fixed on the sounds which strike the ear, and greater dependence is put on touch. "Night has fallen; and all the bubbling brooks chant louder," begins that beautiful "Night Song of Zarathustras," by NIETZSCHE.

SENSE OF PLACE IN THE BLIND.—The certainty with which the blind avoid objects and obstacles in their path is due to the greater attention which they pay to their hearing and touch. An actual sixth sense, "sense of place," was formerly alleged, and supported by SPALLANZANI'S experiments; he allowed blinded bats to fly about in a room across which were stretched cords, and showed how certainly the animals avoided touching them. This so-called sixth sense really is compounded of several stimuli, auditory impressions, and tactile impulses from the face. The air column between the face and the walls served them when blind as the blind man's stick, by conducting pressures and temperatures. Put a blind man into a close mask covering his face and he loses assurance; in walking on snow or on a thick carpet his judgments about surrounding objects are less keen (through loss of sounds and echoes).

LITERATURE CONCERNING THE EDUCATION AND HISTORY OF THE BLIND.—Unfortunately, we cannot here go into details concerning the education of the blind, nor into the absorbing history of the care of the blind. I must, however, refer to the books of KUNZ[1] and SCHAIDLER.[2] Details in the life of the blind are excellently

[1] "Geschichte der Blindenanstalt Illzach." ENGELMANN: Leipzig, 1907.
[2] "Die Blindenfürsorge im Königreich Bayern," Munich, 1905.

treated in MELL'S lexicon ("Enzyklopädisches Handbuch," Vienna and Leipzig, 1900).

ORIGIN AND PREVENTION OF BLINDNESS.—Regarding the origin and prevention of blindness reference must be made to the works of MAGNUS (Breslau, 1883) and HIRSCH (1904), also to that excellent monograph of UHTHOFF'S "Von den Blinden" (Breslau, 1908).[1]

From among the details I will only pick out the following facts for scanty notice :—

We differentiate between hereditary and acquired blindness. The former group consists of either hereditary absence of vision ("Angeborenes Blindsein," MAGNUS), *e.g.*, microphthalmos, and anophthalmos or hereditary loss of vision ("Angeborene Blindheit," MAGNUS), when the child is born with the germ of amaurosis. Some of the blind from hereditary causes must be considered along with those becoming blind in late life, who mostly belong to the acquired group, *e.g.*, sequelæ of fevers or injuries. It is obvious that an individual passing on to blindness from retinitis pigmentosa may continue to see for many years, and those, too, the years of development; yet he is generally reckoned as in the group of hereditary blindness. On the other hand, an acquired blindness can develop so early (*e.g.*, ophthalmia neonatorum) that no visual impressions can ever have influenced the eyes, and the individual considered as blind from birth. The differentiation, so important in the psychology and education of the blind, into early and late amaurosis, only in part coincides with the medical classification of hereditary and acquired.

BLIND CURED BY OPERATION.—In the group of early amaurosis there is great theoretical interest in those individuals who can by operative measures be given a practical amount of vision; these are mostly cases of congenital cataract, and patients who, in the strictest sense of the term, were never "blind." For we should only use the term "blind" for those individuals who have, as the result of irreparable changes, either entirely lost the power of perceiving light (amaurosis: blindness in the scientific sense) or, as the result of irremediable lowering of visual acuity, have lost the power of guiding themselves in strange places.

VISION ACQUIRED AFTER OPERATION.—The problem of how a congenitally blind person learns to see after an operation has greatly troubled the minds both of philosophers and oculists; from the study of these cases conclusions regarding vision in general have been arrived at. Since the time of LOCKE (1632-1704) has the matter been discussed.

"Picture a grown man blind from birth, who has learnt by touch to distinguish between a cube and a sphere made of the same metal and similar in size, so that he can say at once whether he is touching the cube or the sphere. Now imagine both objects placed on a table and the blind man to receive his sight; can he then without touching either of them say which is the cube and which the sphere?"

[1] FICK in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde."

There are two complications which appear to destroy the exact parallelism of the philosophical problem to the real state of affairs. HIRSCHBERG[1] collected in full detail the literature of this subject and noted that LOCKE began with the assumption that the curable blind man before the operation was stone-blind, and that after the operation he had full vision.

But even with a complete cataract such an individual before his operation did possess a rudimentary vision (hand movements, and projection), and if such a case be operated on too late the visual acuity will not be normal, on account of a lowered retinal sensibility (amblyopia ex anopsia). The surgeon must therefore operate on such a child as early as possible, and thus after the operation cannot carry out any really searching investigation.

In other directions there is much of interest in the study of these born-blind after operation. Such a person, according to WILBRAND,[2] presents many analogies to those defects to which the name of memory-blindness is applied (Chapter XI.). In the case of these congenitally blind the normal optic nerve tracts up to the central organ, and the propagation of the peripherally received image is intact after operation, but the objects seen are not elaborated into concepts nor interwoven into ideas.

The first record of observations in the case of such a successful operation is given by CHESELDEN.[3]

"When he firſt faw, he was fo far from making a Judgment about Diſtances, that he thought all Objects whatever touch'd his Eyes (as he exprefsed it) as what he felt did his skin; . . . He knew not the Shape of any Thing, nor any one Thing from another, however different in Shape, or in Magnitude; . . . Having often forgot which was the Cat and which the Dog, he was afhamed to afk; but catching the Cat (which he knew by feeling) he was obferved to look at her fteadfaftly, and fetting her down, faid, fo Pufs! I fhall know you another time. . . . Being fhown his Father's Picture in a locket at his Mother's Watch, and told what it was, he acknowledged a likenefs, but was vaftly furprized; afking how it could be, that a large face could be exprefs'd in fo little Room, faying, It should have feemed as impoffible to him, as to put a Bufhel of anything into a Pint. . . . The room he was in he faid, he knew to be but part of the Houfe, yet he could not conceive that the whole Houfe could look bigger."

MAUTHNER[4] reported the case of a girl aged 20, successfully operated upon for congenital cataract, who had previously learnt to write. When asked to write on a board with a piece of chalk, she accomplished the task by "tracing the form of the letters on the board with her left forefinger and following the movements with the chalk." At a short distance she was quite unable to

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[1] "Geschichte der Augenheilkunde" in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde," xiv.

[2] "Die Seelenblindheit," Wiesbaden, 1887.

[3] 1728. *Philos. Trans.*

[4] *Wien. med. Wochenschr.*, 1880.

decipher the letters which she herself had written in a large and clear hand.

WARDROP in 1826[1] gives observations in detail of a parallel case. The patient in question was quite conscious of improved optical perception, but she had still to acknowledge "I cannot say what I see; I am still much too stupid."

The visual impressions must be learnt by the help of tactile impressions. HIRSCHBERG[2] records how a seven-year-old child, after a successful operation, resembled a child learning words of a foreign language; the easy words were readily understood, but the difficult ones took longer.

After a successful operation patients learn the colours rapidly and with certainty. It must not be forgotten that in none of these cases was there total blindness; in every one before the operation perception and projection of light and colour were present.

WARDROP reports that his patient learnt to distinguish quite small objects by their colour, before she understood what they were.

These formerly blind people have the greatest difficulty in recognizing correctly the objects they see, that is, in associating them with their mental concepts derived from tactile sensations. When WARDROP'S patient was handed "a silver pencil-case and a large key, she distinguished them at once by their feel. If, however, the two objects were laid on a table together, she certainly distinguished between them, but could not tell which was the pencil-case and which was the key." One of UHTHOFF'S operated cases recognized a match-box by sight if it were shown with the label upwards, but whenever the box was placed in perspective she could no longer recognize it.

The appreciation of distance is very poorly developed at first. WARDROP'S patient "reached out her hand much too far in attempting to grasp an object held close before her eyes, and when the object was in the distance grasped at it close before her face."

UHTHOFF observed that the power of appreciating distance within arm's length developed more quickly than it did for greater ranges, where movement through the intervening space must precede any empirical appreciation of its extent.

If both eyes are operated upon successively, the patient does not require to learn afresh with the second eye (HIRSCHBERG); an obvious fact, if we reflect on it, which the comprehension and utilization of visual impressions, the very acquisition of the power of vision involves, and one which is of the greatest importance in the theoretical question of Empiricism v. Nativism (*vide infra*).

If the power of utilizing optical impressions has been established, we can gather from the whole demeanour of the patient, his assured bearing and his facial expression, that the visual

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[1] *Phil. Trans.*, iii.

[2] *Arch. f. Ophthal.*, xxi, xxii.

sense has been aroused.[1] This stage certainly is preceded in many cases by a period of confusion. WARDROP reports "she appeared in a way perplexed, and hardly seemed able to correlate the impressions received through her sense of touch and vision." UHTHOFF relates of a seven-year-old boy that for several weeks, when left to himself, he closed his eyes and relied on touch. It was only after months of training that he relied on his visual impressions and turned them to account.

UHTHOFF concluded from this procedure in visual education, that the doctrine of empiricism (in HELMHOLTZ's sense of the word) was true for vision, though, on the other hand, certain hereditary predispositions and faculties in the sense of nativism are essential. There is evidence in favour of both views in the phenomena observed among the blind. All reports are agreed on this, that after operation seeing must be "learnt" by these people, through the assistance of touch and the ideas derived from it. The relative rapidity of this education is assumed by definite anatomical connections between the retina and portions of the brain.

It must not be forgotten that, in these congenitally blind subjects, along with the field of touch, a certain idea of an optical field exists; from observations on the blind, especially their ability to localize the light effect of pressure phosphenes on the side opposite to the point of pressure, SCHLODTMANN[2] concluded that the localizing function of the retina was congenital; the considerations just related, however, strongly favour the other view.

THE "UN-LEARNING" OF VISION.—Just as one can study the awakening of psychical vision in those born blind, so we can find cases which show how it is possible to unlearn vision. This condition is mostly found in young children with scrofulous ophthalmia, photophobia and spasms of the lids. After the inflammation has subsided such a child appears to be blind. Generally vision is rapidly restored, but UHTHOFF relates an instance where such a condition remained for several weeks. Vision recovered rapidly, so that objects were followed by the eyes, but the tactile movements of the hands were not so readily associated correctly with the visual impressions. The child at first was unable to avoid obstacles, especially if they were not directly in front of the eyes. UHTHOFF says: "It appears as though the associating connections necessary for the act of vision were destroyed or lost, a state of affairs which is easily explicable by the loosely joined psychical mechanism of the infantile brain." If vision be firmly established it is not generally lost by prolonged exclusion. HESS rightly declares ("Erkrankungen der Linse," GRÄFE-SÄMISCH) that the great weight of ophthalmic experience shows that in this respect prolonged blindness of an eye by cataract does not appreciably influence its functional activity. He specially mentions a case by SILEX[3] of a patient aged 83, who, seventy-seven years before had had an injury causing blindness,

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[1] STRAUB: *cf.* "Der Platz des Bewusstseins in der Theorie des Sehens," Stuttgart, 1910.

[2] *Arch. f. Ophthal.*, liv.

[3] *Arch. f. Psych.*, xxx.

and who saw at once after the cataract had been removed. We see how the visual impressions of such an eye could be built up into existing visual percepts. LABANOW[1] reports contradictory cases; he had two cataract patients in their seventh decade, who had been blind for some twenty years. On removal of the lens objects could not be recognized by sight, but could by touch. This state of affairs lasted for about fourteen days. AXENFELD[2] reports the case of a girl, aged 7, who had lost her sight from cataract a year before and only slowly re-learnt the use of her eyes.

SEYDEL'S[3] observations were similar; he noted complete loss of visual memory from cataract.

EDUCATION OF VISION IN CHILDHOOD. EMPIRICISM. NATIVISM.—Visual education in the congenitally blind after operation must not be considered as exactly parallel with the natural process in childhood, as we are dealing with the interweaving of optical sensations amongst conceptions and ideas already developed.

Does the formation of ideas, the accumulation of experience, and the education of sight advance hand in hand during childhood; or is sight congenital and does it precede experience? And to what extent is this latter view correct? This is the essence of those questions, long-discussed, and to-day still undecided, which decide the truth of the empirical or the nativistic hypothesis.

CLAUD WORTH[4] observed the process of learning to see in childhood and recorded that an infant in the first few hours after birth fixed the reflected light of a candle in a darkened room, showing that a certain degree of vision, and preponderance of the fovea existed; it was only after three or four weeks that fixation could be maintained for a few seconds, with either the one or the other eye. The child fixed with both eyes after five to six weeks, though even then wandering movements of either eye to and fro could be observed.

According to W. STERN[5] the "immediate field" (*Nahraum*) is first disclosed to the infant; this consists of a hemisphere formed by a radius of a third of a metre about the head as a centre. In this space a close correlation between objects and clutching movements is established. The supposition that children grasp at objects out of reach cannot be maintained; according to STERN the "expressional movement of the outstretched hand" must not be confused with the "purposeful movement of grasping." STERN repeatedly showed that a child with outstretched hand would peacefully see a watch being slowly brought closer and closer, and only clutched it when the object was within arm's length.

Real knowledge of the "ultimate field" (*Fernraum*) is only possible when the child's powers of locomotion permit excursions into more distant spaces.

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[1] *Klin. Monatsbl. f. Augenheilk.*, 1900.

[2] *Klin. Monatsbl. f. Augenheilk.*, 1900, Beilageheft.

[3] *Klin. Monatsbl. f. Augenheilk.*, 1902.

[4] "Squint, its Causes, Pathology, and Treatment," 3rd ed., London, 1906, Bale, Sons, and Danielsson, Ltd., 6s. net.

[5] *Zeitschr. f. angew. Psych.*, ii., 5 and 6.

Bare outline sketches are most valuable when developing children are learning to recognize pictures. Their diagrammatic nature is in sympathy with the paucity of the child's ideas. A child's attempts at drawing only slowly and at a later stage [1] show conformity to a model with ideas of perspective.

STERN's observations on distorted geometrical shapes in drawing and writing appear important. Two-year-old children are very indifferent to the position of a picture book; when a five-year-old writes figures or letters from memory, the characters are often made in mirrored (reversed) writing. "The optical picture has no definite attitude, no top or bottom, no right or left, we only learn to designate as the top that part of the visual picture which can be grasped by stretching the hand upwards."

GIERING'S[2] investigations of school children show that they very early develop a high degree of space perception. The power of recognizing differences in length generally occurs in the third year.

These data show that vision unquestionably grows in depth and extent with the development of the child; they lead us to no conclusion, however, as to whether a certain material comprehension of the surrounding world is not still congenital. HERING, the most distinguished supporter of this latter—the nativistic—hypothesis formulates his views as follows:[3] "The visual world does not enter the dim consciousness of a child as a double picture drawn on the flat, but as an undivided whole complete with light and colour, as a space in which impressions conveyed from the double retina arrange themselves by instinctive law. Single vision is congenital just as is perspective vision, and neither the new-born babe nor the new-born animal is burdened with the necessity of constructing a single world in all its dimensions out of a double one with a deceptive flatness."

HAMBURGER[4] conducted experiments with chickens hatched out in the dark, and showed that they would only leave their perch for another baited with grain, when it was brought so close as to be almost in contact.

We can allege against this last argument that the mental character of a fowl only suffers slight modification after its escape from the shell; when the light is admitted the chick is already provided with a useful visual power, just as is the case with its sense of position and locomotion. Man's development at his entry into the world's light is not completed to the same extent as is the case in the chick.

It is just as necessary to look upon the potentiality of the eye with its central associations in all their delicacy as congenital, as it is to view the possibility of spatial perception as such. But I think there is no convincing reason for considering the latter to be a

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[1] KERSCHENSTEINER: "Die Entwicklung der Zeichnerischen Begabung," Munich, 1905.

[2] In, SCHUMANN, *Psych. Studien*, Leipzig, 1909.

[3] *Ophthal. Gesell.*, Heidelberg, 1906.

[4] *Klin. Monatsbl. f. Augenheilk.*, Beilageheft, 1905.

perception of the double retina (in HERING'S sense). In my opinion, it is far more likely that appreciation of solidity is of central origin and due to the variable impression which the bodily form of objects makes on our sensory organs.

The world around first crosses the threshold of the awaking consciousness of a child, when it has learnt to translate all sense-impressions into a plastic form with the consciousness whether they belong or not to individual objects[1] (*cf.* Chapter X.).

With regard to the genesis of vision I may finally refer to HARTMANN'S saying, quoted by UHTHOFF in similar circumstances: "In mankind the child appears to enter the world with nothing, and must learn all; in truth, however, he has an unbounded wealth compared to the nimble and alert chick creeping from the egg, he brings it all in undeveloped form, for those germs of development are so many, that only after nine months of fœtal life can they be shadowed forth in the embryo. So we have the maturing of character by progressive development of the mammalian brain going hand in hand with learning, *i.e.*, the moulding of that character by use, and thus we finally have a much richer and fuller result than the mere instinct of the animal can show."

COLOUR SENSATION IN THE CHILD.—PREYER[2] states that children do not distinguish blue from green with certainty. He goes on to show that black, white, yellow and red are the first colours to be correctly named; green and blue, later. Probably the results of colour painting do not exactly correspond to a like defect in the power of distinguishing or recognizing colours. W. A. NAGEL[3] found red-green blindness was quite as readily excluded in his little son as was blue-yellow blindness, although the child had learnt all the colours and kept them in mind throughout the tests, except only blue, which at first he recognized, but would forget in a few days.

WARBURG'S[4] researches show that there is a definite correspondence between the ability to name colours, and the degree of intelligence of the child. The more intelligent the child the less his deficiency in colour nomenclature.

The results of a colour test in a child of 6 years, are only to be accepted with distinct reserve, in the absence of an efficient test of intelligence.

This uncertainty, which we have just mentioned, in recognizing blue is the more interesting, as the defect is met with in the writings and poems of the ancients.

HOMER'S BLUE-BLINDNESS.—The controversy as to whether Homer was blue-blind or not, is due to the English statesman Gladstone, who, on philosophical and archæological grounds, advanced the view of the blue-blindness of the ancients, in a

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[1] LOHMANN: "Zur Frage nach der Ontogenese des räumlichen Sehens," *Zeitschr. f. Sinnesphys.*, xlii.

[2] "Die Seele des Kindes," 6 Aufl., 1905, Bd. xlii.

[3] *Journ. of Comp. Neurol. and Psych.*, xvi.

[4] *Münch. med. Wochenschr.*, 1909.

book published 1858.[1] HIRSCHBERG makes the remark, as SICHEL had done previously in 1841, that the representations of colours by the ancients differed considerably from our own,[2] an interesting fact of special study. GEIGIR strongly supports this view of the blue-blindness of the ancients, and his word carries great weight in the philosophy of speech. He says, concerning ancient times, "The eyes are raised to the heavens in devotion; the gods of heaven are the continual object of their glory and adoration. How strange and wonderful does it not then seem that in the Vedic songs and the Avesta, that in the Bible, the Koran and the Homeric poems, there is never the slightest reference to the blue of the heavens, which, particularly in the homelands of these ancient writers, has such a powerful influence. The opportunity to do so appears so obvious, insistent, one may even say compelling."[3]

A keen scientific controversy on this question was originated in 1877 by MAGNUS[4] in his book, "The Historical Evolution of the Colour Sense." MAGNUS considered that in the history of development there was a period when only light and not colour was perceived. Such is still the case in the peripheral portions of the retina (*see* Chapter VII.). The development of the sense of colour tones was inversely proportional to the vital force they possessed; the greater the power of the latter the earlier the development of the former (red, orange).

The theory that the ancients were colour-blind is supported by etymological evidence. In Homer, the expressions for red and yellow are definite, in contrast to the indefinite reference to green and blue objects. Homer sings of the hyacinthian hair of Ulysses. Blue is wanting in the Pythagorean scale of colours, which only distinguishes black, white, red and yellow.

BLÜMER,[5] later, showed that among the Roman poets also the expressions for blue colours appear to be very deficient.

A great many weighty arguments can be brought against such conclusions as to the state of the colour sense drawn from colour nomenclature. In fact, the whole hypothesis cannot stand. DOR,[6] JAVAL,[7] and HIRSCHBERG, show that even amongst modern authors great defect in colour naming can be shown; in the case of LA FONTAINE and CORNEILLE where such is the case, we cannot conclude that, because they never used the word blue, this colour sense did not exist in their time. HIRSCHBERG says, "If we descend, as I have done, into a freshly opened tomb of ancient Egypt, like those at Assuan of the reign of Se-Renpu in the twelfth dynasty. and certainly 4,400 years old, we can convince ourselves from the

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[1] HOMER Studies, 1863 and 1878.

[2] HIRSCHBERG: "Geschichte der Augenheilkunde," in GRÄFE-SÄMISCHE's "Handbuch der Augenheilkunde."

[3] "Ursprung und Entwicklung der menschlichen Sprache," Stuttgart, 1872.

[4] Leipzig, 1887.

[5] *Berl. Studien f. klass. Philol. u. Archäol.* xiii.

[6] Paris, 1898. [7] *Gaz. Med. de Paris*, 1877.

evidence of our senses from the colouring of the pictures and hieroglyphics, that the people who lived 1,500 years before HOMER had a colour vision quite as good as we of the present day, and certainly had the colour sense of blue." DOR quotes the coloured paintings and stained glass of the ancients; KRAUSE[1] considers that lapis lazuli would not have been so highly prized by the Greeks had they not appreciated its blue colour.

Those comprehensive critical and philological researches of MARTYS[2] and VOCKENSTÄDTS[3] culminate in the demonstration that a perfect equality in colour sense and colour nomenclature cannot be established.

Similarly inquiry into the colour sense of uncivilized races, made with a view to obtaining evidence as to the truth of this hypothesis, has given the same result. In those races which use a common term for several colours, there is still no deficiency in the power of distinguishing between the colours. The needs of daily life evolve the names of colours. The Kaffirs, who confuse green and blue in their speech, have thirty-one expressions for cattle relating exclusively to differences in their colour.[4] Valuable evidence was obtained by KONIG,[5] who conducted a colour test on an Indian. The Indian was able to name all the colours used by his tribe for ornamenting carved wood. When shown a blue pigment and questioned about it he was confused and could not answer. Finally, he went into an adjoining room, where there was a collection of the birds of his native land, and brought back a blue bird's skin. Displayed in the sketch, whose colour he was unable to name, were birds' feathers of the same blue colour.

In conclusion, we should note that a development of colour sensation in man during historical times cannot be proved. Why we find such an absence or paucity of expressions for blue amongst ancient writers is hardly a subject for a discussion on physiological sensation; its elucidation must be sought for in artistic taste.

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[1] "Kosmos," *Zeitschr. f. einheitl. Weltanschauung*, i.

[2] Vienna, 1879. [3] Paderborn, 1888.

[4] See *e.g.*, KIRCHHOFF: *Deutsche Revue*, March, 1881.

[5] "Ges. Physiol. opt. Abhandlungen."

CHAPTER III.

DISTURBANCES IN VISION DUE TO THE REFRACTIVE CONDITION OF THE EYE; PATHOLOGY OF ENTOPTICS.

Emmetropia, Hyperopia, Myopia, Astigmatism.—The ideal state of the refraction of the eye is that in which the eye at rest is focussed for distance, so that every object, which does not lie close at hand, can form a sharp image upon the retina; otherwise expressed, that rays of light falling parallel on the cornea, are so altered in direction that they meet upon the retina. If the "dynamic" refractive power, *i.e.*, the power of the accommodation to focus the eye for near objects, be also well developed, we have the most efficient possible condition. This "normal" refractive condition "emmetropia" is not found in all eyes. Either the eye is in many cases so constructed that the parallel rays only meet behind the retina, and even for distant vision this power of the accommodation to increase the refraction must be employed, which cases we call "hyperopia"; or we have to deal with too great a refractive power of the eye, so that near objects only can be clearly seen (myopia, short-sightedness), and concave lens reducing the refraction are rendered necessary for distant vision. Along with these variations we also find optical systems in which the refraction in one meridian differs from that of the meridian at right angles (the rule in such cases); this condition is termed astigmatism, for if the refraction of one meridian be the ideal emmetropic, the dispersion of light due to the variations in the other meridians make a distant point (στιγμα) appear not as such, but as a diffusion circle. Every one of these refractive errors produces unusual disturbances; either their very existence causes an acuity below normal, or else changes occur as an association or causal connection, which result in defective sight.

Defects in Vision Directly Due to Refractive Conditions.—Disturbances of the former class are well shown in the indistinct images of the uncorrected myope throughout life, or of the hyperope, though in the latter only to be seen when, at a time ranging with the age and degree of the error, the accommodative power is no longer sufficient to replace and correct the deficiency.

Myopes are well known to possess the power of improving their vision to a certain degree by half closing their eyelids (blinking

= μυόειν), and so reducing the diffusion circles. Astigmatic vision belongs to the class of defective sight directly due to refractive conditions, and is always obscured by diffusion when correcting cylinders are not worn (even then, too, in many cases, *e.g.*, in decentering of the cornea, or if the rays are not homocentric, in the two meridians).[1]

These diffusion figures do not correspond to simple forms, rays, oval or rounded outlines, as would be thought from STURM'S *Konoid*,[2] for the subjective observations, *e.g.*, MÜLLER-RÉE,[3] show very complex figures.

I may here refer to the work of GULLSTRAND,[4] which brings out a new view of the physical conditions of vision by astigmatics. From their divided refraction diplopia, or even polyopia, may result.[5]

DEFECTS IN VISION NOT DIRECTLY DUE TO REFRACTIVE STATE.—The hypermetropic eye must be looked upon as an aplastic, imperfectly developed eye; consonant with this view we find in it many functional deficiencies, such as congenital amblyopia (Chapter IV.), defects in fusion, with the resulting strabismic deviations of the eyes, and *amblyopia ex anopsia* (Chapter X.). The stretching of the eye in myopia produces pathological changes in the sclera (atrophy), indirectly affects the light sense (Chapter V.), and produces defects in the visual field (Chapter IV.) The "*mouches volantes*" (*vide infra*) occurring in myopes can be referred in part to these changes in the sclera, and in part to the short-sighted vision.

MACROPSIA AND MICROPSIA IN PARALYSIS OF ACCOMMODATION.—The visual disturbances due to paralysis or spasm of accommodation are not restricted merely to the loss of visual acuity at close range (or distance in the case of spasm). Defects in the power of estimating size commonly occur, and are due to a fallacious estimation of the increased or diminished focussing effort when looking at near objects. Whether, as WILBRAND-SÄNGER ("Neurologie des Auges," vol. iii.) maintain, the same phenomenon of micropsia occurs when an emmetrope looks through a concave lens appears questionable; the transposition of the nodal point of the optical system due to the introduction of the concave glass, seems to have much more to do with the apparent diminution of objects.

PATHOLOGICAL ENTOPTICAL PERCEPTION.—Along with the visual defects belonging to the first group, due to refractive errors and directly produced by them, cases occur showing defects in that physical part of vision which may be designated intra-ocular perception.

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[1] HESS in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde," and GULLSTRÄND, in HELMHOLTZ'S, Phys. Optik., 3rd ed.

[2] *Compt., rend. l'acad., d. Sc.*, xx., and POGGENDORF *Ann.* lxv.

[3] 1896. Danish Publication. Referred to in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde," by HESS.

[4] *Arch. f. Ophthal.*, liii.

[5] HUMMELSHEIM: Ophthal. Gesellschaft, Heidelberg, 1901.

The pathology of entoptics treats of those disturbances of vision produced by an abnormal stimulation of the receiving apparatus, whether this be due to some diseased formation disturbing the course of the rays, or a disordered sensibility from changes in the retina or sclera, or in their blood-supply.

Amongst the entoptical perceptions due to opacities and alterations in the refractive media, the "rainbows" of glaucoma and the "*mouches volantes*" of vitreous opacity are among the most interesting.

RAINBOW VISION.—Looking at a light through a window-pane flowered over by frost, a halo of rings coloured like the rainbow is seen (V. GRÄFE). Similarly this phenomenon may be observed if a light be viewed through a sheet of glass which has been dusted with lycopodium powder. The reason why the light is thus broken up into its constituent elements is evidently to be found in the bending and dispersion of its rays in the clouded medium. The same may often be noticed in a healthy eye, especially with a dilated pupil, and is then[1] due to variation in the refraction of the lens fibres or the corneal epithelium. When in a conjunctivitis mucous flocculi lie in front of the cornea, coloured rings—"*Schleimspectrum*"—are often seen, and a similar appearance is often caused by changes in the lens.

This rainbow vision most commonly occurs in glaucoma, and in such cases is most probably due to œdema and dulness of the cornea (the deeper layers of the epithelium, FUCHS).[2] The rainbow in glaucoma, according to SCHMIDT-RIMPLER,[3] is more brightly coloured than in the cases noted above. The ring is separated from the flame by a dark zone of 2—2·5° in breadth; the green is mostly inside, then yellow, red and violet in order.

The rainbow vision occurs during the interval when, in the so-called prodromal stage of the disease, an attack is making its influence felt on the eye; but even when the glaucoma has become firmly established (*Glaucoma evolutum*) these terrible rings of colour still occur. The attack (and the associated rainbow vision) is induced in many cases by a psychical influence. Anger, passion, excitement, even stirring music or theatrical scenes are capable of calling up the symptoms mentioned.[4] BLESSIG[5] reports a very interesting example of this (*cf.* French expression, *Glaucome émotif*). A celloist, who played with fervour and passion, always noticed these rainbows when performing; after a successful iridectomy he was able to betake himself again with pleasure to the music which he had begun to dislike. It must, however, be remembered in the case of sensitive and excitable people that sudden sensations of colour when listening to affecting music may be due to the so-called *audition colorée* (*see* Chapter IX.).

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[1] DRUAULT: *Arch. f. Augenheilk.*, xl.; SALOMONSOHN, *Klin. Monatsbl. f. Augenheilk.*, xli.

[2] *Arch. f. Ophthal.*, xxvii.

[3] "Glaucom" in GRÄFE-SÄMISCH's "Handbuch der Augenheilkunde."

[4] LAQUEUR: *Arch. f. Ophthal.* xxvi.

[5] *Petersburg. med. Wochenschr.*, 1907.

Further Subjective Visual Disturbances in Glaucoma.—The opacity of the cornea in glaucoma may induce the vision of coloured and bright spheres, quite similarly to that of coloured rings; and we almost invariably find the patients complaining of foggy and misty sight. The opacity of the refractive media disturbs the keenness of perception so that all objects appear in a fog and as though covered over with a veil.

Mouches Volantes.—The appearance of *muscæ* ("*mouches volantes*" myodesopsia) is quite as well known as rainbow vision. These sometimes occur in healthy eyes and are then due to remains of embryonic cells, vitreous fibres, &c., or they may be due to vitreous disease (exudations from diseased choroid, hæmorrhages, &c.). They commonly occur in myopia; a circumstance which may sometimes be explained by the affections of the vitreous and sclera which accompany the medium and higher grades of this refractive state, but also is explicable by the fact that in the short-sighted eye, to a certain extent from its magnifying power, anything which casts a shadow produces sensation. It is generally considered that the common so-called "physiological" *muscæ* which are not associated with any diseased condition, can be distinguished from those of pathological origin by the fact that they are invisible with the ophthalmoscope. This view is in the main correct, but it must be somewhat modified when we consider that Schmidt Rimpler[1] himself was able to perceive intra-ocularly for several weeks a rounded speck the size of a pin head which could not be found with the ophthalmoscope. Schmidt Rimpler considers that the characteristics of pathological *muscæ* are: (1) they occur suddenly; (2) they are more numerous and larger than the physiological; (3) they are of a blacker tint.

Physiological *muscæ* may certainly occur suddenly; as in every entoptical perception, it requires a certain amount of attention to recognize these *muscæ*. If, however, the attention be once directed to them, their appearance is always recurring, often under unfortunate circumstances. Physiological *muscæ* do not generally cause alarm, though nervous, excitable and hysterical people may be thrown into a state of great anxiety by them. Physiological *muscæ* have a transparent appearance, as though they were sketched with watered ink; those of pathological import are quite black. As opposed to opacities of the lens entoptically discerned, these "*mouches volantes*" float about spontaneously; they are seen particularly well when they are whirled about in the eye by rapid glances, especially if the eye be directed towards some diffuse and uniform white surface (a white painted wall, or the sky uniformly clouded or clear). They are more obvious after excesses *in baccho et venere* than in good health.

Much[2] investigated the shape of floating specks, and reported that the simplest form perceived entoptically was an appearance of a veil. The web consisted of "a simple row of closely set filaments

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[1] *Berl. klin. Wochenschr.*, 1911.

[2] *Arch. f. klin. Med.*, lxxviii.

forming a warp, and rows of globules at right angles to them as woof." In the web single filaments stand out in greater prominence; some may dissolve so that the globules alone remain, either singly or in rows. The globules appear to be more persistent than the filaments, they often lie in masses and completely surround small patches of network; then we have the true "*Mouches volantes.*" According to MUCH, this gauzy network always occurs in the morning, and the filaments and globules come

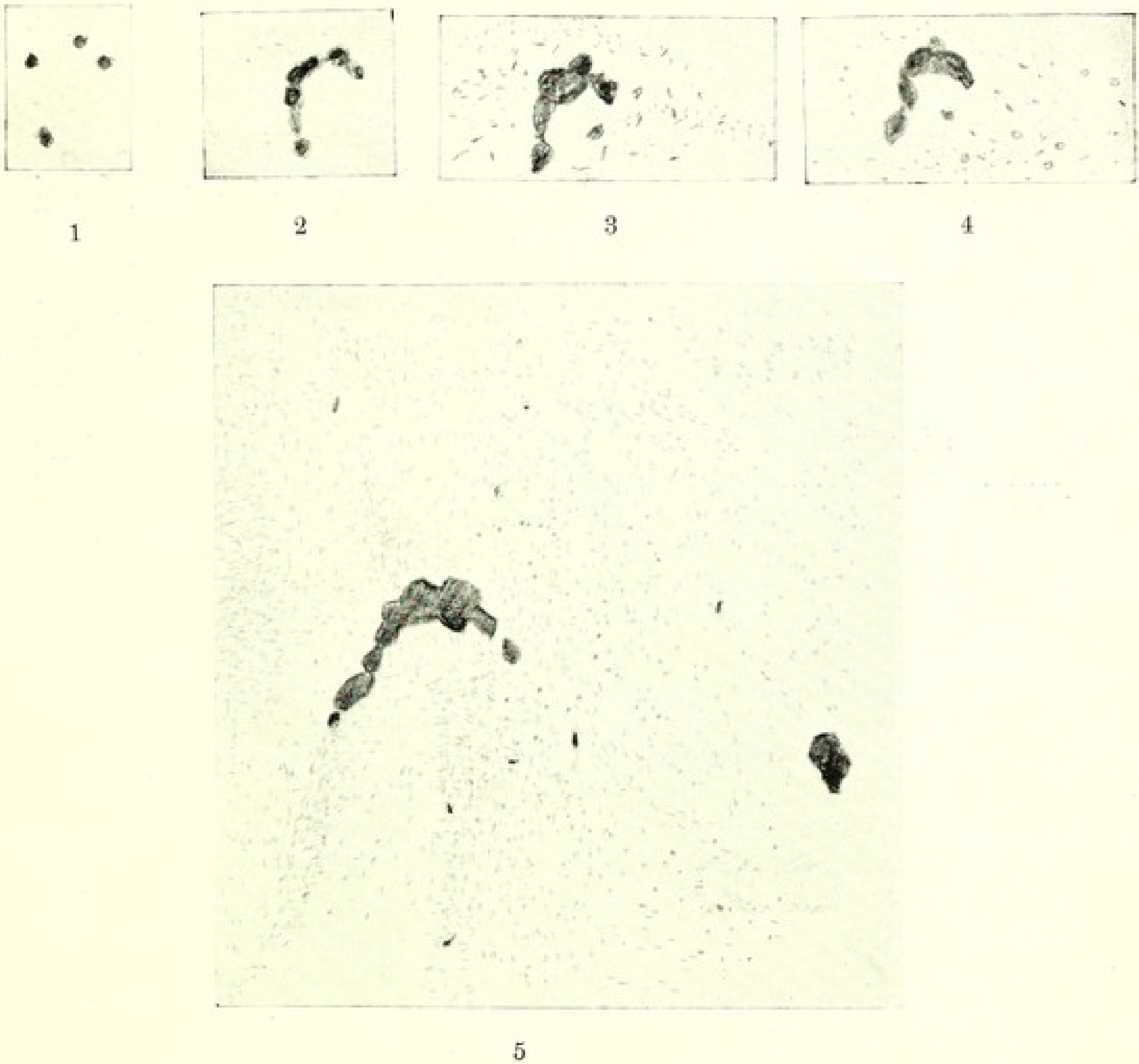

FIG. 6.—Five phases of a positive scotoma in choroiditis disseminata.

on after moving the eyes. MUCH insists that the "veil" must be closely related to the function of the vitreous; perhaps to something of the nature of glandular tissue serving as nutritive and restorative to the vitreous (?).

ENTOPTIC PHENOMENA IN CATARACTA INCIPIENS.—Opacities in the lens may be perceived entoptically in the same way as in the case of the vitreous. They are seen as dotted or linear figures conforming in movements to those of the eye, and remaining fixed when the eye comes to rest. HESS[1] used a lens opacity, subjectively perceived, as an elegant demonstration of the correctness of HELMHOLTZ's theory of accommodation. At the moment of accommodation the spot in the lens was subjectively seen to move upwards. HESS therefore concluded that the lens dropped down, and was to some extent released in accommodation, so that its elasticity, constantly straining after a more globular form, was enabled to act. Along with a general fogginess of the whole field of vision, we often find characteristic complaints by patients with incipient senile cataract. On account of variations in the refraction of the lens fibres, they see the street lamps or the moon double or even multiple (diplopia and polyopia). It is often such a complaint which leads to an exact examination of the lens; a matter of considerable importance when we remember that undoubted cases have been reported (*e.g.*, by EVERSBUSCH), where opacities in the lens (networks) in their incipience have been susceptible, to a certain degree, to medical treatment.

ENTOPTIC PHENOMENA IN DISEASE OF THE RETINA AND CHOROID.—Amongst the varied entoptic phenomena occurring in diseases of the retina or choroid, we should note that hæmorrhages either in or in front of the retina are accompanied by red and black points and spots along with scotomata. These latter are called positive when they are subjectively obvious to the patient without any perimetral examination. In general they do not always appear as black areas, in fact they show great variability. The patients may accustom themselves to these defects in their field, when the scotomata then become negative; on other occasions they again become apparent. A patient with choroiditis told me that the eyes were generally quite quiet, but that when any emotional disturbance occurred, blinding flashes and branching flames shot out of them. Apparently disturbances of the circulation bring about varying conditions of the scotomata. Another patient with choroiditis disseminata saw black scotomata with his right eye, and sketched them from their origin by using care and attention (*see* fig. 6). He saw large patches before the left eye—more recently affected—"these continually came and went, so that at one moment they showed up as white spots (like fat drops on glass), then changed to star-shaped figures (like a fine cobweb wet with dew), and finally to perfectly black spots. Just as they appeared, so these black figures vanished.

PHOTOPSIA METAMORPHOPSIA.—Subjective disturbances due to affections of the rods and cones, or choroidal disease generally, are termed photopsia or metamorphopsia. To the former group belong the phosphenes, flashes of light, and colour; and to the latter the so-called micropsia and macropsia.

PHOSPHENES.—Photopsia often takes the form of progressive phosphenes, from the vision of sparks and long flashes, and because they so often are fixed in shape and position we are justified in the conclusion that they are disturbances due to peculiarities or

[1] *Arch. f. Ophthal.*, xliii.

changes in the circulation. This view is supported by the fact that the movements of the blood can be physiologically discerned entoptically in the form of phosphenes. Bright spots, corresponding to the circulating blood, come and go when the gaze is directed to an evenly lighted sky.[1]

These bright glittering points swarm throughout the whole field of vision, twisting and turning. After many careful investigations I have convinced myself that such phenomena never occur in the narrow zone around the point of fixation; and I therefore conclude that they are due to the movements of the blood corpuscles in the retina. Entoptic phosphenes are particularly vivid over the whole field after violent sneezing or blowing the nose, when fiery spots are seen to course about so rapidly as to produce the impression of streaks of light. Other local circulatory obstructions in the retina give rise to the appearance of large irregular defects in the field; in the resulting black or brownish coloured scotoma the patient will often see fiery globules, lines and figures. An embolism of the central artery naturally causes sudden loss of vision; temporary obstructions to the circulation produce milder disturbances of vision. In this connection there is an observation of HIRSCHBERG[2] on a patient of a nervous temperament, who at the Stock Exchange one afternoon had a headache with flickerings before the eyes. Subjective appearances like "fireworks" followed for a few minutes. The ophthalmoscope revealed an embolism of a branch of the central artery, which rapidly disappeared under massage; vision returned within a day.

PHOTOPSIA AND CHROMATOPSIA.—The pathological phosphenes, in contrast to the accommodative, which show as rings of light,[3] appear as flashes or moving lines of light, and can be referred to circulatory changes in the retina and choroid. We cannot to the same extent ascribe a similar origin to the simple photopsia and chromatopsia showing no change in position. In their case we must postulate either an inflammatory exudation, or a variation in sensibility affecting the retinal end-organs. Complaints of coloured floating specks are often made in cases of retinal or choroidal disease; and a patient once related to me how she saw distinct masses of yellow, green and red spots which moved in a kaleidoscopic manner.

FLICKERINGS.—People with choroidal disease often complain of flickering before their eyes. This symptom was described by FÖRSTER in his classical paper on *Retinitis syphilitica*.[4] It consists in the appearance of bright spots and figures which vibrate and undulate to and fro, and need not necessarily correspond in extent to the scotoma or to a choroidal patch visible to the ophthalmoscope. Objects seen through these flickerings appear to be

[1] PURKINJE: "Beiträge zur Kenntnis des Sehens in subj. Hinsicht." 1899.

[2] *Zentralbl. f. prakt. Augenheilk.*, xii.

[3] E.g. BRUCKNER: "Zur Kenntniss einiger subj. Gesichterscheinungen," *Arch. f. Aügenheilk.*, lxiv.

[4] *Arch. f. Ophthal.*, xx.

motionless. This symptom, which HIRSCHBERG ascribes to a diminution in the blood supply, is often the first symptom of the disease to show itself, and may persist longer than any other functional disturbance.

METAMORPHOPSIA.—Distortion of visible form is always referable to a displacement of sensitive retinal elements from their normal relations to each other; it occurs in detachment of the retina and exudative choroiditis. This distortion must be distinguished from a form of vision as through a lattice,[1] which is due to a "patchwork" destruction of the retinal elements. Metamorphopsia becomes particularly obvious when looking at long vertical lines such as the frame of a door or window. It can be demonstrated by gazing at a system of vertical or horizontal parallel lines; in a case of choroiditis the lines will be seen to tend either out or in at the point of fixation. In the region of the retina corresponding to this distortion, the retinal elements are either crowded up, or separated by an exudate; and if an image of writing or printing fall on such an area the resulting thickening or thinning of the retina will cause discrepancies in the perception of size: micropsia or macropsia.

ENTOPTIC VISIBILITY OF DISEASED AREAS.—Many of these intra-ocular perceptions, owing their origin to some peculiarity in the structure of the membranes,[2] must naturally be profoundly influenced by pathological changes. The literature of this subject is not large.[3] GAHLEN published excellent diagrams showing how choroido-retinal nodules appeared to him by the diascleral test of the vascular shadows. The scotomata which he saw corresponded to the ophthalmoscopic appearances, and gave a good index of the importance of the membranes. When GAHLEN proceeds to say that the perimetric method of examination is a more valuable practical test than the entoptic, I can support him heartily, having been at considerable pains to elucidate the changes in entoptic perceptions, due to diseased processes. The accurate appreciation of entoptic perceptions necessitates a considerable power of physiological observation, and in my opinion the many gaps in this section of intra-ocular pathology will only be filled up when persons are affected, who either naturally, or by training, are fit physiological observers.

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[1] HIRSCHBERG: "Beiträge zur prakt. Augenheilkunde," i, 1876.

[2] A. LOHMANN, in NAGEL'S "Handbuch der Physiologie."

[3] Dissertation, by OLSHAUSEN, Halle, 1885. GAHLEN: "Verhandl. d. Phys. med. Gesell." Würzburg, 1911.

CHAPTER IV.

ABNORMALITIES IN CENTRAL AND PERIPHERAL VISION.

The Central and Peripheral Eye.—The functional activity of the eye varies greatly in different parts of the retina. Acute central vision can be distinguished from indistinct peripheral vision. The difference between them is not merely one of acuity, for while central vision far surpasses peripheral in respect to the optical perfection of the image of an object, and the fine perception of the detail of such image, peripheral vision is superior in the perception of movement. Retinal function can be divided, allocating discovery to the periphery and inspection to the centre. Along with these local differences in retinal activity are associated others which, by adaptation, influence vision in dim light (scotopia), and lower the relative value of central vision; these will be discussed in the next chapter.

Corresponding to these functional differences, the eye may be considered as an organ which unites two forms of apparatus of different functional value.[1]

The "central eye" is an elongated eye with a narrow-angle field (fig. 7); the possibility of a high grade of visual acuity is associated with the delicately inlaid sensory elements, and the provision of an isolated sensory path for each end element. The "peripheral eye," on the other hand, has a wide-angle field and a mosaic of end elements with concentrated sensory connections, and is less adapted for keen perception of detail. The periphery, however, has an advantage over the centre in the elements necessary for vision in dim light.

Contents of Chapter. — Amongst the diseased conditions especially affecting the central eye we note: (1) Congenitally defective acuity (*Amblyopia congenita*); (2) congenital total colour-blindness; (3) toxic amblyopia (*Neuritis axialis*), and other forms of so-called retrobulbar neuritis. A disease especially affecting the function of the peripheral eye occurs in that peculiar degeneration called retinitis pigmentosa. This chapter will conclude with those other anomalies of the field which can be referred to changes in the retina or choroid. The consideration of the visual

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[1] Pütter: "Organologie des Auges," in Gräfe-Sämisch's "Handbuch der Augenheilkunde," ii.

disturbances mentioned must be preceded by a short reference to the normal function of central and peripheral areas of the retina, and some mention of the usual methods of examination[1] (testing visual acuity, taking out fields).

VISUAL ACUITY.—The definition of visual acuity by the smallest angle, subtending which an object can be recognized, does not clearly delimit this visual function. For an accurate measurement we must eliminate everything which is due to intelligence and

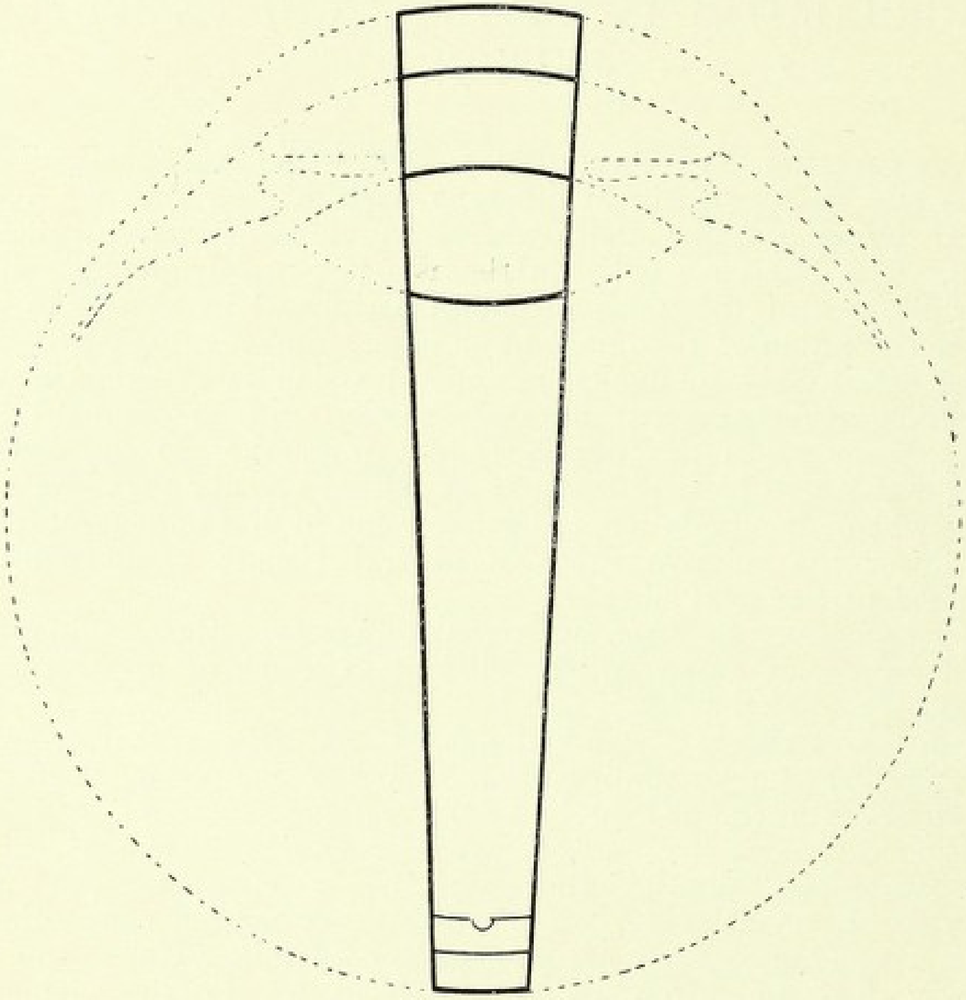


FIG. 7.—Central eye and peripheral eye (after PÜTTER).

practice; a hunter might appear to see where the unpractised perceived nothing. But if the vision be tested by simple objects which leave small play for any interpretation of the sensations, we readily recognize differences in the functional activity of the same eye by different tests.

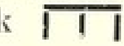
If a white and a black card lying on a flat surface be brought together so that a rectangular part of one is superimposed on the other, the resulting change in contour is recognized when sub-

[1] LANDOLT: "Methods of Examination," in GRÄFE-SÄMISCH's "Handbuch der Augenheilkunde," ii.

tending an angle of 11 seconds.[1] But a greater angle, averaging 1 minute, is necessary for the appreciation of two points as discrete. If a row of 6 to 12 equidistant points be drawn, and observed at such a distance that the visual angle is 1 minute, they will certainly be recognized as discrete, but to count them, the visual angle of the interspaces must be increased at least 4 to 6 times.[2]

The first of the three visual attainments we have mentioned is designated by HERING as "sidelong change of position" (*seitliche Lageverschiebung*). The possibility of recognizing such minute alterations in position, corresponding in the retinal image merely to a fraction of a cone, will be appreciated when we consider that such a visual power does not necessitate the individual action of single cones, but merely of two contiguous rows of cones corresponding in direction to the outlines which invade each other.[3]

In considering the relation existing between the cones at the fovea, and the power of recognizing two separate points, the basis of the minimum angle of distinction has been sought in the structure of the retina and the size of the cones. The hypothesis has been advanced, and supported considerably by calculations, that a single sensory element, either unstimulated or differently stimulated, must lie within the retinal image and between the two elements which are excited by the two points, before these can be appreciated as discrete. The power of counting equidistant points has been called by GERTZ "perception acuity"; he considered it as depending on the existence of a central area. This area differed from the remaining superficies of the locality of most acute vision, in that the sensations derived from it have the greatest sense intensity. The "perception acuity" is rendered possible when each individual point is fixed by direct vision on this central area and accentuated above the others in sensation.

CLINICAL METHODS OF MEASURING VISUAL ACUITY.—The *minimum separabile* is usually taken as the measure of visual acuity; that is to say, the visual angle is defined at which two points are recognized as discrete.[4] SNELLEN, 1862, used letters as a test, the thickness and interval between their constituent lines being 1 minute, and their total size 5 minutes. It was very soon noticed that certain letters and figures thus constructed differed in legibility, and were read at a different distance than the others; the psychical factor of intelligence and other still unnamed factors, also came into play. SNELLEN'S fork  placed in varying attitudes, also

[1] WÜLFING: *Zeitschr. f. Biol.*, xxix.

[2] GERTZ: *Skand. Arch. f. Phys.*, xx.

[3] HERING: "Ber. d. Math. Phys., Kl. d. Kgl. Sächs. Gesell. d. Wiss." Leipzig. Naturwiss. Teil, 1899.

[4] Contrast here GUILLERY'S method, using points to determine visual acuity; these were variously placed in different rectangles, and the examinee was asked where they were. Consider SCHENK'S opinion on this method (*Zeitsch. f. Augenheilk.*, i): "Such an act of vision belongs to the zone between the light sense and the form sense."

LANDOTT's rings (fig. 8) do not have this disadvantage, the examinee being asked to indicate the opening in the figure. On the other hand, the increased brightness of that half of the figure which is open may arrest the attention, even when there is no question of appreciating the *minimum separabile*.[1]

The test cards made on SNELLEN's principle depend upon the hypothesis that the angle of 1 minute is necessary before two separate points can be distinguished. This empirical basis produces, in the construction of the individual letters, mistakes whose origin is difficult to explain. LÖHLEIN and GEBB, in preparing a test card, attempted to escape from a form-construction on principles which did not ensure exactness, and after numerous individual tests undertook to estimate in an arithmetical form the empirical distance of legibility of many signs, letters, and figures. The following table by these two authors shows, on the one hand the varying legibility of the symbols—*e.g.*, the test tables of SCHWEIGGER and HEINE—and on the other how much better their own method was. The individual figures and letters of the test cards are given under the distance in metres at which they actually were recognized.[2]

Symbols nominally to be read at 5 metres	Average actual distance at which they were read by the emmetropic eye				
	9	8	7	6	5
HEINE'S	7	14	2	0 3	8
SCHWEIGGER'S		L	7 0	4 3 2 T E	D 6 5 C
LÖHLEIN und GEBB'S					6 5 U D R 3 7 L

HESS[3] describes the principal defect in test cards as the crowding of simple and complex letters into the same quadrate area, and used for the "international test" numbers of such a form that they were recognized at approximately the same distance, these are 1, 4, 7, 0. For illiterates and as a control LANDOTT's rings were used (fig. 8). The practical point in the utility of LÖHLEIN and GEBB's test is that it is constructed on the basis of test by artificial light, a fact which for practical comparisons and results must be of some importance.

Uncertainties in results occur in the use of HESS's international test, and are due to the fact that the horizontal spaces between the letters are not relatively equal.

[1] LÖHLEIN and GEBB: Knapp's *Arch. f. Augenheilk.*, lxv.

[2] *Idem.*, *ibid.*

[3] *Arch. f. Augenheilk.*, lxiii.

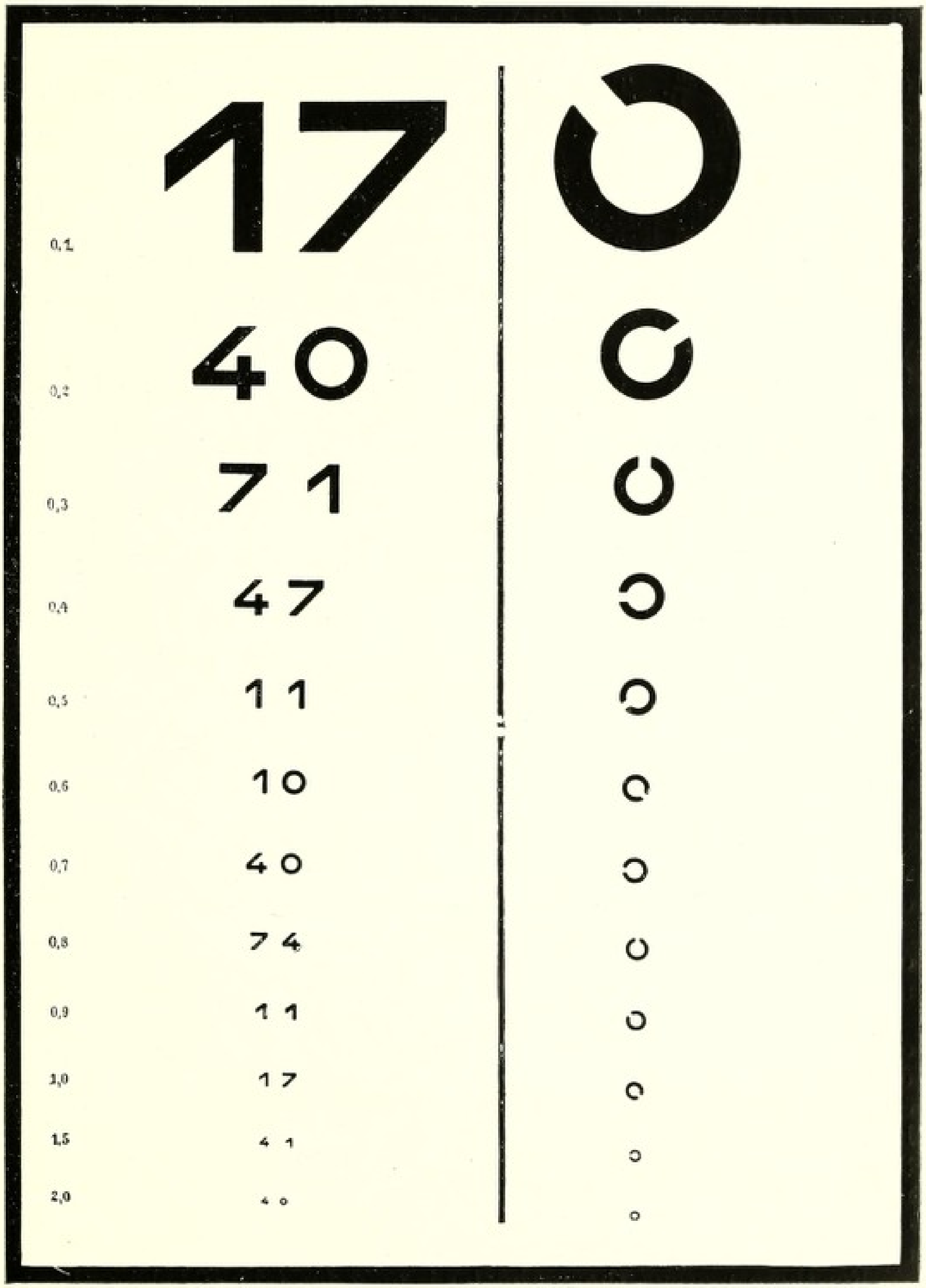


Fig. 8.—International test card (Bergmann, Wiesbaden).

The test is carried out by placing the card at a fixed distance of 5 metres. The number given alongside each row shows the distance (D) at which the thickness of the lines and gaps subtend an angle of 1 minute. The visual acuity is then reproduced by the fraction $\frac{d}{D} = \frac{5}{D}$. The old geometrical progression D = 50, 35, 20, 15, 10, 7, 5, has now mostly given way to an arithmetical one of decimals $\left(\frac{d}{D} = \cdot 1, \cdot 2, \cdot 3, \&c.\right)$.

Though in the low grades of vision a finer graduation of the various degrees is less essential, it is very desirous in the higher grades (LANDOLT), and such a condition is far better met by the decimals than by the older geometrical progression.

FIELD OF VISION.—The chief method of testing the peripheral vision is by an examination of the field of vision,[1] which corresponds to that portion of the field of view from which the eye at rest can receive visual impressions.

The factors determining the extent of the field of vision depend on individual peculiarities (bony margins of the orbit, shape of the nose, upper lid, size of pupil); there are also modifying objective conditions in the state of illumination, and subjective in tiredness, or the unaccustomed nature of the first test, which must be borne in mind. It is desirable in every record of a field to note, *e.g.*, result uncertain, patient weary, sky clouded, &c.[2] If the general condition of the margins of the field be wished, the simplest way is to seat the person so that he is opposite to the observer, and have him fix the opposite eye of the examiner with the eye to be tested. Now move a finger from the periphery towards the centre, and ask when it is visible. Another simple method is to darken the room and shine the light of a candle or the reflexion of a mirror on the retina, working in from periphery to centre, and thus test the functions of the various regions. This method is very valuable when there is very poor vision (*e.g.*, in cataract), when by the ordinary method the object would not be seen at all.

For comparative records of the field, in estimating the progress of any disease, it is necessary to record a plan of the field on a chart, and for this a more exact method of examination is necessary.

Testing the field on a plane surface, such as on a wall, the so-called "campimetric" method has this great drawback, that the different retinal zones are measured at different distances. If the eye be placed 30 cm. from the recording surface, a distance of 85° lateral from the point of fixation would mean a linear distance of 3·43 metres. And if to avoid this inconvenience the eye be brought nearer, the extent of the central and paracentral regions is reduced extremely, and the testing of these areas either made quite impossible or certainly very difficult.

For these reasons the perimeter is used for taking fields; this

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[1] C. SCHLOSSER: "Die für die Praxis beste Art der Gesichtsfelduntersuchung." VOSSIUS: "Zwanglose Abhandlung a. d. Augenheilkunde," 1901.

[2] FREYTAG's charts (S. Hirzel, 1912) have spaces for these.

obviates the defects of the "campimetric" method, as every point on the arc of the machine is equally distant from the mid-point of the eye. The arc can be rotated so that every meridian can be tested separately. To fix the attention as much as possible on the test, it is advisable to exclude all surrounding objects from the field of vision of the patient; the centre of the perimeter should carry a

FIG. 9.—Perimetry.

smooth round disc, so that in this part at least the distraction of surrounding objects will be avoided (UHTHOFF's disc, *see* fig. 9). The perimeter must be well and evenly illuminated; and this object is best attained by placing it before a window, particularly with a northern aspect.

Small pieces of paper or cloth[1] are used as test objects; larger

[1] Heidelberg paper, Marx cloth.

objects (20 mm.) are used for defining the limits of the field and smaller ones in searching for scotomata. Each eye must be tested singly. The HIRSCHBERG and SCHLÖSSER method is thoroughly sound; they cover the other eye with a glass of complementary colour to the test object. The colour of the object is thus neutralized, and besides securing a less tiresome method, there is the advantage that the other eye assists and controls the fixation of the one under examination.

HAITZ[1] method is very valuable in the case of small central scotomata. Two flat surfaces are presented stereoscopically and binocularly fused. Very small objects thus used assist greatly in searching for a scotoma, and so small scotomata are discovered which were not shown by the perimeter.

Coloured test objects, especially blue and red, are used as well as white. As a rule, central disease of the choroid (choroiditis centralis) shows only scotomata for blue, while retinal and optic nerve conditions (toxic amblyopia) show them for red. Quite frequently a progression in the area of a scotoma for different colours is shown; when measured with a red object it is larger than with blue, and this again larger than with white. Perimetric tests of the field margins with coloured objects are very important; for example, in an early tabetic atrophy the field for white may be normal or almost so, while a concentric or interrupted constriction of the field for red may indicate the disease. Such an example shows what brilliant results perimetric examination with colours may give in the very earliest stages of disease, when colour vision at the retinal centre appears normal, or at the most only doubtful.

As a matter of expediency, the physiological scotoma (blind spot) should be demonstrated before searching for scotomata. This spot lies some 15° away from the point of fixation. LANDOLT and DOBROWSKY found that this distance was increased in hyperopia and diminished in myopia. MAUTHNER confirmed this for high grades of myopia, but found in the lower grades the same separation of the blind spot from the centre as in the normal; his explanation should be accepted with great reserve, as on account of the greater distance between the retina and the nodal point of the eye in myopia, a perimetric reduction in the distance readily appears.[2]

REDUCTION IN VISUAL ACUITY TOWARDS THE PERIPHERY.—The visual acuity found by the methods already described in brief, only refers to a small area of the retina, that of most acute vision. Visual acuity drops somewhat rapidly from the centre towards the periphery in all directions, but not equally in all meridians. GUILLERY[3] established an unmistakable preference in the inner meridians of the retina. The visual acuity at about 30° dropped more rapidly vertically than horizontally. If the height of visual acuity be represented as a function of the distance from the centre of the retina in a system of perpendicular co-ordinates, the figure

[1] *Klin. Monatsbl. f. Augenheilk.*, xlii.

[2] HESS in GRÄFE-SÄMISCH's "Handbuch der Augenheilkunde."

[3] PFLUGER's, *Archiv.*, lxviii.

which Dor [1] constructed is obtained (*see* fig. 10). It appears that a spot 5° excentric from the macula has an acuity of only $\frac{1}{4}$, and one 20° excentric, that of only $\frac{1}{40}$. These values are naturally approximate on account of the difficulty of such excentric estimations, and must not be unreservedly used as standards for any individual case, especially for comparative calculations. This great difference in the conditions of acuity in the centre and in the periphery of the retina is evidently connected with some anatomical peculiarity of the area in the centre, and this, as has already been mentioned, is found in the isolated individual nerve connections of this part in

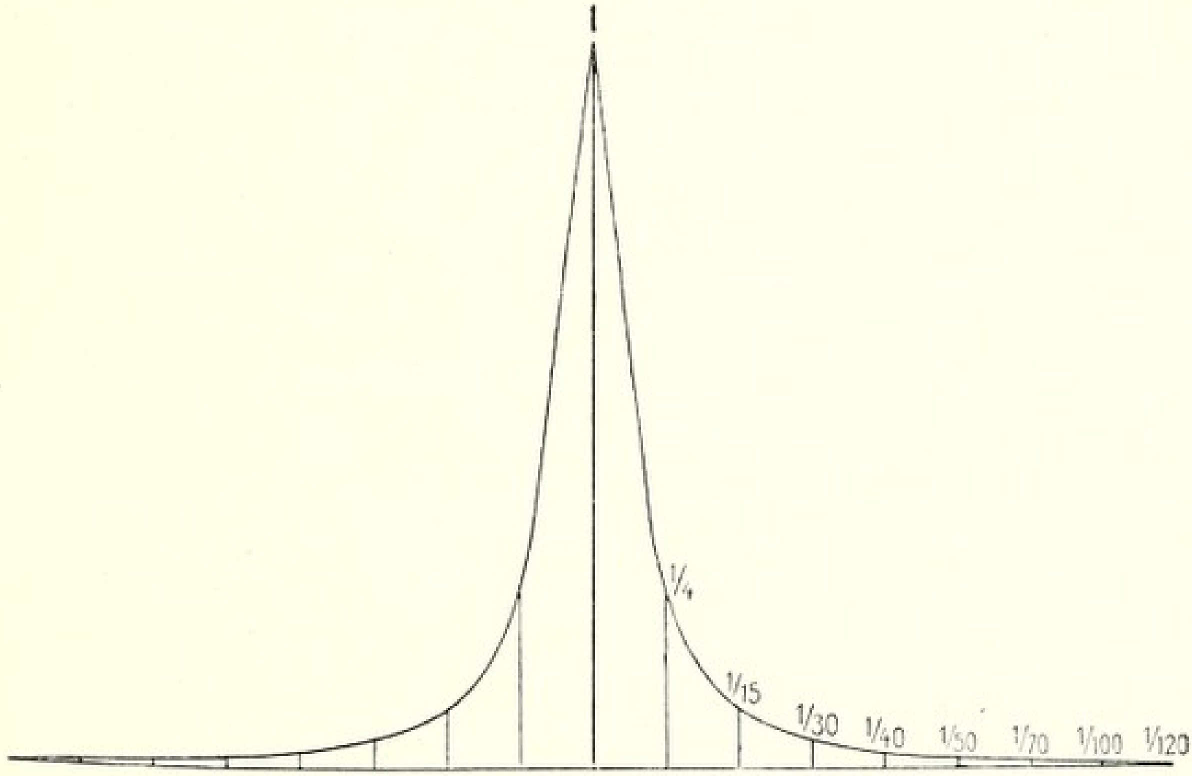

Fig. 10.—The state of visual acuity in the centre and periphery of the retina (Dor).

contrast to the more concentrated ones in the periphery. The areas of discrete sensation in the retina, therefore, differ according to their position, and in the elaboration of this idea the gradual diminution in number of the cones from the centre to the periphery is significant. In the centre of the retina cones alone occur, but as we pass outwards rows of one, two, three or four rods are interposed between the cones which themselves become thicker.[2] The correspondence appears a simple one, but a more careful comparison will show that the diminution in acuity is proportionately greater than the reduction in the cones. It is advisable for the present to refer the decrease in acuity to a predominance of the centre over the periphery, which is more pronounced in the difference of their nerve connections.

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[1] *Arch. f. Ophthal.*, xix.

[2] v. Kölliker: "Handbuch der Gewebelehre," iii.

Amblyopia.—If the visual acuity is below the normal the expression "reduced" (*abgestumpft*) is used, and we speak of an amblyopia. A sharp delimitation of normal visual acuity from amblyopia in reference to the higher grades of vision is difficult, because the maximum power of the eye varies with the state of the individual, age and race. Central vision in old age is less acute than in youth,[1] and appears also to be keener in savage than in civilized races.[1]

The more severe reductions in vision may be due to most varied causes. Either an imperfect image is formed, or the percipient apparatus is defective in its action. A "mechanical" or "physical" amblyopia occurs when we have opacities in the refractive media (corneal nebulæ, lens or vitreous opacities), and when the obstruction is removed the amblyopia disappears. An apparent amblyopia occurs in cases of errors in refraction; this vanishes when a suitable glass is worn. We must not conclude, however, that every "dioptric" amblyopia can be corrected, anomalies such as decentration of the cornea, keratoconus, an astigmatic form of the eye producing heterocentric instead of homocentric pencils of rays are difficult or even impossible to correct by lenses.[2] If the perception of the visual impression is interfered with, then the defect is either due to changes in the retina (organic amblyopia) or to changes in the nervous connections (nerve amblyopia).

Congenital Amblyopia.—At present we are not in a position to define the origin of many cases of congenital amblyopia. Respecting the actual diagnosis of "congenital" amblyopia, it is important to establish that the defect dates from birth, and remains unchanged by treatment (refraction, vision training, &c.), also that there are no changes visible by the ophthalmoscope, or complications in the neighbouring organs (orbit, nasal sinuses) or nervous system. Ophthalmoscopic examination in congenital amblyopia is mostly negative with respect to gross changes, but slight variations may be distinguishable, such as a smoky reflex in the macula with deep pigmentation, or defects like the "hole at the macula"; these fundus changes, though never prominent, are present as a rule. The abstract distinction from amblyopia ex anopsia is important, though in practice it is hardly possible. This amblyopia ex anopsia, which improves with correction and practice, is considered by many authors (Silex, and to some extent Heine) either not to exist or to be extremely rare; others (*e.g.*, Krusius[3]) hold the opposite view, that the term amblyopia congenita, in contrast to amblyopia ex anopsia, is much too widely used. Krusius states as a fact that the vision of an amblyopic eye can, by suitable treatment, be brought up to normal, even though the defect be extreme, provided that the patient be young enough, a result which in later life is seldom or never attainable.

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[1] Cohn: *Arch. f. Ophthal.*, xvii, xl.; *Berl. klin. Wochenschr.*, 1898.

[2] Hess in Gräfe-Sämisch's "Handbuch der Augenheilkunde."

[3] "Ophthal. Gesellschaft," Heidelberg, 1908.

STRAUB in an earlier work[1] records as proof of the congenital nature of amblyopia, that it occurs in non-squinting individuals in whom the eye with good vision is of the same refraction as the defective one. The following table by STRAUB[2] gives a valuable *résumé* of the occurrence of monocular amblyopia in hyperopia, and its relation to squint, isometropia and anisometropia.

MONOCULAR AMBLYOPIA IN HYPEROPIA.

Degree of hyperopia	Isometropes with an amblyopic eye		Anisometropes with an amblyopic eye	
	No squint	Squint	No squint	Squint
1 D	15	7	6	—
2 D	26	12	18	3
3 D	4	11	9	4
4 D	7	7	14	3
5 D	3	5	4	5
6	14	10	18	7
7	4	3	3	2
8	3	1	2	—
9	1	1	—	2
10	—	—	—	1
15	1	—	—	—

We have previously referred to STRAUB'S conclusion that the occurrence of amblyopia with isometropia and isotropia, as shown in the tables, is a proof of its congenital origin. The same writer follows this up by stating that it is not this relationship of the amblyopia (*i.e.*, to the refraction or muscle balance), but that to binocular vision, which is the criterion as to whether it can be considered as "congenital" or has developed "ex anopsia." But when, with no visible cause, defective binocular vision is found in amblyopia, the conclusion that the latter has developed on account of the defect and through disuse, though plausible, is by no means convincing, and certainly does not prove that an anatomical basis does not lie at the root of many cases of "amblyopia congenita."

SCOTOMATA IN CONGENITAL AMBLYOPIA.—Along with the frequent strabismus, and a more or less marked reduction in central visual acuity, we find in congenital amblyopia, normal adaptation (LOHMANN), normal colour sense, and a normal extent of field; in the majority of cases, however, a central scotoma can be demonstrated. This has been observed and recorded by various authors; HEINE'S[3] systematic investigations showed that such a scotoma occurred in 90 per cent. of cases.

If we attempt to represent graphically the condition of such an amblyopic eye, we obtain such contours as are shown in figs. 11 and 12. In the central area of the retina the visual acuity is

[1] *Arch. f. Augenheilk.*, 1896.
[2] *Arch. f. Ophthal.*, lxx.
[3] *Klin. Monatsbl. f. Augenheilk.*, 1905.

represented either by the greatest rise taking the form of a flat plateau elevation, without the normal peak, or by a crateriform depression of greater or less depth occurring in the centre. It is only in the latter forms that a scotoma may be anticipated. There is, however, still the possibility of a state of affairs other than that represented, and one we also commonly designate as a "scotoma." For instance, if as the result of some injury the individual visual elements in the same area suffer damage, and in comparison to their visual acuity show a disproportionate loss of field for colour. The presumptive difference between such a scotoma and that occurring in amblyopia congenita will be appreciated if the following considerations are borne in mind. The form sense, like the colour sense, is generally blunted towards the periphery of the retina;

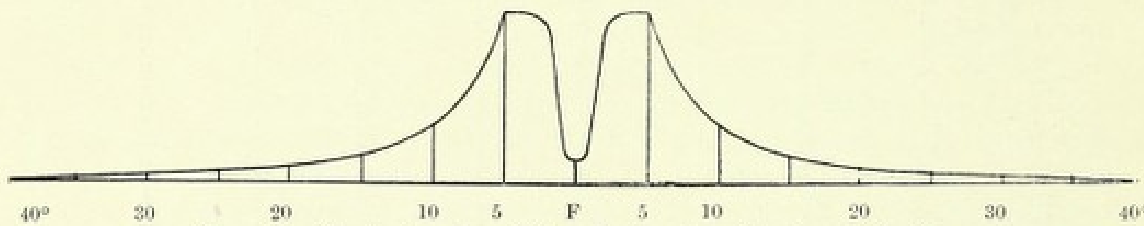

Fig. 11.—Central and peripheral visual acuity in amblyopia.

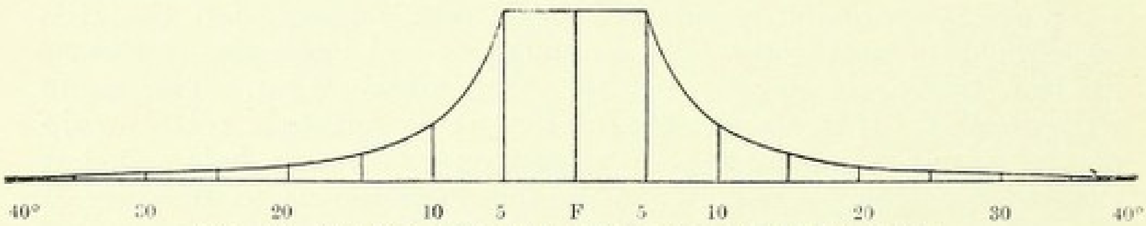

Fig. 12.—Central and peripheral visual acuity in amblyopia.

this is shown by the negative results on testing with a small test object contrasted with those obtained with a large one (*see* Chapter VII). A coloured 5 mm. object is unrecognizable by the normal eye at a point where there is still a vision of $\frac{1}{10}$, a 10 or 18 mm. object, however, is still clearly seen with this degree of excentricity. No one would on this account postulate a scotoma. Now let us consider that the retinal development which normally shows the differences represented in fig. 10, has by amblyopia congenita suffered a change to that of fig. 11; corresponding to the depth and extent of the depression, we can now demonstrate an absolute or relative incapacity to recognize small objects either coloured or white. This will be exactly parallel to the absence of any sensory impulse which the same object would produce at a corresponding spot in the periphery of the retina (*i.e.*, one with the same visual acuity).

The reproach of haggling over words may be cast at such a statement, and it might be held in the same way that even a part of the field is a scotoma, if it is of lower efficiency than a neighbouring peripherally situated spot. We must admit that, in theory at least, even though such a variation be present and a scotoma occur of acquired origin from damage to the retinal elements, or to a lowered central visual efficiency, this has no weight in a discussion on the slight blunting of sensibility which may occur in places in a normally developed eye. Whether in fact this distinction of a scotoma resulting from damage or defective development of the central area of the retina can be maintained, is a question which must be decided by comparative investigations into visual acuity and intensity of the scotoma, on the one hand when pathological changes have occurred, and on the other, in congenital cases. Naturally the visual acuity and the scotomata must not be unreservedly held to be parallel phenomona, particularly in congenital amblyopia; on the contrary, careful attention must be paid to a defect in the field and the visual acuity at exactly the same spot. For it is possible that we may have a central scotoma not coinciding with that portion of the retina which, on account of its visual superiority, is actually used for vision, and which would naturally be tested in estimating any visual defect.

In HEINE's cases an association was established between the visual acuity and the extent and intensity of the interference with the field. In the following table I have recorded in percentages HEINE's results :—

VISUAL ACUITY	SCOTOMA DEMONSTRATED IN				
V.c. =	None	Relative for colour	Absolute for colour	Relative for white	Absolute for white
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
$\frac{1}{2}$	28·4	63·9	..	..	7·1
$\frac{1}{3}$	12·4	49·6	..	..	37·2
$\frac{1}{6}$	12·5	..	..	37·5	50·0
$\frac{1}{10}$	9·0	9·0	..	45·0	36·0
$\frac{1}{20}$	5·8	5·8	34·8	17·4	34·8
$<\frac{1}{20}$	..	..	29·0	8·7	60·9

CAUSE OF CONGENITAL AMBLYOPIA.—At present we are only able to advance conjectures as to the origin of congenital amblyopia, we know of no anatomical basis for the condition. HEINE examined the optic nerve of an eye with typical congenital amblyopia, and the result was negative; as to the condition of the retina no trustworthy findings were obtained. NAUMOFF [1] and VON HIPPEL [2] thought that the cause might be sought for in inter-partum macular hæmorrhage. We must note, however, that such an origin would involve permanent changes visible with the ophthalmoscope (UHTHOFF). The rarity of binocular amblyopia, although bilateral inter-partum hæmorrhages are by no means so rare,[3] is in direct opposition to the traumatic hypothesis for the origin of congenital amblyopia—that damage and injury to the optic nerve-fibres are

[1] *Arch. f. Ophthal.*, xxxvi. [2] *Ibid.*, xlv.

[3] v. SICHERER: "Bericht der Heidelberger Gesellschaft für Ophthalmogie," 1907.

produced by inter-partum hæmorrhages. The results of investigations[1] in the new-born, where only a rudimentary suggestion of a fovea was found, perhaps have some bearing on amblyopia; it should further be noted that SEEFELDER demonstrated the complete absence of the fovea in a case of aniridia.[2]

Viewing the hyperopia so constantly associated with congenital amblyopia, as the origin of the defective vision, DONDERS presumed that the latter was dependent on the former, and was due essentially to the reduction in size of the retinal image without an increase in number of the percipient elements. Against this MAUTHNER showed that such grounds would only explain a reduction in vision from $\frac{20}{20}$ to $\frac{17}{20}$ in a hypermetrope of 12D.[3]

CLAUD WORTH is of the opinion that the anomalies of congenital amblyopia are due to the failure of the necessary predominance of the macula, not to a general lowering of the sensibility of the visual apparatus. WILBRAND and SÄNGER[4] suggest that the cause of the amblyopia cannot be in the retina or gross ophthalmoscopic changes would be visible. My own opinion[5] is that we must suppose either that the cones are spaced further apart, and do not show in the centre that crowded arrangement which contrasts with the periphery, or else that the nerve connections from the closely packed cones of the fovea are less isolated and more grouped than usual. I have attempted to support this view[6] by investigations on the fusion-frequency in congenital amblyopia. I found that the central fusion-frequency in amblyopic eyes was greater than normal; variations at different points in the retina could not be shown to occur to the same extent as in the normal eye. I therefore concluded that the conditions in the amblyopic eye resembled those in the periphery of the normal retina; I also attempted to explain amblyopia "ex anopsia" in the same way. In such cases the absence of the effort to acquire acute vision removed during development the stimulus to maintain the proper isolation of the individual retinal elements.

LOCAL VARIATIONS IN THE RETINA OF FUSION-FREQUENCY.—By the expression "fusion-frequency" (v. KRIES) is meant the rapidity of interruption necessary for a periodic stimulus to produce a steady impression. The test is made with rotating discs, having alternate sections of white and black. When we examine different parts of the retina we find that with increasing distance from the fovea the rate of rotation must be increased to give a uniform steady impression. The test must not be made with small-sized flickering objects; or this law may readily be reversed; we must always bear in mind that the visual acuity rapidly decreases from the centre to the periphery, and use a test object of sufficient size. There is a ready

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[1] WOLFRUM: *Ibid.*, 1908.

[2] *Arch. f. Ophthal.*, lxx.

[3] HESS, "Anomalies of refraction and accommodation" in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde."

[4] Über Sehstörungen, 1892.

[5] *Arch. f. Ophthal.*, lxv.

[6] *Ibid.*, lxviii.

everyday test observation showing the correctness of this statement. If, when travelling along a double railway line, the wood or iron sleepers laid at regular intervals on the track be noticed, the flickering is definitely prolonged when central fixation is replaced by peripheral.

Just as the reduction of visual acuity in the periphery can be referred to a wider spatial extension of the sensory units, so I attempted to refer the local variations in fusion-frequency to the delay in propagation of this stimulus due to the sensory areas being more extensive. As I have mentioned, I found in the centre of the congenital amblyopic eye a condition similar to the periphery of the normal eye—a fact which supports the comparison between the centre of the amblyopic eye and the periphery of the normal.

FUSION-FREQUENCY AND DISEASE OF THE FUNDUS.—BRAUNSTEIN[1] devoted himself to the study of intermittent retinal stimulation, and concludes from examination of the fusion-frequency that we have here a method by which it is possible to recognize disease of the eye when no other method would do so. MARKOW,[2] on the other hand, could not convince himself of the special delicacy of this method of investigation. "The flickering test in medical hands has no diagnostic advantages over the other methods of testing differences in sensibility." HESSBERG[3] made many investigations with regard to the value of "fusion-frequency" in the diagnosis of fundus diseases, and found no marked variation from the frequency which might have been presumed to be present. He was certainly quite unable to establish any classification of different groups of diseases, as did MARKOW with glaucoma, choroidoretinitis, and retinitis. BRAUNSTEIN, in a controversy, found fault with HESSBERG's method of investigation, in that he used too large a disc; it was not suitable for an exclusive examination of the retinal centre, and it varied in rotation speed at different parts of its radius. HESSBERG, in his reply, referred to my own views already mentioned, and insisted that the size of the disc and the visual acuity must be in a definite proportion, otherwise reduction in the fusion-frequency will occur on account of undesirable diminution in the size of the test object.

TOTAL COLOUR-BLINDNESS.[4]—A second affection which may be looked upon as an advanced condition of amblyopia congenita is represented by total colour-blindness. In this affection the colour scotoma extends over the whole field, and is accompanied by a central relative defect in the field (amblyopia or scotoma). The fact that total colour-blindness, in contrast with congenital amblyopia, is always binocular, prevents too extensive an analogy being drawn between the two conditions. Total colour-blindness is also characterized by other symptoms which complete the clinical picture, and are not present in congenital amblyopia.

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[1] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xxxiii.

[2] WESTNIK: *Ophthal.*, xviii.

[3] *Arch. f. Ophthal.*, lxix and lxxii.

[4] Monograph by GRUNERT, 1903, *Arch. f. Ophthal.*, lvi.

Clinical Symptoms in Colour-Blindness.—Total colour-blindness occurs more frequently in males than in females, and is often found in the children of consanguineous parents. The child at an early age suffers from photophobia in bright daylight, and shows this by blinking and covering its head; these patients cannot distinguish colours, and see better in a dim light. On closer examination defects are frequently found in the refraction (astigmatism), which do not appear amenable to correction. Ophthalmoscopic examination may show changes in the retina, choroid, and optic nerve—though these variations from normal need not necessarily occur. An enlargement of the macula without any foveal reflex is often observed (Rönne). The visual acuity varies from $\frac{1}{10}$ to $\frac{1}{5}$, and rarely reaches $\frac{1}{3}$. Rählmann[1] records the only case of total colour-blindness with normal visual acuity. Light sense and adaptation are good. Uhthoff[2] and Rönne[3] record extraordinary rapid adaptation. The colourless band of the spectrum shows variation in intensity corresponding to the dark-adapted normal eye. Comparisons, by means of colour-tops between black and white discs and variously coloured paper, showed that green and blue were recognized as light, and red generally as black. Rönne was unable to determine any shortening in his cases of the spectrum at the less refrangible end (this in contrast to Grunert).

Nystagmus in total Colour-blindness.—Nystagmus is an almost constant condition in total colour-blindness, and with it an improvement in vision may possibly be obtained. It can be imagined how this condition blurs the after-images which otherwise would exert a disturbing influence. From theoretical considerations König advanced the view of a scotoma in absolute colour-blindness, and demonstrated it practically; the nystagmus has been considered as due to this defect in the field, areas of retina of equal visual acuity surrounding the scotoma, alternately taking up the function of fixation. Kries explained total colour-blindness by a failure in retinal cones, the nystagmus and photophobia being due to the bleaching and restoration of the visual purple. (The normal eye has a slight nystagmus; according to the researches of Marx and Trendelenburg[4] its angle of vibration being 5 minutes).

Scotomata in total Colour-blindness.—König, Uhthoff and Nagel were able to show a scotoma in total colour-blindness; while Hess and Hering[5] emphasized its absence. It is often possible to demonstrate such a scotoma if special methods are used. Uhthoff's method may be mentioned; it is based on a test with a ring-shaped object. Hessberg[6] particularly insists on the examination for a central scotoma taking place in a darkened room, the illumination of which is carefully reduced, and varied systematically

[1] *Zeitschr. f. Augenheilk.*, ii, and *Zeitschr. f. Ther. u Hyg. d Augenheilk.*, ii.

[2] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xxvii.

[3] *Klin. Monatsbl. f. Augenheilk.*, 1906, ii.

[4] *Zeitschr. f. Sinnesphys.*, xlv.

[5] Pflüger's *Archiv*, 1898.

[6] *Klin. Monatsbl. f. Augenheilk.*, xlvii.

in different examinations. RÖNNE[1] could not find a scotoma either by the usual methods or by UHTHOFF'S; he considered that an excentric fixation was probably evidence of a scotoma—he found that the blind spot was at 14° to 18° in one eye, and 10° to 14° in the other.

HESS,[2] on the contrary, claimed that the condition of the retinal centre was the same in the normal and the totally colour-blind eye. He showed that the phases of the after-image lasted for the same time, and were of the same character as in the normal, and that just as in the normal eye a central part of the retina, corresponding to the most acute vision, was relatively less sensitive for faint illumination, when the eye was adapted for darkness.

In the next chapter we will discuss the significance of the central scotoma in total colour-blindness when dealing with the *Duplizitäts-theorie*, and the presumptive evidence which we have about the origin of total colour-blindness will be deferred till then.

It is strange and surprising that in spite of the nystagmus the central scotoma can still be found. Scotomata of 3° to 1° in extent are recorded, even one of 52 minutes (GRUNERT), though the movement of the eye even in a restricted nystagmus is estimated at 5° to 10°. To explain this phenomenon GERTZ[3] presumed that a definite visual impression could be psychically picked out from the sequence of all the impressions received. The object intermittently seen, appears most clearly in one definite direction; this direction can be distinguished from the others, and so in some way the attention is thus directed.

Along with those congenital forms of central retinal deficiency which we have mentioned, others should be noted which result from disease. When we consider the dictum of EDINGER—that a high degree of functional activity involves an increased morbidity—we see how that part of the eye which is functionally the most valuable, and has the greatest calls upon it, is most readily attacked by disease. Just as vascular changes are most commonly or exclusively found where metabolism is most active (central choroidites), and as the area of most acute vision has the least resistance to traumatism ("high vulnerability" HAAB), so we find that in many diseased processes affecting the optic nerve, those nerve-fibres suffer most which supply the macula lutea (papillo-macular bundle).

TOBACCO-ALCOHOL AMBLYOPIA.—Toxic amblyopia[4] is not a systemic disease like tabes, where the essential pathological lesion may range over a wide extent. The damage due to the toxic process is usually limited to the fibres generally affected; in its pathology the disease appears to be an interstitial neuritis. It

[1] *Klin. Monatsbl. f. Augenheilk.*, 1903.

[2] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xxix.

[3] *Arch. f. Augenheilk.*, lxx.

[4] UHTHOFF: "Augenstörungen bei Vergiftungen," GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde"; and EVERSBUSCH: "Therapie der Augenerkrankungen" in PENTZOLD-STINZING'S Handbuch.

should, however, be noted that other authors (*e.g.*, BIRCH-HIRSCHFELD)[1] ascribe the primary rôle to degeneration of the ganglion cells of the retina.

CLINICAL SYMPTOMS.—Toxic amblyopia makes itself evident by a mistiness in vision, and considerable reduction in visual acuity, even to the extent of one-tenth or lower. The patients complain of greater difficulty in bright light or sunshine, and in the dusk a relative and absolute improvement occurs (nyctalopia).

WILBRAND and SÄNGER ("Neurologie des Auges") seek the explanation for this in the relative acceleration of the katabolic processes with the retarded anabolism. With a low intensity of illumination the restoration of the visual substances can keep better pace with their consumption. Another explanation for the nyctalopia occurring in toxic amblyopia will be given in the next chapter ("Disturbances of Adaptation"). The defect found in the field in toxic amblyopia usually takes the form of a horizontal oval, extending further in the temporal than the nasal direction; a pericentral scotoma is much rarer. The scotoma is generally a relative one, if it has become absolute then the defect for red is greatest and that for blue and white smaller. The absolute scotoma need not necessarily be centrally placed in the relative one, it may lie excentrically, intermediate between the macula and the papilla, at the so-called "nuclear spot."[2] It may be noted that this graduation of the margin of the scotoma for various colours is not so marked in the other forms of retrobulbar neuritis.

The scotoma is mostly negative, that is to say, it is only discovered when the field is taken out. It may lead to illusions and even hallucinations. A patient, who was an innkeeper, related to me that he had often seen people put their heads in at the door, when, as his wife could certify, no one could possibly have opened the door. The difficulty in recognizing silver, copper, or nickel coins is often the first subjective symptom of the disease.

Both eyes are almost always equally affected; UHTHOFF denies the existence of unilateral cases. I have seen one such in a potman, but in this case a recurrence took place in the formerly unaffected eye, while the other, previously affected, remained free.

Provided that the conditions are favourable, the final result is good; a partial scotoma, or even atrophy, may remain; in rare cases we may find changes in the periphery of the field, and corresponding irreparable and progressive deterioration in the optic nerve outside the papillo-macular bundle. Toxic amblyopia is caused by the excessive use of alcohol and nicotine (each of these poisons can by itself produce the disease); their influence is especially marked when the nutrition is lowered; of the two alcohol has the greater influence. The statement that a clinical differentiation between tobacco and alcohol amblyopia is possible is opposed by UHTHOFF.

OTHER FORMS ON RETROBULBAR NEURITIS.—Various affec-

[1] *Arch. f. Ophthal.*, lii.

[2] *Arch. f. Augenheilk.*, xviii, SACHS (Kernstelle).

tions of the optic nerve between the eye and the inside of the skull are designated as retrobulbar neuritis (hæmorrhages, exudations, or syphilitic new formations may be the cause, also the spread of an inflammation from the nasal sinuses to the periosteum of the orbit and the perineural sheath of the optic nerve.[1] Multiple sclerosis contributes many examples of this affection). The central defect may be so great that there only remains a crescentic portion of the temporal field; after a temporary almost complete amaurosis such a field will show a recovery first for white and later for red and blue.

CENTRAL SCOTOMA IN POSTERIOR SINUS DISEASE.—BIRCH-HIRSCHFELD demonstrated, and emphasized,[2] that when a diseased process, originating in an inflammation or a tumour of the posterior nasal sinuses, attacks the optic nerve or the orbit and causes a severe disturbance of the vision even to the extent of blindness, the first eye symptom is the formation of a central scotoma. In reference to the importance of an early recognition of such a scotoma, we can heartily support BIRCH-HIRSCHFELD when he declares it to be of the greatest clinical value in the extremely difficult diagnosis of the affections of the sphenoidal and posterior ethmoidal cells. In contrast to the scotoma due to alcohol and tobacco, this develops rapidly and shows great tendency to progression.

According to HOEVE,[3] an enlargement of the blind spot for colours precedes the scotoma; it is in the progress of the disease that a central scotoma develops, and fuses with the enlarged blind spot. HOEVE'S symptom has been freely confirmed; GJESSING[4] recorded its occurrence in 50 per cent. of the cases of visual defect due to nasal disease. In posterior sinus disease this last author described ring scotomata often surrounding the fixation point. Many such cases have been described,[5] but it is difficult to say to what extent they are functional and not caused by the neuritis. HAM records a case in which hysteria was established.

DE KLEIJN,[6] who confirms the enlargement of the blind spot in posterior sinus disease, also found some peripheral contraction of the field without any explanatory ophthalmoscopic signs.

CENTRAL SCOTOMA IN NEURITIS AND OPTIC ATROPHY.—The central scotoma occurring in inflammatory and atrophic conditions of the optic nerve is obviously an expression of the vulnerability of the papillo-macular bundle. In his article in "GRÄFE-SÄMISCH" UHTHOFF states that a central scotoma is rarely seen in tabetic atrophy. FUCHS,[7] on the other hand, says that he has seen this

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[1] EVERSBUSCH and BIRCH-HIRSCHFELD in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde."

[2] *Arch. f. Ophthal.*, lxv.

[3] *Arch. f. Augenheilk.*, lxiv, and lxvii.

[4] *Arch. f. Ophthal.*, lxxx, I.

[5] MACWHINNIE: *New York Med. Journal*, 1910; RUSS WOOD: *Lancet*, 1910; HAM, *Ned. Tijd. v. Gen.*, 1911.

[6] *Arch. f. Ophthal.*, lxxix.

[7] Amer. Ophth. Congress, 47th meeting.

central defect more frequently in tabes. It is not necessary to consider the scotoma as a complication (from an associated retro-bulbar neuritis or toxic amblyopia), it can be accounted for by degeneration of the nerve substance. In a scotoma the essential changes are mostly in the optic nerve, they may exceptionally lie far back in the chiasm and cause bi-temporal hemianopsia.

Increased Vulnerability on the Macula Lutea to Trauma.—The high morbidity of the site of most acute vision is shown by its high vulnerability and the occurrence of "*commotio retinæ*" when the eye suffers a contusion. Haab[1] calls attention to the fact that an opacity is often found at the macula disturbing central vision, whether the "Berlinsche Trübung" of the retina be more or less in the periphery, upwards or downwards. "This is just the form of macular affection which will explain the occurrence of the other macular conditions. If the globe be struck at its equator, the retina at the point of impact is most injured, and the opposite spot is less damaged (*contrecoup*). The remainder is evenly disturbed, only the macula being damaged, plainly from its high vulnerability."

This explanation of Haab's requires amplification, for cases of "Berlinsche Trübung" occur in the immediate vicinity of the macula while there is still good visual acuity.[2] I have tried to explain this phenomenon by my theory of the mechanics of *commotio retinæ*,[3] referring such an injury to the "Attenuation of Structure." The firm implantation of the nerve into the coats of the eye has, in the cases quoted, protected the macula from being wrenched.

Central Scotoma in Choriodo-Retinitis Centralis.—The papillo-macular bundle of the optic nerve is most often attacked by disease. We also find the macula to be a site of election for disease, because the choroid whose function is nutritive has here its greatest activity and is often the early site of limited arterio-sclerosis.

This central scotoma is distinguished from those due to retinal and nerve affections by the graduations of the disturbances in colour sense (Chapter VII), as well as by disturbances in adaptation (see next chapter).

The size of the central scotoma may vary greatly. As a "minimum" scotoma, Heine[4] records an observation in a case of diabetes with minute white spots in the macula. When reading fine print, the letter fixed (*e.g.*, "n") would occasionally disappear at the far point of his 4D myopic eye.

Pigmentary Atrophy of the Retina.—In contrast to the great variety of the affections of the centre of the field, it is very rare for the centre to be intact and the periphery almost exclusively affected. Pigmentary degeneration of the retina furnishes an

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[1] Ophthal. Gesellschaft, Heidelberg, 1888.

[2] Siegfried: Beiträge z. Augenheilkunde, xxii; Lohmann: *Klin. Monatsbl. f. Augenheilk.*, 1906.

[3] *Arch. f. Ophthal.*, lxii.

[4] *Klin. Monatsbl. f. Augenheilk.*, 1905.

example of this unusual state. This is a hereditary disease, mostly affecting the children of consanguineous parents, and is due to some constitutional anomaly, though it is also acquired through syphilis. In it, even though the disease is in an advanced stage, the visual acuity often remains good, both relatively and absolutely. At the same time, however, there is an early and profound contraction of the field, offering great impediment to orientation and free movement. The helplessness of such a patient can be imagined if anyone looks through a stethoscope, and with the vision thus

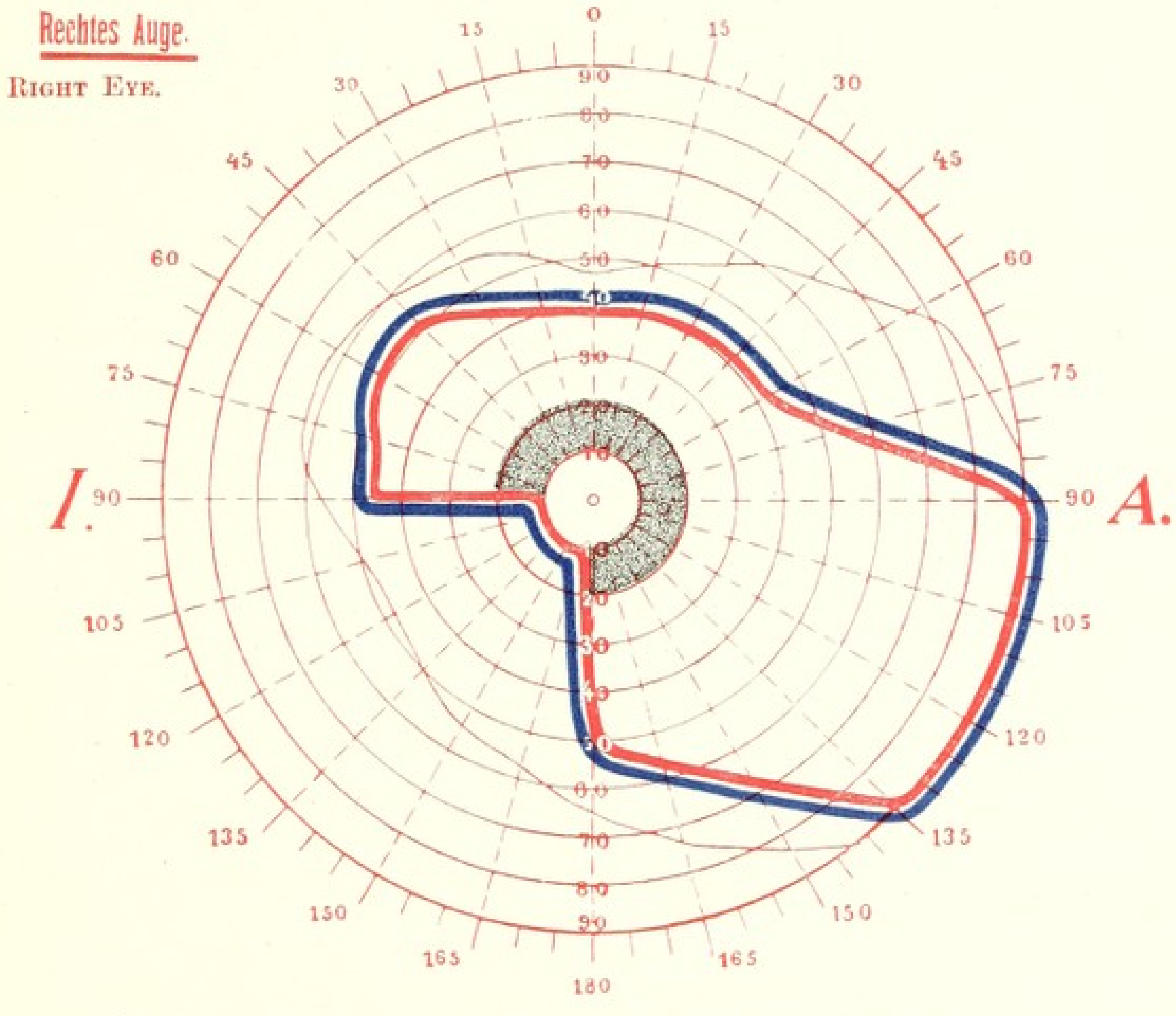

Fig. 13.—Sector defect and ring scotoma in pigmentary atrophy of the retina.

possible attempts to find their way about. To this defect in the field is also added great interference with adaptation, so that in artificial, or in evening, light the impression of complete blindness is produced.

Ring Scotoma.—It is a matter of common observation that the defect in the field does not always involve the whole periphery, but takes the form of a "ring scotoma" (fig. 13). By the use of a strong light stimulus Koellner[1] was able to demonstrate some

[1] *Zeitschr. f. Augenheilk.*, xvi.

function in the periphery, even in advanced cases; according to him the ring scotoma is the first defect to be found in the field in pigmentary degeneration. He refers the ring scotoma to peculiarities in the course of the vessels; in the ring-forming zone in the posterior part of the choroid the arteries are not united by anastomoses, but only by capillaries; any retardation of the circulation must, therefore, first make itself evident in this region. This hypothesis transfers the origin of the visual defect to the changes in the choroid, but there are records of pigmentary degeneration where the primary changes were found in the retina on pathological examination, and that, too, without any previous lesion of the choroid.[1]

Speaking generally, when a ring scotoma is proved to exist, an affection of the posterior (neuro-epithelial) layer of the retina may be inferred; no explanation of the resistance of the central region of the retina can be given at present without considerable reserve. Besides the hypothesis of KÖLLNER referred to above, the view has been advanced that the trunks of the retinal vessels surrounding the posterior pole of the globe may have an influence (HERSING); the cause has been sought in the influence of the *venæ vorticosæ* (SCHÖN); GALLUS considers that changes occur which damage the outside of the optic nerve in the optic foramen.[2] Besides occurring in pigmentary degeneration, ring scotomata have been found in myopia (WETTENDORFER,[3] WEISS), in multiple sclerosis (UHTHOFF), in hysteria (*vide infra*), and in syphilitic neuritis (KÖLLNER).[4]

FIELD IN GLAUCOMA.—The field in glaucoma is reduced, especially on the nasal side. Its contour is oval with its longest axis horizontal, the longer part of the axis lying externally.[5] RYDEL[6] explains this peculiarity by vascular changes which influence the periphery. The vessels in the nasal section of the retina have a radial distribution, while those in the temporal section bend round the macula to reach the periphery. In association with this longer course of the vessels, the vision in the nasal part of the field corresponding to the outer half of the retina, will first be influenced.

According to the researches of BJERRUM,[7] confirmed by RÖNNE,[8] a lesion of quite a different nature is responsible for the restriction of the field in glaucoma. BJERRUM employed a small ivory disc of 1-3 mm. in size, mounted on a black rod, and tested the field on a black curtain at a distance of 2m. He described a defect in the field passing out from the blind spot and

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[1] STOCK: *Klin. Monatsbl. f. Augenheilk.*, 1906, and Bericht d. Ophthal. Gesellschaft, Heidelberg.

[2] Further see WILBRAND and SÄNGER: "Neurologie des Auges."

[3] "Beiträge z. Augenheilkunde," 1902.

[4] "Störungen des Farbensinus," Berlin, 1912.

[5] SCHMIDT-RIMPLER in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde."

[6] *Arch. f. Ophthal.*, xviii.

[7] "Med. Selsk," 1889. [8] *Arch. f. Ophthal.*, lxxi.

bending round the fixation point, corresponding exactly to the course of the arched retinal fibres. The nerve-fibres, just like the vessels, radiate out from the papilla in the nasal half, but in the temporal half it is only the papillo-macular bundle which has such a course, the other fibres in their passage to the periphery bend round the macula and unite in a horizontal line, the "retinal raphe" running through the point of fixation. According to BJERRUM and RÖNNE, glaucoma specially affects these arched fibres; the direct nasal and the direct temporal maculæ remained unaffected.

This explains the bow-shaped scotoma (shown by RÖNNE [1] to be present in 42 per cent. of cases); thus is explained the characteristic defect in the field shown in the diagram; and thus we have an explanation of why the margin of the field often follows the horizontal meridian in the nasal field.

According to RÖNNE the shape of the defect in the field is the result of the uneven stretching which the nerve-fibres experience by the glaucomatous excavation; that the seat of election is in the part of the field corresponding to the arching retinal fibres, is explained by these fibres being subject to different conditions than are the horizontal ones.

CONTRACTION OF THE FIELD IN OPTIC ATROPHY.—According to SCHÖN and UHTHOFF the concentric contraction of the field which occurs in optic atrophy can be classified in two categories; either a general shrinking takes place or else sector-shaped defects develop in the field. WILBRAND and SÄNGER[2] consider that, in general, the prognosis in the first form of field is more unfavourable than in the second. However, it appears that this import cannot be given to the two variations in the field.[3]

In the one case the disease affects the whole thickness of the nerve, while in the other only definite bundles are involved. If these lie on the nasal side of the retina, fields with indentated defects will be found, while in lesions of fibres on the temporal side, that peculiar form of field which we have described under "Glaucoma" is seen. This last form is of interest when occurring in tabetic atrophy, inasmuch as it furnishes an indication of the nature of the pathological process. RÖNNE[4] concludes from the fields that "as a factor in the production of tabetic degeneration the lesion of the ganglion cells is of considerably less importance than that of the nerve-fibres."

ISLANDS IN THE FIELD.—The concentrically contracted and the sector forming fields have this in common, that the percipient parts of the retina forms a connected whole. DE KLEIJN and KOOY [5] showed that in all affections of the optic nerve, if they were carefully examined, isolated percipient areas could be found in the field. The

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[1] *Klin. Monatsbl. f. Augenheilk.*, 1908.

[2] "Neurologie des Auges," III.

[3] RÖNNE: *Klin. Monatsbl. f. Augenheilk.*, 1911.

[4] *Arch. f. Ophthal.*, lxxii.

[5] *Ibid.*, lxxvii.

origin of these islands will be at once clear when we consider that groups of functionally active nerve-fibres remain unaffected by the destructive process, and are surrounded by areas of atrophied elements; the reason will also be clear why patients with nerve affections may, in spite of extreme contraction of their fields, still show in everyday life so comparatively slight an incapacity.

Disseminated Choroiditis and Detachment of the Retina. The so-called choroiditis disseminata is a form of disease which, in an even more marked manner than the retinal diseases (*e.g.*,

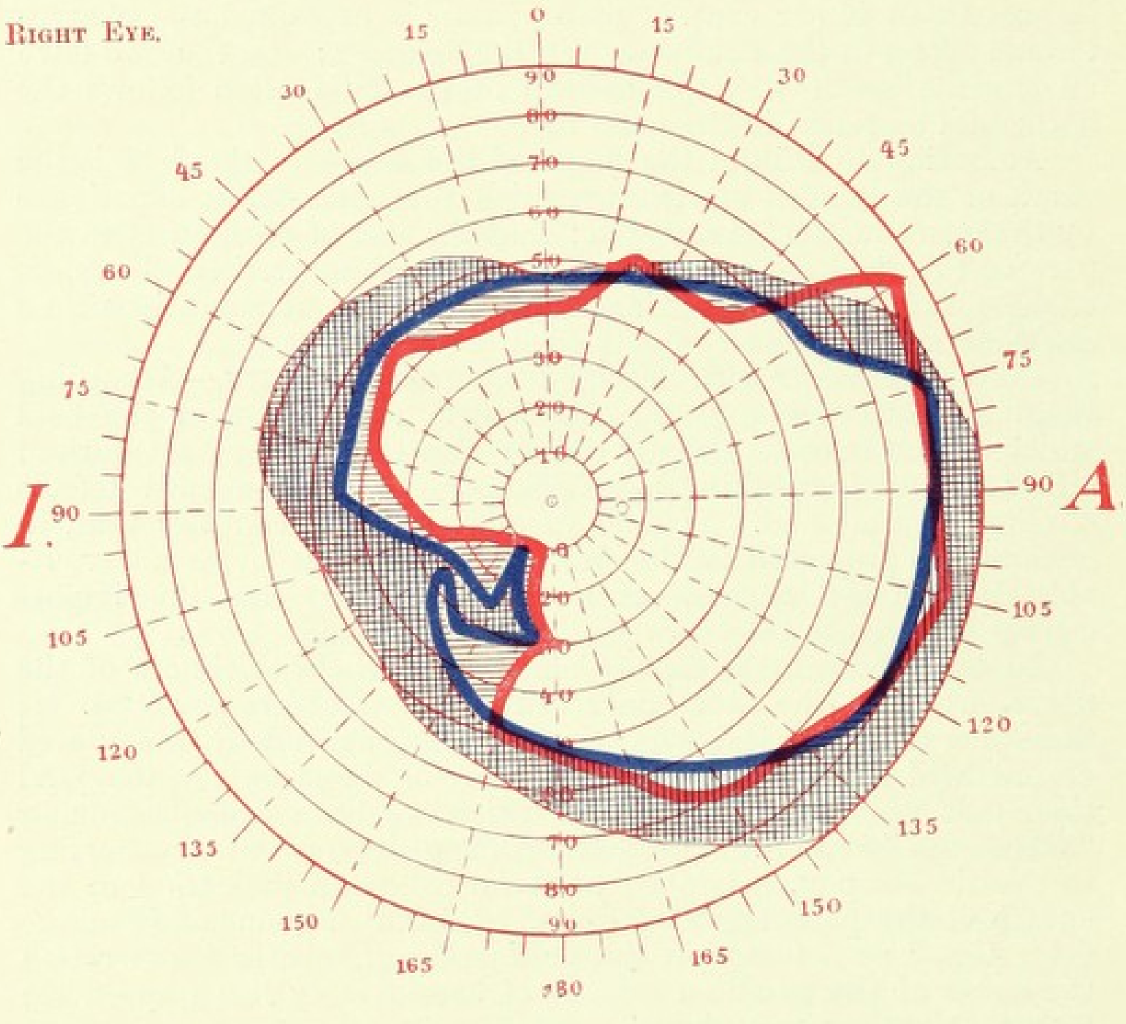

Fig. 14.—Field in embolism of a branch of the retinal artery.

albuminuric retinitis), occurs indiscriminately throughout the fundus without any special predilection either for the centre or the periphery, and in it the scotomata, corresponding to the site and extent of the foci, are also irregularly distributed. In detachment of the retina, which, at any rate in its later stages, tends to occur downwards, the corresponding upward defect in the field is found. In typical cases these patients complain that in the street they can only see the feet of persons coming towards them. After reposition of the retina a defect for red often remains when the field for white and blue has returned to normal (SCHLÖSSER). If the loss of field takes the form of a positive scotoma, the typical visual disturbance in detachment of the retina will be observed by the patient. A man once told me that the first notice he had of his affection was "a black cloud rising from the lower border of the eye and enlarging from day to day." In his anxiety the patient made tests of his field with his fingers, and noticed that "the shadow was convex upwards, and its upper margin appeared to cut off his fingers." An obscuration of the whole field then ensued on a severe chill, and after a certain amount of recovery a defect in the upper part of the field remained. Apparently the exudate lying behind the upper part of the retina had sunk down.

EMBOLISM OF CENTRAL ARTERY AND THROMBOSIS OF VEIN.—When a blocking of the central artery of the retina (embolism) is the origin of a visual defect, complete amaurosis will result if the trunk of the retinal vessel is blocked, and a partial defect if only a branch is involved. If the macular area be supplied by a retino-ciliary artery, this important region of the retina will remain unaffected.[1] The condition called "thrombosis of the retinal vein" leads to a grave visual defect, either total blindness or extensive defect in the field. In fig. 14 a field is given which occurred in a case of embolism of a branch of the central artery of the retina. The patient stated that the eye was suddenly blinded eight days previously; his vision had so much improved that it was only on the advice of his doctor that he had his eye examined. The ophthalmoscope showed a white nodule down and out in the fork of a retinal vessel. The field indicated the area nourished by the chief branch by the sector-shaped defect, and that of the smaller branch by the hooked process downwards.

For the changes in the field due to disease of the optic nerve trunk or the visual centre, see Chapter XI.

CONCENTRIC CONTRACTION OF PSYCHIC ORIGIN.—We will now consider contractions of the field due to psychic causes. The best known of these is the field described by FÖRSTER as "elastic" (*Verschiebung*). This field is peculiar in that it is smaller when taken out with a test object moved centrifugally than when the object is moved centripetally. Some observers (KONIG, FREUND, WERNICKE) consider this type of field to be pathognomonic for traumatic neuroses, others (SCHMIDT-RIMPLER, SIMON, &c.) showed that it also occurs in health. KLIEN[2] found the "elastic" type in the "complementary" field of healthy patients. (By complementary field KLIEN means one which is not influenced by physiological obstructions, such as the nose, orbital margin or lids, and which is maintained, even though, when recording a meridian, an excentric point on the opposite meridian is taken for fixation instead of the zero point). WILBRAND[3] and SÄNGER explained the

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[1] FRÄNKEL: *Arch. f. Augenheilk.*, xlix.

[2] *Arch. f. Psychiatrie u. Nervenkr.*, 42.

[3] "Uber Sehstörungen," 1892.

"elastic" type of field as due to exhaustion, and SALOMONSOHN [1] considered that it was the result of variation in attention. Regarding the significance of this type of field KLIEN observes that a given test object, on account of the greater functional activity, and the closer apposition of the areas of sensation, will excite a more vigorous stimulation in the centre than in the periphery. If an object be moved centripetally the stimulus increases proportionally in intensity, while cn centrifugal movement it diminishes; it is obvious in the latter case that after the stronger stimulus the sensibility for the weaker succeeding one will be lowered.

Another form of concentric diminution of the field is found when a few movements are made throughout the whole field; exhaustion of the field then shows itself by a rapid contraction if centrifugally tested.[2] If each half meridian (like the hand of a clock) be repeatedly tested, the margin of the field will show a "spiral" outline.[3] WILBRAND'S "oscillating" field is found when an object is slowly moved, and it is seen at one moment and invisible at the next. The ring scotoma of hysteria, described by N. REUSS [4] and others, can be quite well explained by the occurrence of an "oscillating" field (WILBRAND).

The "tubular" field [5] is often considered as especially characteristic of simulation and hysteria. In such cases, when the field is taken at various distances, it does not enlarge in the usual way, but always retains the same linear dimensions from the zero point. KLIEN found that the "tubular" field was not present in all cases of simulation, but only in those in which the malingerer attempted to estimate distances from the mid point; if in his statements, the malingerer uses a certain degree of intensity to check his admissions as to visibility of the coloured object, a tubular field may not be found. In these cases the fields for various colours will follow very closely the physiological laws for the relative limits of the fields for colours.

KLIEN found another peculiarity in the field in malingerers. When there appeared to be a considerable concentric contraction, the point of fixation was taken on the arc of the perimeter away from the centre; the field was then found not to have moved proportionately, but to have "dragged along" as though adhering to the fixation point,[6] a condition which appears to arise from the tendency to locate the appearance of the object always at the same point on the perimeter.

In diseases associated with disturbances of the attention (epileptic dulness, many forms of alcoholic delirium, and epileptic dementia) KLIEN demonstrated a field of the inverted "elastic" type, *i.e.*, the field was smaller tested centripetally than centrifugally. This in-

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[1] *Deutsche Zeitschr. f. Nervenheilk.*, 1896.

[2] WILBRAND. [3] SCHLÖSSER, *loc. cit.*

[4] "Des Gesichtsfeld bei funktionellen Nervenkrankheiten, 1892.

[5] GREEF, *Berl. klin. Wochenschr.*, 1902.

[6] Original fixation point (T.).

version of the "elastic" field can be appreciated when we remember that, in disturbance of the attention, impressions on the consciousness remain abnormally fixed, and, on the other hand, changes in the state of stimulation of the senses very slowly rise into consciousness. These variations in the field which we are considering, have been observed by Klien in arterio-sclerosis cerebri, when areas of softening are present though not affecting the visual region, in traumatic psychoses, commotio cerebri, dementia præcox, dementia paralytica, dementia senilis, and in conditions of severe depression.

Field in Hysteria.—Seeing that the concentric diminution of the field in hysteria so often takes the "tubular" form, it may be considered as due to the imaginary defective vision. Greef has shown that if, during the examination, traps be laid for patients, the hysterical person shows much less discrimination in recognizing them than the malingerer. Klien also agrees with this explanation of the contraction of the field in hysteria, and proved too the "dragging" of the field.[1] Janet's experiment is only apparently contradictory; in hysterical contraction he recorded a further contraction if the attention at the zero point were confused by the sudden proposition of an arithmetical problem. It is certainly true that in those cases where the contraction of the field is due to imaginary defective vision, the field would enlarge if the attention be distracted, just as is the case in ether inhalation (Janet). Klien concluded from the remarks of his patient when being tested: "It is quite impossible at the same time to do a sum, and to watch out there," that in hysteria there is a psychic difficulty in attending to a calculation in the centre and at the same time making observations in the periphery of the field, and that the auto-suggestion of such an idea causes a still further contraction of the field.

[1] "Geisteszustand der Hysterischen.

CHAPTER V.

THE DISTURBANCES OF ADAPTATION AND OF THE LIGHT SENSE; THE EVIDENCE FOR AND AGAINST THE DUPLICITY THEORY.

ADAPTATION.—In every other sensory organ we find merely a threshold of sensibility, but in the visual organ there is a phenomenon which is quite peculiar—the variation of the threshold with changes in the surrounding illumination. This variability in the minimal stimulus, which is greatly lowered in darkness, must apparently be considered as an essential exhaltation in the function of the eye, due to the variations in conditions brought about by the succession of day, dusk, and night. The slow improvement of vision in the dark has long been known. GOETHE refers to it in his work on colours in the following words: "He who goes from the light of day into a darkened place at first recognizes nothing, but little by little the sensibility returns to the eye more quickly for strong stimuli than for weak, the former in a minute, the latter in seven to eight minutes" ("Didaktischer," Teil I, 10) and "prisoners who have long languished in darkness acquire so great a sensibility of the retina that they are able to recognize objects in the dark (probably in a faintly illumined gloom)." ("Didaktischer," Teil I, 12).

Since the time of AUBERT[1] we apply the term "Adaptation" to this function of the eye, and understand by it: "The accommodation of the eye to varying degrees of illumination." In considering the dioptric condition of the eye, we recognize a positive and a negative phase of accommodation according to the increase or diminution in the refractive form of the lens; so we can divide adaptation into dark adaptation and light adaptation, according to whether the eye is more sensitive to faint light stimuli, or, on the contrary, the sensibility is reduced.

Complete adaptation for darkness is the limit to the scale of rise and fall; this point is defined by the smallest light stimulus which it is possible to perceive, after the eye has been accustomed for several hours to complete darkness; this extreme positive limit is opposed to complete light adaptation, *i.e.*, that extreme condition

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[1] "Physiologie der Netzhaut," Breslau, 1865.

of the eye when an increase in the intensity of the surrounding light for the purpose of causing an alteration in its state cannot be borne without dazzling.

In our daily life abrupt changes from daylight to absolute darkness and *vice versâ* do not ordinarily occur. We find persistent gentle transitions in both directions; the eye, therefore, is generally found in an intermediate state of adaptation and can readily accommodate itself in both directions to the needs of the moment. There is a wide range of adaptations for light and darkness, corresponding to the daily variation in the intensity of the light which meets the eyes.

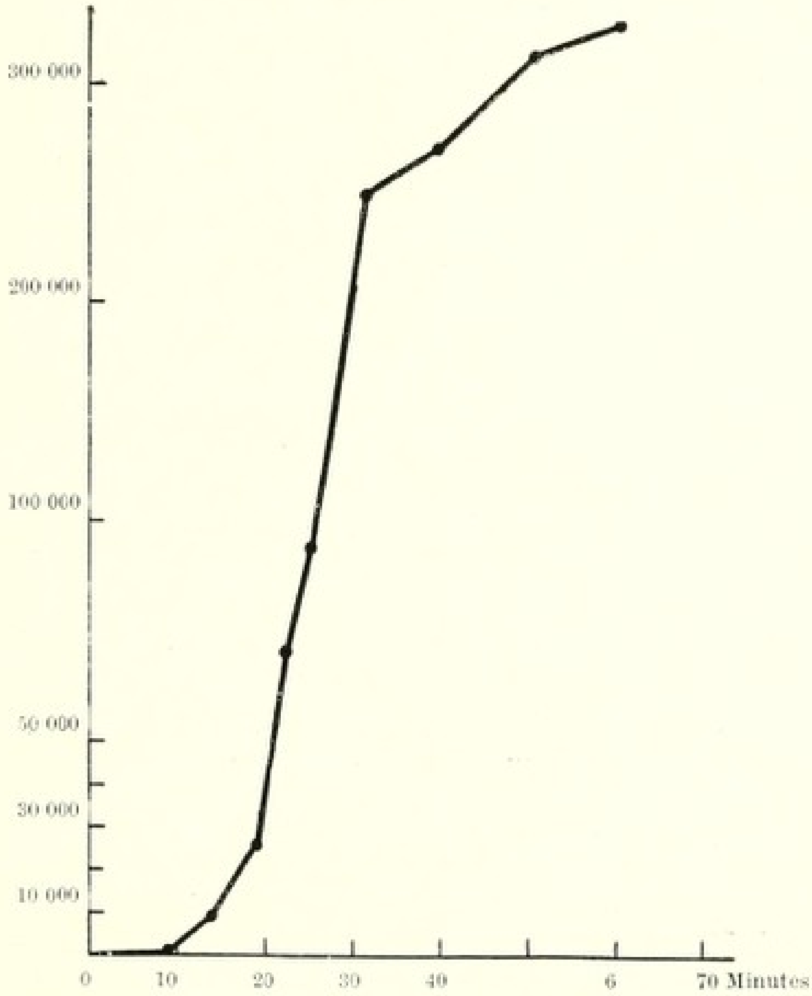

FIG. 15.—Curve of adaptation (*ad modum* PIPER).

QUANTITATIVE INVESTIGATION OF THE ADAPTATION TIME.—AUBERT was the first to investigate the rate at which dark adaptation occurred. He made use of an incandescent platinum wire, which varied in luminosity by changes in resistance to the current. He recorded an increase in the sensibility of the retina—very rapid in the first minute of darkness, and continuing more and more slowly to increase after the tenth minute; after two hours the sensibility was increased thirty-five times. It is difficult to explain why this rule of AUBERT's differs from those records of the later observers, which we will immediately discuss. The source of light appears to have been red, and supra-minimal for the fovea. AUBERT'S figures, which BEHR[1] confirms, correspond to the results obtained on testing the power of adaptation of the fovea (*vide infra*), a part of the retina which has not the most active adaptation. NAGEL further showed that AUBERT began with an indeterminate middle state of adaptation, which must be taken into the consideration of his results.

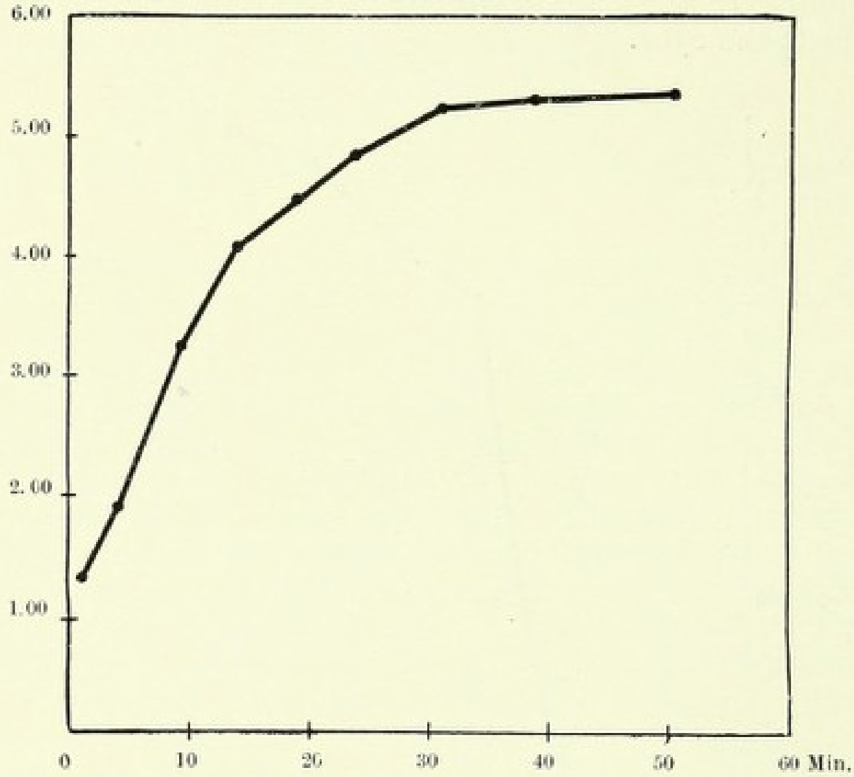

FIG. 16.—Adaptation curve according to the logarithms of sensibility values (NAGEL).

The more recent investigations of adaptation can be traced to the commencement of a discussion by W. A. NAGEL,[2] the Berlin physiologist. PIPER'S investigations gave figures which assessed the increased sensibility of the eye, when adapted for darkness, at

[1] *Arch. f. Ophthal.*, lxxv.

[2] I may mention the following works: PIPER: "Über Dunkeladaptation" (*Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xxxi). PIPER: "Über das Helligkeitsverhältnis monokular u. binokular ausgelöster Lichtempfindungen" (*ibid.* xxxii). PIPER: "Über die Abhängigkeit des Reizwertes" (*ibid.*, xxxii). LÖSER: "Uber die Beziehungen zwischen Flächengrösse und Reizwert leuchtender Objekte" (Festschrift f. J. HIRSCHBERG, 1905). W. A. NAGEL: "Beobachtungen über Druck u. galv. Strom auf d. dunkeladapt. Auge" (*Zeitschr. f. Sinnes-Phys.*, xxxiv). NAGEL und SCHÄFER: "Dunkeladapt. der Netzhautzapfen" (*ibid.*, xxxiv). SIMON: "Fixation im Dämmerungssehen" (*ibid.* xxxvi). LÖSER: "Einfluss d. Dunkeladaptation auf Farbenschwelle" (*ibid.*, xxxi). LOHMANN: "Helladaptation" (*ibid.*, xli). VAUGHAN: "Einfluss von Santonin auf Dunkeladaptation" (*ibid.* xli).

thousandsfold. According to the earlier views, the curve of adaptation showed first a very steep ascent, then a slower and slower rise. According to PIPER, the curve of the first six to ten minutes was almost horizontal, then it suddenly rose, and again, after about forty minutes, ran a more horizontal course.

In plotting his curve, PIPER took the exact measurement of the intensity of the light which the eye could distinguish, as reciprocal in value to the state of sensitiveness of the eye (*see* fig. 15).

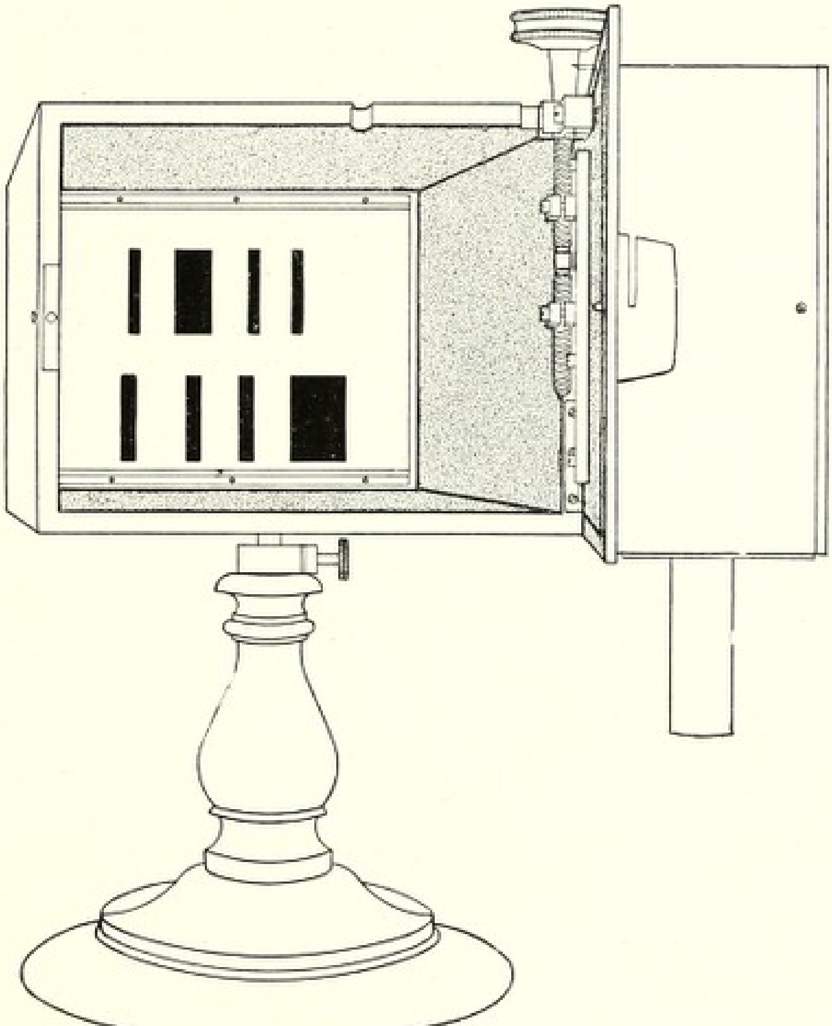

FIG. 17.—FÖRSTER'S Photometer.

Now it is very easy to show that this view, that the subjective sensibility of the eye is inversely proportional to the threshold of sensation, cannot be maintained. BEST[1] showed that the sensibility of the eye did not increase by amounts which could be added together like the intensities of the light; the increase in sensibility did not occur in an arithmetical, but rather in a geometrical manner. Thus, a decrease in the threshold-value of 50 MC. (from 100 to 50 MC.) and a similar reduction of 0·5 MC. (from 1 to 0·5 MC.) leads to the same reduction in the sensibility.

[1] *Arch. f. Ophthal.*, lxxvi, 1.

When, following BEST, we take this as a basis in plotting out the adaptation curve, a curve is obtained which follows AUBERT'S rule; according to it the retinal sensibility rises rapidly and evenly in the first twelve minutes of darkness and more slowly after the 18th minute (*see* fig. 16, which is plotted out from the same values as is fig. 15, only the logarithms of sensibility values are used as ordinates). Adaptation curves showing similar characters to that in fig. 15 were obtained by INOUYE and OINUMA, who carried out the investigation[1] of the one eye adapted for light by the aid of the other eye adapted for darkness.

Though this argument of BEST'S is correct, I neglect it in my subsequent remarks, because in my experience pathological cases are easily enough recognized when the curve is graphically represented *ad modum* PIPER, either by a delay in the steep ascent, or by a diminution of its height. BEST is certainly correct in saying that this curve does not represent the "sensibility of the retina"; and I would recommend that the expression "irritability of the retina" be used for this curve.

METHODS OF TESTING ADAPTATION.—To determine the process of adaptation a special apparatus is required, and one was designed for this purpose by FÖRSTER,[2] consisting of a wooden box in which the test objects are black lines. It is illuminated by a candle shining through an opal glass, which can be varied in size by an AUBERT'S slide (*see* fig. 17). A normal eye can distinguish the dark portions of the test objects from the light with a screen opening of sq. mm., after an adaptation to darkness of ten to fifteen minutes. Many objections have rightly been taken to FÖRSTER'S apparatus; light-sense and form-sense are tested at the same time (MAUTHNER, BJERRUM), also its results do not agree with those which are free from fallacies (TREITEL, LOHMANN). The fact that the FÖRSTER photometer still has a great vogue among ophthalmic surgeons is due to its convenience and easy applicability, as well as to the valuable indications obtained by its use.

NAGEL'S adaptometer[3] is an instrument which is free from fallacies (*see* fig. 18). An opal glass slide of 10 cm. diameter is the object observed; it is viewed at arm's length, about 57 cm., and thus subtends an angle of 10°. This slide is placed at the front of a box 80 cm. long, at the back of which are three 25 c.p. osmium lamps. The intensity of the light can be varied (1) by an AUBERT'S slide adjustable in size from 1—10,000 sq. mm.; (2) by three screens each of which has a darkening power of 20.

An appropriate pale red spot is used for fixation (red light does not prejudice adaptation); wandering movements of fixation prevent exhaustion. To obtain a uniform initial point in reckoning light adaptation, the patient is either placed for fifteen to twenty minutes in the bright midday light, or a sufficiently bright artificial light is allowed to act on the eye for a corresponding

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[1] *Arch. f. Ophthal.*, lxxix.

[2] "Über Hemeralopie u. die Anwendung eines Photometers in der Ophthalmologie," Breslau, 1875.

[3] *Zeitsch f. Augenheilk.*, xvii, 3.

time. In estimating the threshold of sensation attention must be paid to peculiarities in the vision of faint lights. Different values are obtained if we pass from sub-minimal stimuli, or from supra-minimal; in the former the value is higher than in the latter. PIPER, LOHMANN, HORN, and others, estimated the threshold obtained by passing from supra-minimal stimuli, STARGARD preferred the other method (passing from sub-minimal).

The progress of adaptation to darkness, so far from being hindered by the action of a supra-minimal light for a short time, is actually advanced by it; the highest grades of adaptation are, however, of very short duration (NAGEL).

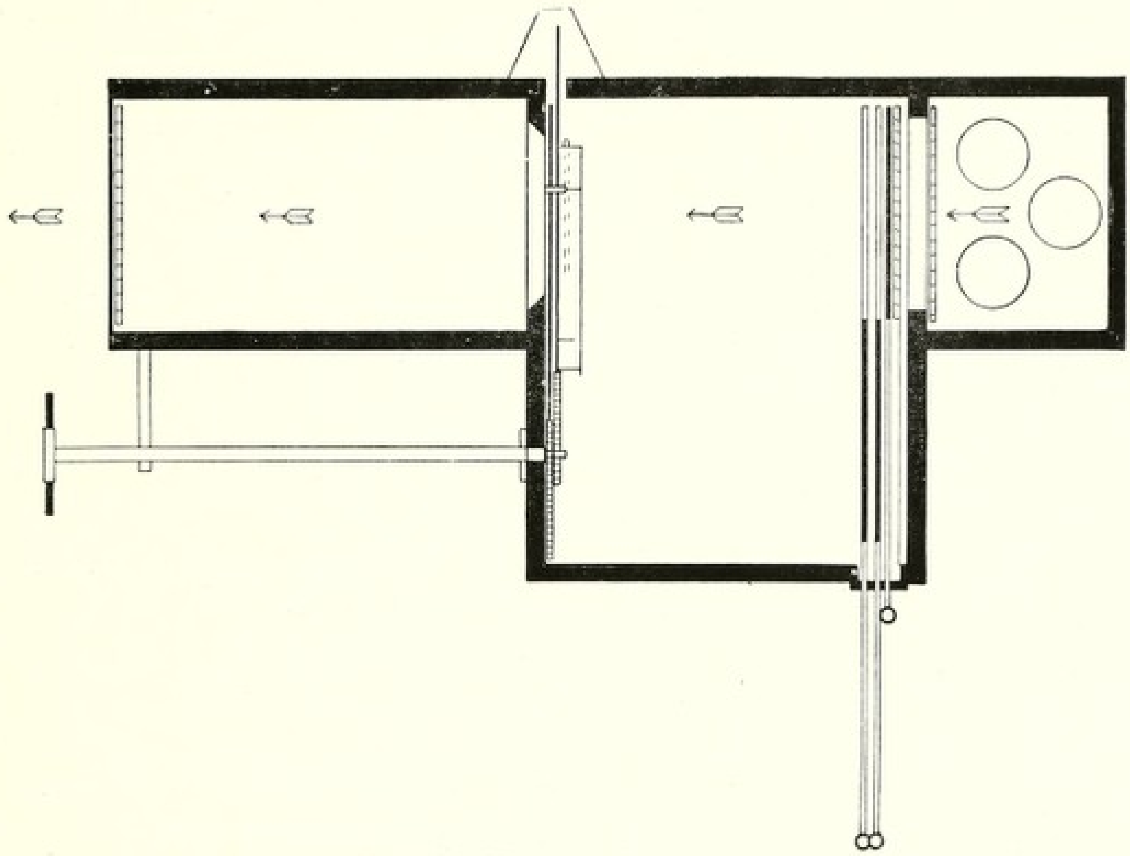

FIG. 18.—NAGEL'S adaptometer.

With the apparatus of FÖRSTER or NAGEL the adaptation of the whole retina is obtained, but with STARGARD'S photoperimeter[1] (*Dunkelperimeter*) comparative measurements can be made of different parts of the retina. The test objects are small lights, subminimal for the eye when adapted to light.

BREADTH OF ADAPTATION.—The intensity of illumination of the opal glass slide in the adaptometer, sufficient to excite sensation in an eye well adapted to bright light, is given by NAGEL as 1 metre candle. After three-quarters of an hour in the dark, an intensity of $\frac{1}{50000}$ to $\frac{1}{150000}$ will be recognized, and after sixteen hours in the dark an intensity of $\frac{1}{270000}$. The breadth of adaptation, which varies in different persons, can in general be said to assume two different types, one recognized by a rapid and great

[1] *Klin. Monat. f. Augenheilk.*, 1906.

increase in the sensibility, the other by a slow and restrained one. TSCHERMAK'S association of the two types of adaptation with anomalous systems of colour vision cannot be upheld. As to the cause of this difference, WÖLFFLIN[1] regarded it as due to the influence, on the visual purple, of a well-developed pigmentation similar to the appearance of different shades of hair. I have noted that there are certain mechanical factors at work, for instance, a large pupil or an increased transparency of the iris, by causing a mild chronic glare, will restrict the initial rise of the adaptation curve both in time and extent. Certainly it is difficult to support this last statement by experimental evidence, and the difficulties arise when we consider the presupposed conditions. Some series of investigations ascribe an influence on adaptation to the pupillary diameter, but the effect of any such variation is not so great as that due to the two different types of adaptation. In those cases which I have examined having a pathological difference in the size of the two pupils, I found a definite difference in the breadth of adaptation. NAGEL has repeatedly shown that under atropine the adaptation curve is greatly diminished. Although the breadth of adaptation differs in different individuals the curve is always the same in the same person, provided always that the conditions of the test are alike (the same initial grade of adaptation, similar light exposure during the adaptation). PIPER speaks of a "curve-constant."

SUMMATION OF STIMULUS, INFLUENCE OF SENSATION, AND SIZE OF THE OBJECT.—PIPER specially notes that in binocular tests the adaptation curve reaches about double the height of that obtained when the eyes are tested singly; this occurs after the lapse of fifteen minutes. This "summation of stimulus" generally occurs, but it is not invariable (WÖLFFLIN, LOHMANN, STARGARD). This phenomenon does not occur in the light-adapted eye,[2] and PIPER explained it by the supposition that all monocular subminimal stimuli are propagated up to a point where they can come in contact with the connections from the other eye; if at this point a stimulus be added from the other eye a sensation results; if such be not added then no sensation ensues.

My own view is that this binocular summation of stimuli is a special case of the law of the dependence of the perception of feeble stimuli on the extent of their plane area.[3] BEHR[4] is opposed to me, and he conducted investigations which showed an increase in the binocular stimulation effect, when parts of the retina quite in the periphery were stimulated, whose sensation difference was much less than that of paracentral areas.

I cannot admit that BEHR'S experimental researches into the important factors in perception show that a slight strabismic deviation, with the consequent utilization of areas more efficient in

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[1] *Arch. f. Ophthal.*, lxi.

[2] FECHNER: "Abh. d. säch. Gesellschaft der Wissenschaften," vii, 1866.

[3] PIPER: *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xxxii.

[4] *Arch. f. Ophthal.*, lxxv.

perception, can be avoided. My own view is that in such cases the summation of stimulus is brought about by an increase in the area of the retina which is stimulated, the increase affecting a retinal area with a maximum power of perception, and I am supported by SIMON'S[1] investigations; this writer observed that when small, feebly illuminated points were looked at in a badly lighted room there was a variation in the deflection of the two eyes.

PIPER considered the possibility of referring this binocular summation of stimulus to the rule previously laid down by AUBERT and TREITEL that the stimulation value of a luminous object varied with its angular dimensions. Whereas I accepted an increase in the dimensions of the retinal area (of maximum perception) stimulated, as due to what can be called a squinting position with reference to the macula, he took no account of such summation of area. I clearly showed the summation of stimulus in the case of squinters, a fact which supports me in the explanation given above, though I must admit that STARGARD was unable to show this summation of stimuli in squint to the same marked extent.

REGIONAL VARIATIONS IN RETINAL SENSIBILITY.—In these last remarks I have referred to regional variations in the perception of the retina, and now I will go into these fully. The fact that the fovea, when adapted for darkness, is at a disadvantage with the paracentral area has long been known, especially by astronomers, who stated that they could see certain stars better by excentric fixation. DOMINIQUE FRANCOIS ARAGO[2] noted the fact that small, feebly luminous stars were better seen when one looked passed them. This phenomenon is especially well seen when a cluster of stars, formed of bright and dull points close together, is observed, so in the Pleiades four or five stars are seen by direct examination, and still more by looking past them.

More exact details of the regional variations in the adaptation in the retina are provided by the investigations of v. KRIES and PERTZ.[3] In an eye well adapted to darkness the sensibility increases centrifugally with each degree until at 10° to 20° from the fovea the maximum is reached. On the other side of this maximum the sensibility decreases towards the periphery in approximately concentric circles.[4]

As to the adaptation at the fovea itself we have the observations of NAGEL and SCHÄFER[5] and WÖLFFLIN.[4] As KRIES expresses it, there is a physiological hemeralopia at the fovea; the dark adaptation of the fovea, which, as compared to the paracentral area, must be designated as moderate, reaches its maximum more rapidly, and shows itself earlier. In the early stages of adaptation it is easily shown that a perceptible light stimulus is more readily recognized

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[1] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xxxvi.

[2] An astronomer, 1786-1853.

[3] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xv.

[4] WÖLFFLIN, *Arch. f. Ophthal.*, lxxvi.

[5] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xxxiv.

centrally than paracentrally—a state of affairs which is rapidly reversed.[1]

It used to be considered that the adaptation at the fovea proceeded more slowly, but that it eventually equalled that of the periphery. TREITEL explained the state of the fovea as greater tiredness of the retina for vision in bright light.

For a considerable time experimental evidence has been available concerning the low value of the centre, and this was once made very clear to me, as after the night's rest I saw the morning dawn. My bed was shut off from the window by a folding screen, and the night was so dark that after several hours in my room I could distinguish nothing. As the morning dawn slowly crept in, I was able to discern the first glimpses of light on the wall opposite the window by excentric fixation. As the grey of the morning waxed, a less excentricity of gaze enabled me to see the light on the wall; I was then conscious of a definite central scotoma, which vanished with the increase of the dawn.

STARGARD[2] was unable to determine that emmetropia or hyperopia had any influence on adaptation, and that, too, when the age was taken into account. PIPER'S investigations convinced him that adaptation was freer in youth; WÖLFFLIN,[3] however, came to the conclusion that age had no material influence on adaptation. He certainly showed that there was a slight decrease in the value of adaptation in the fifth and sixth decennial periods; perhaps analogous to the decrease in the central vision which shows itself in the later years of life. There is not necessarily any disturbance of adaptation essentially associated with myopia; if such a condition be found, it is evidence of some interference with nutrition, and is of serious import, independently of whether there are changes in the fundus or not (LOHMANN). In a large series of cases STARGARD showed—as opposed to the views above quoted—that a slight diminution of adaptation set in from the 27th year onwards. As to the height of myopia, STARGARD concluded that in myopia of from 0·5 D. and 12 D. the adaptation was apparently constant, but that beyond 12 D. there was a distinct diminution to be noted (see later).

INFLUENCE OF DRUGS AND LIGHT.[4]—According to WÖLFFLIN, strychnine and brucin cause an increase in the breadth of adaptation by $\frac{1}{4}$ to $\frac{1}{5}$. VAUGHAN,[5] in opposition to FILEHNE, could trace no influence on the course of darkness-adaptation to santonin.

With regard to the local action of atropine, we have already stated that atropine mydriasis produces a great diminution in the rise of the adaptation-curve (NAGEL). On the other hand, the exhibition of pilocarpine favours the adaptation. Early experiments (KUSCHBERT) showed that pilocarpine produces an increased formation of the visual purple; and considering the secretory action of

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[1] LOHMANN: "Helladaptation," *Zeitschr. f. Sinnesphys.*, 1906.

[2] *Arch. f. Ophthal.*, lxxiii. [3] *Ibid.*, lxi.

[4] DRESER: *Arch. f. exp. Path. u. Pharm.*, xxxiii; WÖLFFLIN, *Arch. f. Ophthal.*, lxv.

[5] *Zeitschr. f. Sinnesphys.*, xli.

pilocarpine, the choroid was compared to a gland. In my opinion, the action of the pilocarpine is more of the nature of a shade, like an obscured glass. The wearing of dark glasses favours adaptation, as its action is to limit the restrictive influence of the light on the adaptation.

The investigations of NICOLAI[1] and RABINOWITSCH[2] show that the precedent conditions of illumination, according to their duration and intensity, exercise a restraining influence on the course of dark adaptation. In my work on "Adaptation to Light,"[3] previous to these writers, I gave then curves which graphically showed the delay in the recovery of the curve of sensibility after the action of varying intensities of light for varying times, on the eye well adapted to light. Similarly, the action of dark glasses appears comprehensible. It would be interesting to know whether different kinds of glass (smoked glass, FIEUZAL's glass, amethyst or yellow glass) differed in their action in dark-adaptation. Experiments by my colleague BECK, under my direction, though not yet concluded, appear to show that the various forms of glass only influence the adaptation by their power of obscuration.

REFLEX CHARACTER OF ADAPTATION MECHANISM.—NAGEL and PIPER insist that in adaptation each eye is independent of the other, so that the adaptive power of a well protected eye is not affected by the free exposure of the other eye to light; BEHR, however, showed that when one eye was steadily illuminated the dark adaptation of the other was considerably influenced and suffered restraint, and this could not be shown to occur in the peripheral temporal parts of the field which have no relationship with the other illuminated eye.[4] BEHR concluded from his investigations that the mechanism of adaptation is not purely retinal, but stands in a very definite state of dependence on some higher centre, and v. KRIES[5] makes this comment, that though reflex influences are at work still the whole process of adaptation must not be considered as of reflex origin.

PATHOLOGY OF DARK ADAPTATION.[6]—It must be generally admitted that pathological variations in the curve of adaptation can be recognized as occurring in two directions (HEINRICHSDORFF). The reduction makes itself evident in a prolongation of the flat initial portion of the curve. The steep ascent of the curve should occur after ten minutes in the dark, but it only takes place in these cases after a varying length of time. Or the course of adaptation may change in that the curve, though beginning normally, shows a flattening in the middle of its ascent, or suffers a setback in final sensibility.

We now see clearly the reason for improving the technique of

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[1] *Zentralbl. f. Phys.*, xxi. [2] *Zeitschr. f. Augenheilk.*, xix.

[3] *Sinnesphys.*, xli. [4] *Arch. f. Ophthal.*, lxxv.

[5] *Klin. Monatsbl. f. Augenheilk.*, 1911.

[6] HEINRICHSDORFF: *Arch. f. Ophthal.*, lxiii; LOHMANN: *Arch. f. Ophthal.*, lxv.; HORN, *Arch. f. Augenheilk.*, 1907; MESSMER: *Zeitschr. f. Sinnesphys.*, xlii; BEHR; *Arch. f. Ophthal.*, lxxv; STARGARD *Arch. f. Ophthal.*, lxxiii; WÖLFFLIN: *Arch. f. Ophthal.*, lxxvi.

testing adaptation, by taking account of the whole course of the process, before coming to any conclusion as regards its character, otherwise the fortuitous occurrence of a certain adaptation after a certain time, may simulate a normal condition. KRIENES[1] expresses this view in the following words: "It is thus apparent that no correct appreciation of the course of the adaptation will be obtained, if the customary photometric examination is made after only fifteen to twenty minutes in the dark. A patient will call himself night-blind when his night-blindness remains after ten minutes, for he has not always the opportunity of waiting to see if, after a further time, his sight is not again restored. The examining surgeon is astonished when he finds in such a patient that after twenty minutes in the dark the threshold of sensation is not raised."

We can go further and say that the disturbances of adaptation are caused by diseases of the neuro-epithelium of the retina. The differentiation of cases of choroiditis with defective adaptation, and retinal or nerve affections with a relatively good adaptation, as advanced by FÖRSTER,[2] can only be made in general terms, and as I have pointed out, is not an invariable rule.

RETINAL DISEASES. ALBUMINURIC RETINITIS.—In contradiction of the older views (FÖRSTER, TREITEL) I found that in albuminuric retinitis and retinal hæmorrhages due to the same cause, the adaptation was considerably interfered with. I consider that the explanation of this is to be found in the implication of the chorio-capillaris, as is shown by the investigations of Duke KARL THEODOR and others. STARGARD states that the changes in the retina, and the resulting hæmorrhages, are themselves responsible for these changes in the adaptation. He not only demonstrated the disturbances of adaptation at the site of a vitreous or retinal hæmorrhage, but also the deleterious effect on the retinal elements of the blood pigment further off, a condition due to the toxic action of iron, which is so well known in "exogenous" siderosis of the globe.

PIGMENTARY ATROPHY.—Patients with pigmentary atrophy of the retina, corresponding to their symptoms, show a profound restriction of adaptation, and this is explicable by the participation of the choroid in the diseased process, as well as by the diseased condition of the retinal elements, especially the neuro-epithelium.

We must note that BEHR found, in patients with retinitis pigmentosa, that after a quarter of an hour in the dark the adaptation value was normal. BEHR's conclusions from this observation will be considered later. At this stage the fallacy, which BEST noted, can be pointed out; unfortunately the whole course of the adaptation is not given and so we cannot see whether it did not show protraction. In HORN's case, referred to by BEHR, a patient

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[1] *Arch. f. Augenheilk.*, xxxi.

[2] FÖRSTER found (ZEHENDERS, *Monatsbl.*) in the first group syphilitic choroiditis, choroiditis disseminata, retinitis pigmentosa, ablatio retinæ, yellow atrophy (syphilitic). With slight change in adaptation, optic neuritis, retinitis apoplectica, albuminuric retinitis, white atrophy, hemiopia ex apoplexia, nicotine amblyopia.

with pigmentary atrophy of the retina showed a curve extremely retarded at its commencement though certainly reaching a normal elevation. STARGARD examined a large number of cases of retinitis pigmentosa, and certainly demonstrated temporary remissions of vision in the dark; also he showed a broad absolute ring scotoma by his photoperimeter (*Dämmerungsperimeter*), when in daylight there was only a narrow one having practically no effect on vision. Cases giving a good result when the adaptation was tested with NAGEL'S apparatus showed a ring scotoma when tested with the photoperimeter, thus agreeing with their complaint of hemeralopia.

DETACHMENT OF RETINA.—TREITEL and HORN showed that the adaptation was good in cases of detachment of the retina: a state of affairs which can be understood when we remember that those parts of the retina tested are not affected by the detachment. A different state of affairs could certainly have been anticipated, seeing that there is a definite interference with colour vision at the macula, even in cases where that area is not involved in the detachment. STARGARD strongly recommends examination with the "photoperimeter" for the exact delimitation of the *secessus retinæ* and makes the assertion that adaptation to darkness is completely absent at those places where the retina is detached. On the other hand, I can give the case of a young man with a so-called complete detachment on the one side, and on the other only the inner and upper quadrant free. The patient said that in the dusk of the evening he could only see with the left eye, and then only downwards, everything else was black. In full daylight he could see the whole of any person with the right eye, though the image was distorted. When it was dark he saw absolutely nothing with that eye. In a dim light in the morning,[1] after lying in the dark, he could see better. I examined this patient's right eye in the extreme periphery so that a detached portion was certainly under the test:—

After 2 minutes'	adaptation	to dark	the sensibility	was	0·147
,, 12 ,,	,,	,,	,,		0·178
,, 20 ,,	,,	,,	,,		0·250
,, 33 ,,	,,	,,	,,		0·313
,, 42 ,,	,,	,,	,,		0·417

To exclude the light I very carefully bound up the eye in the dark with cotton-wool and a black silk bandage (this STARGARD held did not exclude a possible reposition of the retina, but I consider that the whole history of the case did exclude it); then I made examinations of the following days at intervals of several hours.

After 24 hours'	adaptation	the	sensibility	was	12·5
,, 48 ,,	,,	,,	,,	,,	100·0
,, 72 ,,	,,	,,	,,	,,	357·0
,, 112 ,,	,,	,,	,,	,,	1428·0

I must admit that, in spite of the direction in which the reflected light was thrown, a part of the eye may have been reached where there were remnants of attached retina; I do not think it necessary

[1] The latter observation unfortunately is not contained in my publication.

to ascribe the increase in sensibility to this. My hypothesis that visual purple can reach the detached retina through the exudates, can hardly be upheld in view of the researches of ANDOGSKY,[1] referred to by STARGARD. I believe that a considerable proportion of that increase in sensibility, which I have demonstrated in detachment of the retina, is due to the adaptation of the retinal cones. STARGARD thinks that this view cannot be seriously considered. But why not? If the adaptation of the cones in the fovea centralis is very slight when only a single possible test is made with a 1° object, does that exclude the possibility that with a larger object the effect of the stimulus will depend on the size of the object?

I consider, too, that a complete absence of adaptation in a detached retina is by no means proven, though I freely admit that such adaptation is extraordinarily inert and hardly noticeable practically. I will here expressly acknowledge the great service of STARGARD's photoperimeter in the diagnosis of retinal detachment and its extent.

In passing I must refer to STARGARD's statement that the adaptation to darkness is regained after the reposition of the retina; this can only be true if the retina has not suffered too great damage during the period of detachment. WÖLFFLIN, who "even after the lapse of an hour" did not find any increased adaptation, could not show the slightest trace of it after the retina was replaced.

CHOROIDAL DISEASE.—In affections of the choroid I found, as did HORN, the same general form of disturbance of adaptation occurring to a marked degree, independently of whether the lesions in the different processes were localized in the centre or were spread over the whole fundus. We can readily see how in a central choroiditis of arterio-sclerotic origin vascular changes with variations in nutrition can occur in those parts which appear to the ophthalmoscope to be unaffected, and that these changes will first show by alterations in adaptation.

While TREITEL leaves it doubtful whether a disturbance of adaptation can fail in a "florid" choroiditis, in my cases of florid choroiditis disturbances of adaptation, though slight, were always found. In a recurrent case of disseminated choroiditis where the vision was reduced to $\frac{5}{7}$ (with no central scotoma), and which resolved after eight days' treatment, there was a slight disturbance of adaptation.

STARGARD pointed out that the adaptation value in general depended on the size and the closeness of the individual choroiditic nodules. In many cases he demonstrated a normal adaptation even at places where there were numerous fresh nodules. He therefore concluded from his investigations that examination with the photoperimeter gives more exact information regarding functional changes in choroiditis.

NERVE AFFECTIONS, RETROBULBAR NEURITIS. — STARGARD showed that the adaptation was normal in retrobulbar neuritis (toxic-amblyopia and multiple sclerosis), and that a scotoma could

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[1] *Arch. f. Ophthal.*, xliv.

be found with the photoperimeter. This variation in the adaptation of the retina at its centre and its periphery is important when we attempt to explain the improvement of vision in toxic amblyopia by subdued light (nyctalopia). WILBRAND and SÄNGER thus explain the nyctalopia; the improvement in vision in a dim light is due to the fact that under such conditions the constructive metabolism of the visual substances can keep pace with their consumption. It might be considered more correct to look for the cause of this in circumscribed localization of the functional disturbance, and in the discrepancies—especially positional—between maximal perceptions of the light and dark adapted eye.

OPTIC ATROPHY.—In agreement with HORN and myself, STARGARD demonstrated a great restriction of adaptation in tabetic optic atrophy, parallel to the other disturbances of function. In my own investigations on adaptation in optic atrophies, all those cases with a disproportionately great affection of adaptation appeared to belong to the group of glaucomatous degenerations in contrast to the other forms of atrophy.

A regular association of lowered adaptation with contraction of the field cannot be demonstrated, as was claimed by HERZOG working under VOSSIUS.[1] I consider that the great diminution of adaptation in glaucoma, especially noted by MAUTHNER, was due to a circulatory disturbance in the choroid.

BEHR found great variation in adaptation in the different affections of the optic nerve trunk; it certainly appears that a disturbance of the adaptation as an isolated phenomenon, with absolute or relative normal function of the eye in bright light, can be found in simple degeneration, inflammatory degeneration, and purely inflammatory processes of the optic nerve (tabetic, syphilitic, and neuritic atrophy).

These disproportional function disturbances were only intermittently found in multiple sclerosis; after the subsidences of exacerbations the adaptation recovers. In contrast to these cases, a severe depreciation of the function of the eye in bright light, combined with a relatively unaffected adaptation, is found in mechanical pressure on the optic nerve.

Regarding the state of the adaptation in affections of the nerve tracts, reference must be made to Chapter XI.

HEMERALOPIA.[2]—We apply the term hemeralopia to a disproportionate reduction of vision in dim light. In the daylight such patients can find their way about comparatively or even absolutely well, but as soon as twilight sets in they see very badly or not at all. This complaint of very defective vision in the dark, in the diseases which we have been considering, is termed hemeralopia, and we speak in such cases of a symptomatic hemeralopia. On the other hand, genuine essential hemeralopia is a disease in which no causative indications are to be found either in the clinical

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[1] Dissertation, Königsberg, 1887.

[2] Monograph, KRIENES, Wiesbaden, 1896.

symptomatology or by pathological investigation. In general, the origin of the hemeralopia can be ascribed to pathological changes in the rods, particularly a failure in the visual purple or its defective regeneration. This hypothesis is capable of experimental proof up to a certain point.

STARGARD[1] was unable to support PARINAUD's hypothesis that the hemeralopia in icterus was due to the solution of the visual purple by means of bile pigment, as shown by the reaction of the two substances in a test tube. He found in artificially produced icterus—by ligature of the bile duct—that the visual purple in the rabbit's eye was unchanged. HESS[2] certainly could not produce hemeralopia by artificial icterus in fowls.

GENUINE HEMERALOPIA.[3]—Genuine hemeralopia is characterized by the absence of all ophthalmoscopic signs; and we presume a defective nutrition of the choroid, to account for the defective vision in dull light. This disturbance of nutrition may be of congenital origin (congenital hemeralopia), but acquired forms exist which are either of a general nature or are due to some local condition in the eye. In the first class are included those diseases tending to debility and general weakness, inanition and protracted convalescence. Malnutrition is the cause of the frequent hemeralopia which occurs in poor-houses and orphan asylums; the same can be said of scurvy.[4] A review of the incidence of hemeralopia in different countries is interesting from the point of view of national economics, as it is indirectly proportional to the national well-being. Hemeralopia is rare in England but common in Ireland; it is common also in the Danube countries and in Russia, where it is endemic in the times of great fasts.

Not only the quantity but also the quality of nutrition can have considerable influence in the causation of hemeralopia; when the diet is deficient in essentials, especially fats and albumen, the damaging influence is particularly great. UHTHOFF[5] observed hemeralopia in a gymnast who took severe physical exercise and was a rigid vegetarian. He was given another diet chiefly milk and eggs for four days, and the hemeralopia which had been present for four weeks disappeared. In diseases of the liver (cirrhosis, and ordinary icterus) hemeralopia commonly occurs, and in these cases a further sign of defective nutrition is found in the patches of xerosis of the conjunctiva (BITOT). Malaria and malarial cachexia must be included amongst the causes. Hemeralopia can occur as a latent form of malaria, and in malarial districts hemeralopia will often disappear on the exhibition of quinine. PROKOPENKO[6] found the malarial parasite in the blood and in the corpuscles of moon-blind horses. UHTHOFF considers that alcoholism is a powerful factor in the causation of hemeralopia. I

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[1] Bericht der Ophthal. Gesellschaft, Heidelberg, 1908.

[2] Ophthal. Gesellschaft, Heidelberg, 1908.

[3] KRIENES, Wiesbaden, 1896.

[4] v. MICHEL: "Bayer. ärztl. Intelligenzblatt," 1882.

[5] *Berl. klin. Wochenschr.*, 1890.

[6] Wratsch, 1892, vii.

noticed more cases of hemeralopia in beer drinkers in the hot summer of 1911. Undoubtedly the abuse of alcohol, either directly or through its sequelæ, gastritis and debility, combined with the extraordinary uninterrupted bright sunlight, acted as the damaging factor.

Along with the conditions of general nutritive disturbance already mentioned, are local conditions producing dazzling of the eyes and causing hemeralopia. A painter is recorded as having hemeralopia while painting the white façade of houses; on changing his work the symptoms disappeared. I personally knew a young sculptor with typical hemeralopia, who was relieved by wearing dark glasses while at his work. Krienes considered that hemeralopia in soldiers was the result of the glare. Their maintenance of an erect and rigid attitude did not allow them to avoid the continual glare of the light. Their narrow and tight neckbands caused changes in and obstructions to the retinal and choroidal circulation.

In hemeralopia the most marked changes are those of adaptation. Förster and Krienes specially mention that the centre of the retina is affected first, and recovers last; at the commencement of their affection the patients complain of a positive central scotoma on entering a dark room. Later, the defect in adaptation spreads over the whole fundus, and on testing the adaptation an extraordinarily poor adaptive variation in the threshold of sensation is found.

The visual acuity is normal, but there is often a contraction of the field for blue, the so-called inverted colour field.

If there is icterus this contraction for blue may be considered as a dioptric symptom.[1] Krienes, however, considered that the yellow discoloration of the vitreous was not the important factor, a simple opacity in the periphery of the vitreous such as occurs in malnutrition or inflammation of the choroid being sufficient to obstruct rays of short wave length. The disturbance of the vision for blue is shown in that small dark blue objects, such as cornflowers in a field, are not seen by the hemeralope as blue, but as black; a phenomenon which also appears in a normal eye after exposure to the glare of a strong light (Nagel).

Tests for Light Difference.—Besides the threshold of sensation, whose estimation is not possible without consideration of its variability due to changes in the surrounding illumination (adaptation), the light difference is of great importance in estimating the light sense of the eye. This is usually determined by a rotating disc, and its amount by the extent of the black section which must be mixed with the white so that it will be distinguished from the latter as grey.

Further Detail of the Laws for Testing the Light Difference.—I shall not now deal further with the rules for testing light difference, nor the various forms of discs used

[1] Hirschberg: *Berl. klin. Wochenschr.*, 1885.

(Maxwell's, Masson's, and Donders'); it is sufficient to make the general statement that the test is of less clinical interest than that for adaptation.[1] The test for light difference in a bright light, and the minimal stimulus in the dark, were formerly considered as of equal value in the examination of the light sense. Ole Bull[2] appeared to give the preference to the light difference test, because it was more easily made and did not require a special dark-room. Bjerrum[3] opposed this view, and emphasized the fact that the results of the two tests are not interpendent.

Hillemanns'[4] observations show that the light difference tests cannot be neglected for those of adaptation. This author set himself to study the changes in the light sense in myopia, a line of investigation which appears desirable on account of the contradictory views which are held on the question. According to Seggel the light difference is normal in only 55 per cent. of myopes, and in the higher degrees of myopia it is more affected than the visual acuity. Stilling held the opposite view, and could not find any interference with the light sense in myopia.

Hillemanns came to the conclusion that, although disturbances in the light sense did not play the great part in the pathology of myopia claimed by Seggel, they were still important factors. The changes are shown in the delayed adaptation and hemeralopia, which appears by Seggel's and Treitel's test cards; in a bad light the sensation for blue also shows variations similar to those found in hemeralopic states (*e.g.*, inverted colour field).

The central light difference, too, was disturbed, if tested in an unfavourable or reduced light. Hillemanns, however, in opposition to these claims, found that tests of the light-minimum, and the determination by the adaptometer of the adaptation curve for the aggregate light sense, in a dark adapted eye were of little value in proving that the light sense was disturbed in myopia.

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Duplicity Theory.—To conclude our observations on the disturbances in the light sense and adaptation, we will shortly review the duplicity theory. The evidence for and against will be given; especially as this theory, according to the opinion of some authors (v. Kries, Nagel), finds a detailed support in the pathology of the eye, particularly in that of hemeralopic functional disturbances and colour-blindness; while according to other observers (Hering, Hess), this apparently simple and obvious point of view will not bear critical investigation.

A good general statement of the duplicity theory is given by Piper in an article: "Über die Functionen der Stäbchen und Zapfen und über die physiologische Bedeutung des Sehpurpurs" (*Med. Klin.* 1905. Nos. 25 and 26). A detailed review with refer-

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[1] See Landolt: "Untersuchungsmethoden," in Gräfe-Sämisch's "Handbuch der Augenheilkunde," ii.

[2] *Arch. f. Ophthal.*, xxvii. [3] *Ibid.*, xxx.

[4] *Klin. Monatsbl. f. Augenheilk.*, 1909. *Vide* Literature.

ences is provided in v. KRIES' article in NAGEL'S "Handbuch der Physiologie," and in W. A. NAGEL'S additional articles to the third edition of HELMHOLTZ'S "Physiologische Optik" (Hamburg, 1911).

The idea that variation in the form of the neuro-epithelial elements was associated with differences in function dates from M. SCHULTZE.[1] It was, however, only after the work of PARINAUD and v. KRIES that the duplicity theory was evolved and substantiated — vision in bright light with perception of colour ascribed to the cones, achromatic vision in darkness to the rods—facts in comparative anatomy first led to this view. M. SCHULTZE found that the rods were more numerous in cave dwelling animals than in those living in the open. The retina in the lizards and snakes has cones only. In the night-birds (owls) rods preponderate, while in day-birds (pigeon, fowl) the cones were formerly supposed to be in great excess. In the retina of the fowl[2] there are many more rods than were previously thought to be present when only thick sections were examined. In agreement with this HESS,[3] using special methods, showed that fowls had a great breadth of adaptation, and that the idea that they were night-blind was a fable (*see* Chapter I). At the present time the duplicity theory is supported by various facts of physiological optics, which have been to some extent given already, and which will be briefly collected.

THE COLOURLESS INTERVAL.—Vision in the dark (scotopia) is essentially different from vision in bright light (photopia). If a feeble spectrum be observed by an eye well adapted for darkness, achromatic light will first be seen, and only as the intensity is increased will colour be perceived. Conversely with the eye well adapted for light, colour in deepening saturation appears out of the darkness as the illumination is increased from sub-minimal to supra-minimal. The colourless interval only occurs when the eye is well adapted for darkness.

PURKINJE'S PHENOMENON.—If selected matched red and blue bottles are placed together so that in daylight the red appears lighter than the blue, and the illumination be gradually reduced, as adaptation increases and the illumination diminishes, the red bottle will grow darker and even appear black, while, on the contrary, the blue will grow lighter and more white. PURKINJE[4] described this phenomenon on the appearance of colour sensation at dawn: "Blue first appeared to me. The play of red colours, which shine brightest in daylight, carmine, cinnabar, and orange, for some time appeared very dark, and throughout could not be compared to their general brightness." NAGEL remarks on this quotation that this indication of blue as the brightest colour must

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[1] *Arch. f. mikrosk. Anat.*, ii, 1866.

[2] GARTEN, in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde."

[3] *Arch. f. Augenheilk.*, lvii.

[4] "Neue Beiträge zur Kenntnis des Sehens in subjektiver Hinsicht," Berlin, 1825.

be due to the casual choice of the coloured objects amongst which the green was specially dark.

SCOTOPIC LUMINOSITY VALUES.—As a matter of fact, the brightest part of the colourless spectrum for the dark adapted eye is in the green (circa 535 $\mu\mu$), whilst for the light adapted eye the brightest part passes towards the less refrangible end (circa 590 $\mu\mu$).

When the luminosity values of the individual colours of the spectrum are determined and considered as functions of the variously refrangible lights of the spectrum, in a system of rectangular co-ordinates, a curve is obtained, which has a different course from that of the eye adapted for bright light (fig. 19).

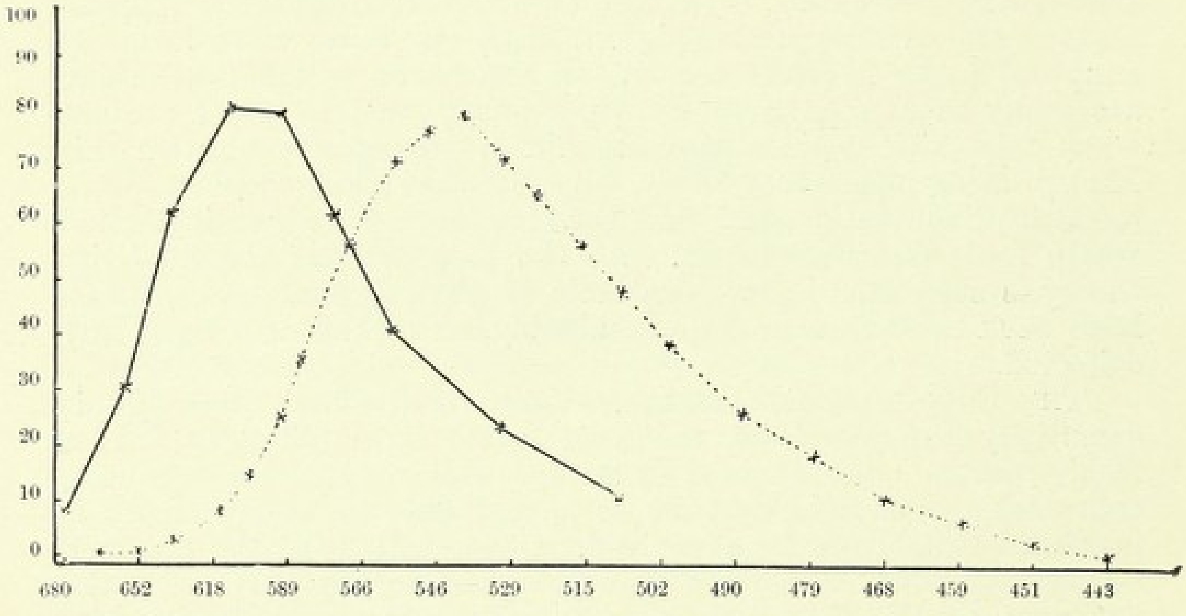

FIG. 19.—Luminosity curve of the spectral band for the light adapted eye (continuous line), and for the dark adapted eye (dotted line) after PIPER.

Such a comparison of luminosities is possible in achromatic scotopic vision. For a comparison in bright light, either peripheral values must be taken (v. KRIES), *i.e.*, the achromatic impressions of the periphery of the retina, or the achromatic impressions of extremely small coloured stimuli (*minimalfeldhelligkeiten*).[1] In both cases results are obtained which closely correspond. TRENDELENBERG'S[2] investigations have shown a correspondence between the curve of scotopic luminosity and that obtained by the bleaching of the visual purple (fig. 20).

This correspondence between scotopic efficiency and the state of bleaching cannot be accidental, and the duplicity theory sees in the visual purple and the structures which contain it (the rods) the elements and the visual material for vision in dusk.

[1] SEEBECK: *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xli.

[2] *Ibid.*, xxxvii.

Spatial Variation in Retinal Sensibility.—This spatial variation in the sensibility of the retina agrees very well with the relations of the rods and the cones in it. In the rod-free portions, such as the perifoveal, the adaptation is poor, and this is a part of the retina where the cones occur. The phenomenon of Purkinje shows a relative subordination of the macular area, as also do adaptation tests. Tschermak[1] considered that the adaptation of the centre though much slower was eventually quite as high, but Nagel, on the contrary, states that when using a visual angle of 1 to $1\frac{1}{2}^{\circ}$ Purkinje's phenomenon was definitely absent.

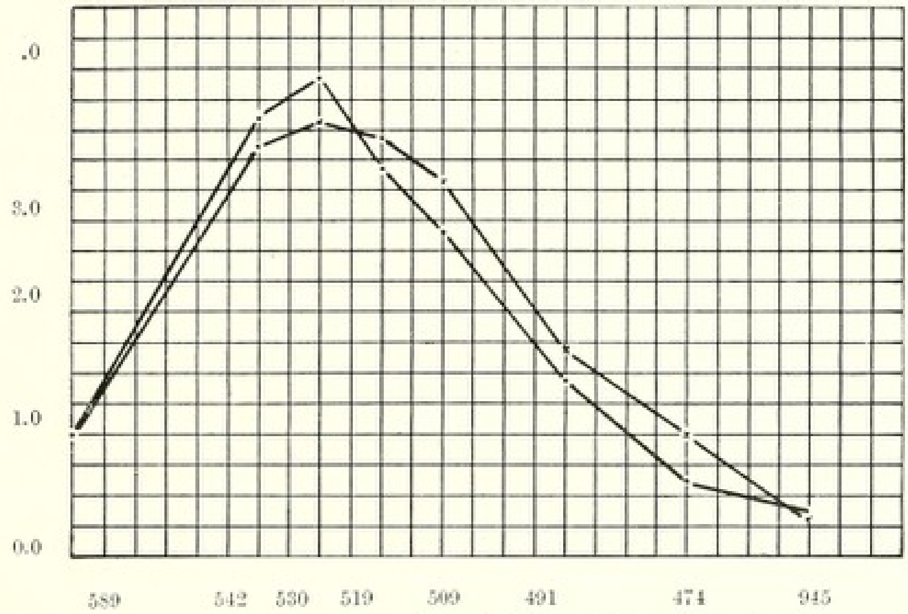

Fig. 20.—Curve of scotopic luminosity and that of bleaching by the spectral rays (Trendelenburg).

Value of Scotopia in Vision.—The view of the duplicity theory that the sensation of white (and grey) in the light adapted eye is brought about by the combined activity of the three components of the colour-perceiving cone-elements, and in the dark adapted eye by the rods and the visual purple, is freely considered to be very doubtful. It must not be forgotten that the facts given above have hardly any analogy in the physiology of the senses; this functional separation of the rods and cones, however, is worthy of discussion even if it does not appear likely. Nagel took a blue (cyan) as indicator for scotopia, as blue could still be recognized qualitatively when it was below the foveal threshold, a condition which is not present with other colours. Nagel considered that he was supported by the fact that the midnight sky, not absolutely devoid of light, appears blue, and a moonlight scene appears bathed in a bluish tint. Experimental comparisons of the visual impression produced by white on a light adapted and a dark adapted eye

[1] Pflüger's *Archiv*, lxx; v. Kries and Nagel: *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xxiii.

showed that there was a greenish-blue tint seen by the latter. If colour-blind persons compare a spectrum light of long wave length with a short one, they are quite unable when adapted for dark to discern either the brightness or the colour tone; the cyan-blue of scotopia diffuses throughout. Only in comparisons within the limits of 480 and 485 $\mu\mu$ (cyan-blue) does the appearance remain unaffected by change from daylight to dusk ("invariable region" of spectrum).[1]

DUPLICITY THEORY AND PATHOLOGY OF VISION.—The conditions of hemeralopia and total colour-blindness are brought forward to support and to illustrate the duplicity theory; the first showing an alteration in the rods, and the latter a deficiency in the cones. These views are not unopposed, and we will now shortly review the arguments for and against.

HEMERALOPIA AS A DISTURBANCE OF THE RODS.—The view, first advanced by PARINAUD, that hemeralopia is due to a change in the visual purple and in the rods, is strongly opposed by HESS.[2] By careful tests HESS demonstrated phenomena which opposed the duplicity theory of the functional activity of the rods (PURKINJE'S phenomenon, low sensibility to light at the macula). Further, he found cases where the foveal area, free from rods, was diseased; then, according to the duplicity theory, red light, which only acts on the cones, had to be very intense before it could be perceived by the hemeralopic eye.

I must here mention that I[3] have found in hemeralopes that the light difference of the macular area in a state of light adaptation differed markedly form the normal.

HESS concluded from his observations that the duplicity theory did not fully explain hemeralopia. We must at present admit that night-blindness negatives those changes in the visual epithelium which we associate with the accommodation of the eye to varying intensities of light.

v. KRIES and NAGEL reply to HESS that the hypothesis of the duplicity theory does not necessitate a complete absence of the scotopic apparatus. Neither is the theory contradicted by the fact that the cones are also affected. The salient symptom in the clinical picture is the extreme affection of the scotopic apparatus, compared to which any lesion of the photopic apparatus is quite subordinate.

Independently of HESS'S criticism, BEHR and HEINE consider that they have grounds for the opinion that hemeralopic symptoms are to be considered as due to affections of the cones. v. KRIES, as well as BEST (*vide supra*), opposes this view, pointing out that disturbances of the adaptation show themselves by an initial delay in the curve, or in a normal onset without a normal high summit. It is not possible, however, to differentiate the former type of abnormal adaptation as hemeralopia, and as essentially different

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[1] v. KRIES and NAGEL: *Zeitschr. f. Sinnesphys.*, xii.

[2] KNAPP'S *Archiv*, lxii.

[3] PFLÜGER'S *Archiv*, 1912.

from the latter. The essential change is the same, there is merely a difference in its form. A more exact basis for BEHR's view, in my opinion, will only be furnished if comparative investigation of the fovea and the perifovea show in the first type a damaged fovea, and in the second type an intact one. TREITEL[1] advances an opinion which is essentially the same. He is opposed to the designation of changes in two different functions as disturbances of the light sense ; on the one hand, a diminution in the light sense as shown by an increase in the light difference and the threshold of sensation, and, on the other, the disproportional reduction in visual acuity, due to slight reduction in the illumination, which is called hemeralopia.

TOTAL COLOUR-BLINDNESS: FUNCTION OF RODS.—The supporters of the duplicity theory consider total colour-blindness as a condition of the eye in which sensation occurs entirely through the activity of the retinal rods, which contain the visual purple; the cones being absent or functionless. The peculiar distribution of luminosity in the spectrum of the colour-blind appears to favour this view, the complete absence of colour vision and the photophobia also agree with it. The functional activity of the rods alone is favoured by the condition of visual acuity, which, according to A. KÖNIG, differs from that of colour seeing people, in that it increases in a different manner when the light is increased, and does not show that sharp bend upwards, which in the normal can be referred to the visual power of the cones. The condition of the fusion-frequency points in the same direction, for in the total colour-blind this is just as much reduced as it is in normal eyes in the condition of scotopia.[2]

The existence of a central scotoma would be especially significant, for, according to KÖNIG, a defect must be present at the point of central vision. In many cases, though not in all, such a scotoma can be found. HESS especially states that he could not find a scotoma in photopia. He expresses himself thus : In uncomplicated cases of total colour-blindness the scotoma is not present. On the other hand, he found in the dark adapted totally colour-blind eye, a central depreciation of function equal to the normal (*see* Chapter IV). These observations are confirmed by others, and in my opinion are strongly against the view that the cones are entirely absent in total colour-blindness. We can quite well imagine with v. KRIES, how regional variations are possible in spite of the fact that rods alone are present throughout the whole retina as well as in its centre; it is more difficult to follow the elaboration of this idea advanced by GRUNERT, who holds that the rods in the area of most acute vision have a lower sensibility because they are at a part of the retina which normally is free from visual purple.

On the other hand, the idea that the cones have a lower sensibility in total colour-blindness is a very attractive one; their complete absence does not appear proven by the observations

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[1] *Arch. f. Ophthal.*, xxxi, xxxiii, xxxvi, xxxvii.

[2] v. KRIES: *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xxxii.

which we have been considering. The defective vision, the absence of colour sensation, and the other symptoms can be considered, without any straining, as due to a severe restriction of the function of the cones along with an increase in that of the rods. Regarding the central scotoma I would refer to what I have said on this point in a previous chapter, when considering congenital amblyopia. I would here only note HESSBERG's[1] findings in a case of total colour-blindness. He writes: The central scotoma was examined in a darkened room whose illumination was carefully reduced, and graduated in the various tests. The objection that with such a great reduction in illumination (3 to 5 metre candles), a central scotoma would also be found at the normal macula (hemeralopia of the fovea!), is considered by HESSBERG to be untenable, as in a normal case a much greater reduction of the illumination would be necessary. If, however, we presume a restriction in the function of the cones, in the sense of the previous remarks, then the rise in the threshold of stimulation, which HESSBERG's researches show to occur, is not at all astonishing.

HERING'S VIEWS.[2]—The fact that the variation in luminosity value of the different parts of the spectrum, as seen by the totally colour-blind eye, agrees with that of the normal dark adapted eye, was discovered by HERING. Opposing the view which presumes a functional differentiation of the rods from the cones, HERING depicts the phenomena and anomalies referred to in the following way. Any particular ray of light will influence one or more visual substances; HERING distinguishes a black-white visual substance from the colour visual substances (red-green, and blue-yellow). Every kind of ray will influence the black-white, but only the coloured rays will influence the other substances. At a certain degree of darkness the colour substances cease to be sensitive, their threshold being higher than that of the black-white substance. Total colour-blindness, according to HERING, is to be explained by the absence of the visual substance for colour.

Sensations correspond to alterations in the elaboration and disintegration of this hypothetical substance. An exhaustion or an excessive change in the visual substance will be counteracted by the self-regulation of the metabolism (adaptation). According to HERING, if the "dissimilatory" activity of metabolism is in excess, the tendency to dissimilation is checked, and that to assimilation increased, a tendency to an ascending change sets in, till, finally, the descending tendency falls to zero. A variation in the opposite direction then sets in, when the process of assimilation prevails.

We shall not go into the further elaboration of this idea; it can be found in that excellent article of HERING's which has recently appeared,[3] and which gives an elegant and complete record of his teaching concerning the visual sense.

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[1] *Klin. Monatsbl. f. Augenheilk.*, xlvii.

[2] Akad. d. Wissen., Vienna, 1869, ii. PFLÜGER's *Archiv*, xl, xlix.

[3] "Grundzüge der Lehre vom Lichtsinn," in GRÄFE-SÄMISCH's "Handbuch der Augenheilkunde," ii.

CHAPTER VI.

THE SENSE OF COLOUR AND ITS CONGENITAL ABNORMALITIES.

PHYSIOLOGICAL VIEW OF COLOUR IS OBJECTIVE.—To that renowned mathematician, ISAAC NEWTON (1642-1727)[1] is due the existing conception that the multitude of bright colours radiated to us from the world around, is not due to peculiarities in the objects themselves, but in the light reflected from them into our eyes, and its varying wave length. His teaching on the science of colour, and his renowned experiments, resulted in the production of the objective spectrum. He placed a glass prism in front of a small round hole in the window of a darkened room, so that the sun's rays passing through the opening were refracted to produce a coloured elongated picture of the sun. At that end where the refraction was least the colour was red, and where the refraction was greatest the colour was violet; between were yellow, green, and blue. By again mixing the rays thus dispersed, NEWTON reproduced white light. By mixing individual homogeneous lights, colours were produced which visually resembled homogeneous light, but differed from it in respect to refractive divisibility. According to NEWTON, all the colours which we recognize in the world are either lights of homogeneous nature, or are mixtures of such.

This science of colour was further advanced by THOMAS YOUNG (1773-1829). In his "Theory of Light and Colours" he characterized light as a wave motion in the ether, a hypothetical fluid pervading the whole universe, and considered that colour was due to oscillations of varying frequency produced in the retina by light. As he could not imagine each coloured light to have a corresponding nerve impulse, he postulated a reduction of the sensory elements to three, corresponding to the three colours, red, yellow, and blue. According to YOUNG green was produced by the light vibrations partially affecting both the blue and the yellow sensory elements. With respect to the nature of these sensory elements, YOUNG conceived that there were three kinds of nerve-fibres, each subserving the sensation of a primary colour.

YOUNG's hypothesis was elaborated and confirmed by HELMHOLTZ, and is familiar to us as the "YOUNG-HELMHOLTZ Theory of

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[1] HIRSCHBERG: "Geschichte der Augenheilkunde," iii, § 6, in GRÄFE-SÄMISCH's "Handbuch der Augenheilkunde," ii.

Colour." It consists essentially in the assertion of a "colour triangle," which has resulted from the elaboration and analysis of this view of our colour sense, based on the physical nature of light.

Laws of Light Mixture.—Before proceeding to the laws of the admixture of light, it is advisable to consider the construction of an apparatus by which lights of different refrangibility can be mixed and compared with other lights, either composite or homogeneous. We will shortly describe Helmholtz's spectrum apparatus as shown in fig. 21. A parallel beam of polarized light, from which all other rays are excluded, is supplied by a Nicol's prism (*n*) held before a lamp (*l*). A second (achromatic) doubly refracting prism (*d*) only permits the passage of light polarized in two planes at right angles to each other. If the Nicol is adjusted to 0° light can only pass through it which is polarized in one of the planes of the doubly refracting prism, and if the Nicol be placed at 90° only light polarized in the other plane of the doubly refracting prism is transmitted. By suitable adjustment of the position of the Nicol between 0° and 90° the proportionate quantities of the light in the two beams can be varied.

The beams of light issuing from the doubly refracting prism (*d*) are not parallel but divergent, if then this prism be brought nearer to, or removed further from another prism (*p*) placed in the middle of the apparatus, the points on the refracting surface of this latter prism, on which the two beams impinge, will be brought closer together or removed further apart.

If the observer's eye be directed to the opposite angle of the prism, it will receive rays from the surface on which the two beams of light are impinging, but only those of a pure homogeneous spectral colour which corresponds to a particular part of the spectral band produced by the refractive power of the prism.

While the central prism (*p*) provides for the colour analysis of the lights, the doubly refracting prism varies the lights to be mixed according to their refrangibility, and the Nicol determines the proportion of the two kinds of light.

For the purpose of comparing two such beams of light as are thus obtained, a similar arrangement of apparatus is provided on the other side throwing its light through the prism (*p*) into the other half of the field of observation.

If our colour sensations are examined by comparing homogeneous and composite lights together, and by considering the effect of stimulation with reference to the quantitative and qualitative properties of the homogeneous light refracted through the prism, we arrive at a series of laws for the admixture of light which can be graphically represented in a table of colours.

By the mixture of homogeneous lights, light can be obtained which appears similar to some other homogeneous light; the mixture of spectrum green with spectrum red in definite proportions produces the same colour tone as that of spectrum yellow. Other mixtures produce tones which are not to be found in the spectrum; thus a mixture of spectrum red and spectrum violet gives a special purple tone.

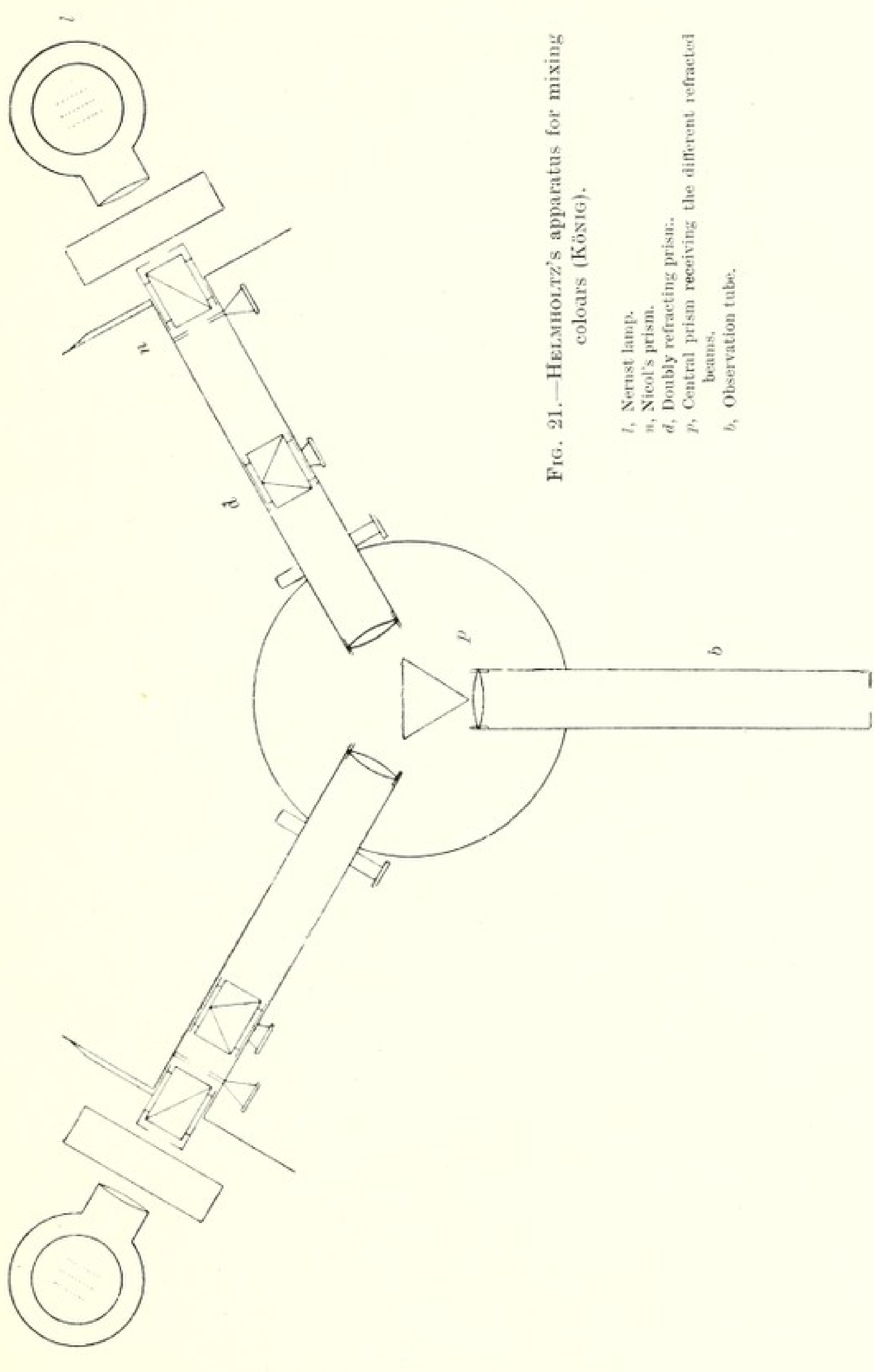

FIG. 21.—HELMHOLTZ'S apparatus for mixing colours (KÖNIG).

l, Nernst lamp.
n, Nicol's prism.
d, Doubly refracting prism.
p, Central prism receiving the different refracted beams.
b, Observation tube.

Further, for each individual homogeneous light, other rays can be found, which when mixed with it in suitable proportions produce white light. Such pairs of colours are called "complementary."

GRASSMANN'S dicta are to be considered in the laws of light mixture; they indicate that forms of light which appear similar, though physically unlike, have the same physiological action when in other light mixtures. For instance, spectrum red mixed with spectrum green gives spectrum yellow; spectrum blue-green mixed with spectrum violet gives spectrum blue. If now the quantitatively and qualitatively particular blue and the equally characteristic yellow which matches these mixtures be mixed, a light will be obtained which has the same appearance as that obtained by the mixture of the four lights. Further, if any of the components of a mixture be altered, the appearance of the mixture will be altered.

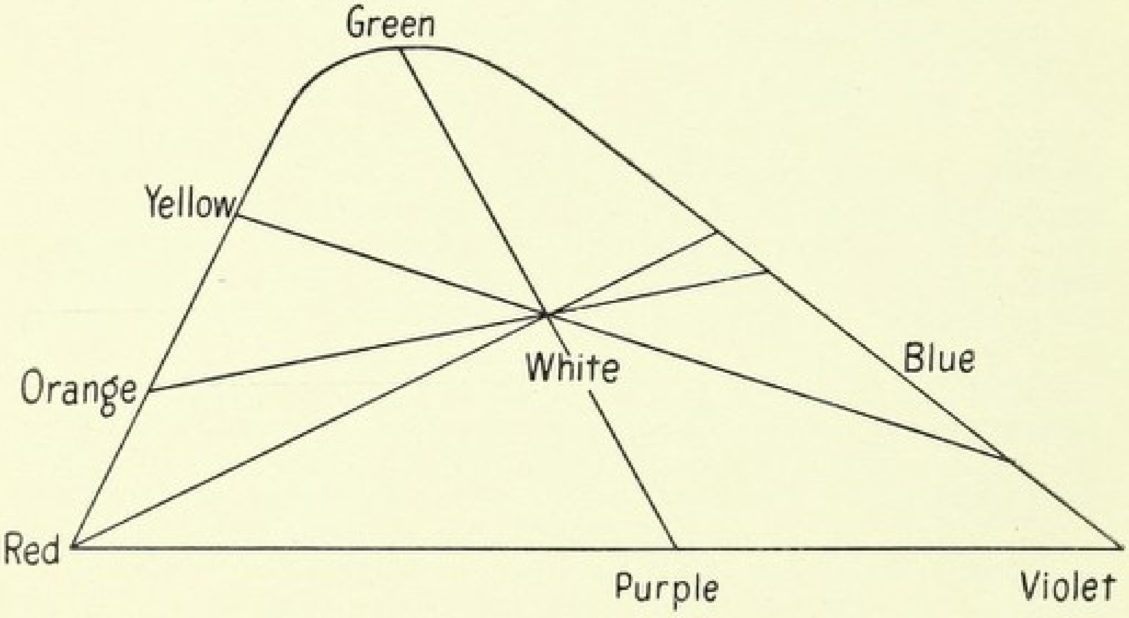

FIG. 22.—Colour diagram (after PIPER).

COLOUR DIAGRAMS.—Fig. 22 shows a colour diagram. Straight lines represent the long and short wave length portions of the spectrum, and for each homogeneous light here represented a mixture of similar appearance can be made from the end lights (red and green on the one side, blue-green and violet on the other). The portion of the spectrum of long wave length is represented at an angle to the portion of short wave length, because it is impossible to match a light of middle wave length by the mixture of lights of short and of long wave lengths. The angle is rounded off because light of this wave length, mixed with lights of long and of short wave lengths, produces an unsaturated whitish mixture. If the ends of this bent line are joined, the colour tone of purple is obtained. The point in the centre of the triangle shows how the complementary colour is found; for instance, if red be joined to this point, and the line produced, it will cut the triangle (the spectral band) at the point indicating the homogeneous light which, mixed with red, will give white.

YOUNG-HELMHOLTZ THEORY OF COLOUR.—Such a colour chart does not involve adherence to any colour theory; it shows quite freely and graphically the possibilities which can be arrived at by experimental mixtures. But as it also shows that all the colours of the spectrum (according to KÖNIG, 160) can be referred to three colours, it forms the basis of the YOUNG-HELMHOLTZ theory of colour vision, according to which three distinct and differentiated kinds of nerve-fibres in the retina suffice to convey the great multitude of colour impressions.

All three kinds of nerve-fibres are stimulated by each light; but the red fibres to their greatest extent by light of long wave length, the green fibres by light of medium wave length, and the violet fibres by the short waves.

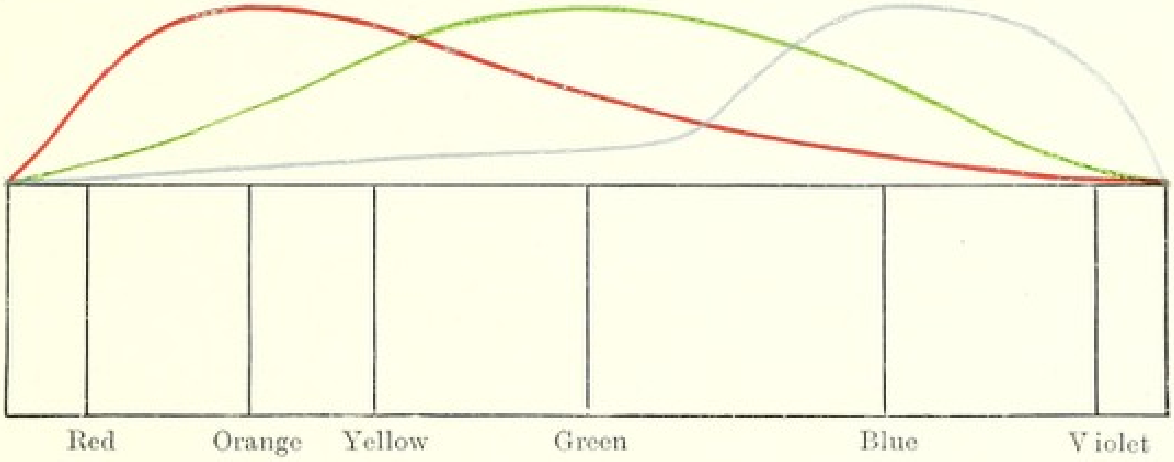

FIG. 23.—Valency curves of the three components of the colour sense.

Fig. 23 shows the manner in which the quantitative stimulation of the individual fibres by yellow or blue is to be appreciated on this hypothesis. The conclusions drawn from the laws of light mixture have in recent times found a technical application in the LUMIÈRE colour photography. In front of a sensitive plate is a screen formed of minute grains of starch coloured red, green and violet. The variously coloured light passes through the starch grains in an elective manner with respect to quantity and quality, according to the valency curves of fig. 23, and makes its impression on the bromo-silver plate. The plate is then developed as a diapositive, and will filter light in the same manner, only allowing the original colours to pass; thus we can obtain very fine photographs in natural colours. Just as in ordinary colour printing the colours are superimposed, so in this form of reproduction the light and shade values, and the variations of colour are not reproduced as delicately as they occur in nature. The stippler too, by his art, attempts the production of purer colour-effects, by setting close together spots of different colours to be fused by the eye itself.[1]

THE SUBJECTIVE PSYCHOLOGICAL VIEW OF COLOUR.—The

[1] RÄHLMAUN *Klin. Monat. f. Augenheilk.*, xlvii, Beilageheft.

idea that the conditions underlying colour sensation are to be sought for in the physical conditions of the light itself, is opposed to the subjective view based on the analysis of the sensations themselves. GOETHE, consciously and emphatically opposed to the prevailing opinion, takes up the standpoint in his science of colour, that the essential nature of colour will be most readily understood if we exactly analyse the effect which it produces on ourselves. Before GOETHE artists had voiced individual observations of this nature, but he was the first to attempt thus to cover[1] the whole field. GOETHE recognized the opposition of yellow to blue, and also the transition of both colours to red. Pure red consisted in the removal of everything causing yellow or blue. HELMHOLTZ takes this exception to GOETHE; that he thought he saw in the green, the blue and the yellow by whose admixture the artist produces his green. But GOETHE had well recognized the individual character of green, "the blend soothed the eye and the mind, as do the primary colours."

HERING'S THEORY OF COLOUR.—LEONARDO DA VINCI, and later AUBERT, recognized the quartette of colour sensations (red, green, yellow, blue), and these were further analysed in HERING'S "Theorie der Gegenfarben." Imagine a circle of bright colours merging into each other. Beginning with red, and passing in one direction, shades are met which become more and more yellow till a pure yellow is obtained, having no trace of red. After this yellow come the transitional colours to green, and finally green itself entirely devoid of yellow. Green and red are connected by shades of colour which pass through blue in which there appears no mixture of red or green.

In such a circle showing transitions through all the bright colours, four opposed spots are found: red, green, yellow, blue. This opposition of the colours appears when analysing sensations, and in correspondence with it HERING postulated the existence of a red-green and a blue-yellow visual substance, from the constructive and destructive metabolism of which sensations result. Every light as well as its colour-effect produces a colourless stimulation, which is similarly due to changes in the white-black substance (Chapter V). On the addition of a complementary light, the stimulus of the opposed colour is reduced; at the same time there is a physiological addition to the colourless effect, and therefore a sensation of grey or white.

This objection can be taken to HERING'S theory, that in the black-white form of sensation there is no indifferent point which cannot be compared to white or to black, as is the case with the red-green or the blue-yellow; there is also a doubtful element in the hypothesis in that it is not only the process of dissimilation that produces a stimulus, but perception may also be due to assimilation. The well-known phenomena of contrasts are well explained

[1] A. v. TSCHERMAK on GOETHE; PFLÜGER'S *Archiv*, cxvii. Re GOETHE, see "GOETHE als Naturforscher," by MAGNUS, Leipzig, 1906; and STILLING'S Strassburg lecture, 1899.

by this hypothesis; after steadily fixing a coloured pigment, and then looking at a colourless surface, the contrast colour appears. Just as this "successive contrast" is well explained, so also is the "simultaneous contrast." In this condition, which is shown in the appearance of coloured fringes, the dissimilation of a definite visual substance will induce the assimilation of the same substance in the adjoining parts, and thus the appearance of the complementary colour.

Colour perception in peripheral vision is also in favour of HERING'S theory. In the extreme parts of the field a simplification of vision occurs in that all colour tones approach yellow and blue; in fact there is here a red-green colour-blindness (Chapter VII). If, however, we examine the whole group of the congenital abnormalities of colour vision the simple explanation of red-green and blue-yellow blindness is hardly sufficient;[1] on the other hand these abnormalities, which have been more closely studied by KÖNIG, v. KRIES, and NAGEL, can be explained with far less difficulty by supposing that the primary sensations are three, as in the YOUNG-HELMHOLTZ theory.

ZONE THEORY OF V. KRIES.—A certain degree of weariness regarding these many theories of colour vision may be noted, and many investigators take up the position that provisionally, until a theory is found which will explain all the phenomena of colour vision in a sufficiently clear manner, they should strive to bring forward new facts to support what is already known; for example there are many blanks in our patchwork knowledge of the congenital defects in colour vision. For the present, and until a new KANT supplies the connecting bridge between the objective and the subjective views of colour vision, it might be well to rest content with the "Zonentheorie" of v. KRIES,[2] which after all is probably only a transcription of the known facts. v. KRIES infers that the immediate basis of the procedure in peripheral vision must be arranged in the three-colour system, while the central phenomena are built up on the four-colour hypothesis. The formation of colour in vision will vary in the successive sections of the visual organ.

Functionally, colour-vision is to be considered as a red-green and blue-yellow sense. The physiological basis, however, is in a triple division of the percipient organ, with three different photochemical substances in the cones. This leaves uncertain what may be the physiological basis of the functional change of colour sense in peripheral vision, where the one sense is supposed to be depreciated to a much higher degree than the other.

This triple elaboration of the end-organ of the eye appears to me to be particularly illuminating, as an entoptical phenomenon[3] which I have described can well be thus explained. Naturally such an

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[1] *Cf.* "The Accessory Hypothesis of G. E. MÜLLER." Bericht über I Kongress für exp. Psychologie, Giessen, 1904.

[2] NAGEL: "Handbuch der Physiologie."

[3] *Zeitschr. f. Sinnesphys.*, xli.

argument can only be advanced with great reserve as it is by no means devoid of fallacies.

With my eye in a condition of medium adaptation, I looked for a short time at an even grey surface, the clouded sky, then closing my eyes I obtained an after image in which small glittering points appeared and vanished. These were of three colours : blue-green, purple-red, and yellow. As these points were close together at the point of clearest vision, and in the periphery, corresponding to the dispersion of the cones, appeared scantily, I considered the phenomenon as an entoptical perception of the cones, and the three colours to be explained by the hypothesis of the triple perception of the end-organ.[1]

On the other hand, I have pointed out in an article ("Über die theoretische Bedeutung gewisser Erscheinungen aus der Farbenpathologie"),[2] that the laws of light mixture and colour contrast are shown to be valid when (as far as possible) the peripheral sensation is excluded ; a condition which must be present on the zone theory of v. Kries. I then considered the fact, first recorded by v. Reuss,[3] that the flickering scotoma appears in the contrast colour when tinted glasses are worn. If the scotoma moved towards the periphery I saw changes in the contrast colour corresponding to the physiological state of the periphery of the field. As we have good ground for considering that this scotoma is of central origin, and as the whole end-organ is subjected to the same coloured stimulus, we can conclude from the foregoing that the laws of contrasts in colours are also valid for the central "zone."

I have also reported a case of "*audition colorée*"[4] in which the diphthongs ö and ü gave respectively the colour mixtures of o with e, and u with i. It will be readily understood that a "mixing" of colour impressions, which would be perceived as distinct in the periphery, can take place in the centre, in an analogous manner to the combination of impressions separated by time intervals, brought about by the so-called fusion-frequency.

Colour Sense in Animals.—Concerning the colour sense of animals, it is sufficient for the present to say[5] that the mammals and the birds appear to have a colour sense analogous to that of man, but the state of affairs in fishes is still controversial.

The early experimental answers to this question, such as those of Lubbock in the case of bees, will not stand criticism, as they took no account of luminosity. Nagel and Himstedt[6] trained a poodle, who on the order, "Seek red," learned to distinguish in a large number of balls and sticks of different shades, the colour required. In his investigations of the colour sense in pigeons and hens, Hess[7] utilized the fact that they are guided by vision in

[1] See also Hess : *Arch. f. Ophthal.*, lviii.

[2] *Zeitschr. f. Sinnesphys.*, xlvi. [3] *Arch. f. Augenheilk.*, liii.

[4] See Chapter IX.

[5] A. v. Tschermak : Rectorial Address, Vienna, 1910.

[6] Nagel : "Colour Sense in Animals," Wiesbaden, 1902.

[7] *Arch. f. Augenheilk.*, lvii.

picking up grains of corn. He concluded from his tests that they had the same qualities of vision as man had when wearing suitably coloured glasses; this last modification is due to the fact that fowls have in their retina red and reddish-yellow oil globules which will only let the yellow and green rays pass unaffected.

Amongst the fishes HESS[1] demonstrated photosensitive individuals, which, when in the illumination of the spectral band, always sought out those places which appear brightest to the dark adapted human eye. To the obvious conclusion that fishes are colour-blind, HESS added the possibility that there may be a colour sense which differs from the human in luminosity values.

The investigations of BAUERS[2] and FRISCH[3] indicate that a colour sense probably exists in fishes. FRISCH was able to produce a different colouring in the minnow[4] according to whether the animal was placed on grey or yellow paper of similar brightness, a reaction which did not take place in fishes which had been blinded.

PSYCHOLOGY OF COLOUR SENSATION.—As to the psychological value of colour we must again refer to GOETHE's "Farbenlehre."[5] He differentiated the warm and the cold rays. "The warming effect is most clearly marked if a landscape be viewed through a yellow glass, especially on a grey winter day. The eye will be gladdened, the heart expanded, and the spirits enlivened." On the contrary, blue produces the sensation of cold, and reminds one of shadows.

Colours favourably or unfavourably placed form harmonies or discords by their contrast actions.[6]

Colour sensations show a dependence on the climate and mode of living of the people.[7] Those who live under a bright sky, always feeling the effect of a richly coloured surrounding, must have an intense longing for bright colours. An agricultural people will have a sense peculiarly susceptible to the varying play of colour in plants, while an essentially hunting or pastoral race will acquire an accentuated appreciation of the finer shades of colour in cattle and wild animals. The psychical value of colour also depends on the sensibility of the nervous system in general; thus we have those more finely organized natures who prefer the more delicate variations to the more powerful stimulation of their senses.

The æsthetic significance of colour finds a definite and comprehensive expression in its symbolism. Red in its general sensory action is more exciting than a short wave light, in purple it is the

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[1] *Arch. f. Augenheilk.*, lxiv, Supplement.

[2] PFLÜGER's *Arch.*, cxxxiii.

[3] Verhandlungen der Deutschen zool. Gesellschaft., 1911.

[4] *Phoxinus lævis* (carp family) (T.).

[5] PELTZER: "Uber Malweise u. Stil in der holländischen Kunst," 1903, Heidelberg, p. 88.

[6] RÄHLMANN: "Über Malerei u. Farbensehen," Munich, 1902.

[7] MAGNUS: "Farben u. Schöpfung," Breslau, 1881.

attribute of the greatest might, and is also the colour of fiery, exuberant youth, and of love.

THE EDUCATION OF COLOUR SENSE.—The poor development of colour sensation, shown by colour naming, is not only present in childhood but shows itself also in later years as a "colour-ignorance"; it was the cause of VIRCHOW'S complaint that his students were rarely able to indicate pathological phenomena by the colour impressions which they produced, and it explains why attempts are made at the education and refinement of sensation for colour. The case is very different when we presume, as in his time did FAVRE (Lyons) that congenital colour defects can be cured; we must rather, with MAGNUS, content ourselves from the first with raising the colour sensation to that degree of efficiency which is potential in its state of development. The tables of colours[1] devised by MAGNUS for this purpose show all the colours in varying shades and saturations; they are certainly very suited to the purpose and not at all expensive. I imagine it difficult to support the optimistic view advanced by MAGNUS as to the conquest of colour-blindness. His statistical investigations showed that colour-blindness occurred in 3 to 4 per cent. of men and only in 0·25 per cent. of women, and he connected these percentages with the fact that women have much more to do with coloured objects. MAGNUS infers that a more thorough education of colour sensation will cause a percentage reduction of colour-blindness in men. It is very fallacious to advise exercises in colour to a colour-blind person, and to give them colour charts for this purpose. It would only lead the colour-blind persons to "soak" their minds with those signs which are secondary in the recognition of colours, so that eventually, on superficial examination, they would pass as normal; but throughout their whole lives, in spite of all training, their colour sense will deceive them in strange surroundings.

CONGENITAL COLOUR DEFECTS.—During the last few years a closer study of these congenital defects has enlarged our knowledge of them; the work of KÖNIG, v. KRIES, NAGEL, and others has been particularly valuable in this respect. The investigators I have named take up a position more or less based on the YOUNG-HELMHOLTZ theory; for when the anomalous colour systems are analysed by means of the spectrum and the various combinations of homogeneous lights, there are shown to be three possibilities in the classification of those cases in which *two* homogeneous lights, one of short and the other of long wave length, suffice to represent all the colours which the spectrum presents to these persons (dichromes). In the normal we have shown that *three* colours are necessary (hence the term normal trichromatopsia), but in the dichrome one of the three components is wanting. If the first component (red) is absent the case is one of protanopia, if the second (green) deuteranopia, and if the third (blue) fail tritanopia. Protanopia and deuteranopia form the class of HERING'S red-green blind; the tritanopes are the blue-yellow blind. If the spectrum produces a

[1] Breslau, 1902.

sensation which only varies in intensity, then we have the condition of complete colour-blindness—the class of monochromes. Between the partially colour-blind (dichromes) and the normal trichromes are the "colour-defectives," of whom the large proportion (? all) have been recently studied and designated as anomalous trichromes.

RECENT LITERATURE ON DEFECTIVE COLOUR VISION.—Our more recent knowledge of dichromatopsia and anomalous trichomatopsia has been increased and extended by the work of W. A. NAGEL. The chief informative articles on the subject are: "Einführung in die Kenntniss der Farbensinnstörungen und ihre Diagnose" (Wiesbaden, J. F. Bergmann, 1908). The articles by COLLIN are also very good (Heft 32, "der Veröffentlichungen aus dem Gebiete des Militär-Sanitätswesen," A. Hirschfeld, Berlin, 1906); also ROSMANIT ("Zur Farbensinnprüfung in Eisenbahn- und Marinedienst," Braumüller, Vienna and Leipzig, 1907), and ZEITLMANN ("Der Farbensinn und seine Störungen," *Zeitschrift für Bahn- und Bahnkassenärzte*, 1907, Nos. 8 to 10). The position is thoroughly stated in H. KÖLLNER's book, "Die Störungen des Farbensinns, ihre klinische Diagnose und Bedeutung" (S. Karger, Berlin, 1912).

RED-GREEN BLINDNESS.—The great majority of congenital colour defects consist in confusion, with uncertainty and inability in the recognition of red and green. If we take such a case and analyse the colour system by the spectrum apparatus and by mixtures of lights, we find that all the colours of the spectrum can be represented by the mixing of two kinds of homogeneous light—one of long, and the other of short wave length (dichromatopsia). At the long wave end of the spectrum (red) there is a definite zone consisting of homogeneous lights of different wave lengths, which appears to the normal eye as qualitatively uniform, and in which variations of intensity produce matches. If a red-green colour-blind person is thus examined this zone (the so-called end-zone) extends much further into the spectral band, right up to that point where the normal eye would recognize a difference in the quality of the light (red, orange-yellow and green). The red, yellow, and green of the normal eye appear to the red-green colour-blind eye as one colour in varying intensities of illumination, and these colours will be confused by such a person if there be any change in the intensity of the light (confusion-colours).

We can also distinguish two groups amongst the red-green colour-blind; in one the end-zone is much shorter than in the other (or in the normal) (*see* fig. 24). There are also marked differences in the proportionate amounts of long and of short wave length light necessary when they are being mixed and matched with the colours of the spectrum. A glance at the "gauge curve" (KÖLLNER) shows the summit of the long wave light in the one form to correspond to homogeneous light of 571 $\mu\,\mu$ (curve 1), and in the second group to correspond to a homogeneous light of 603 $\mu\,\mu$ (curve 2). In each case the curve of the short wave light remains the same. The differences in red-green blind persons here shown is readily explained by the HELMHOLTZ

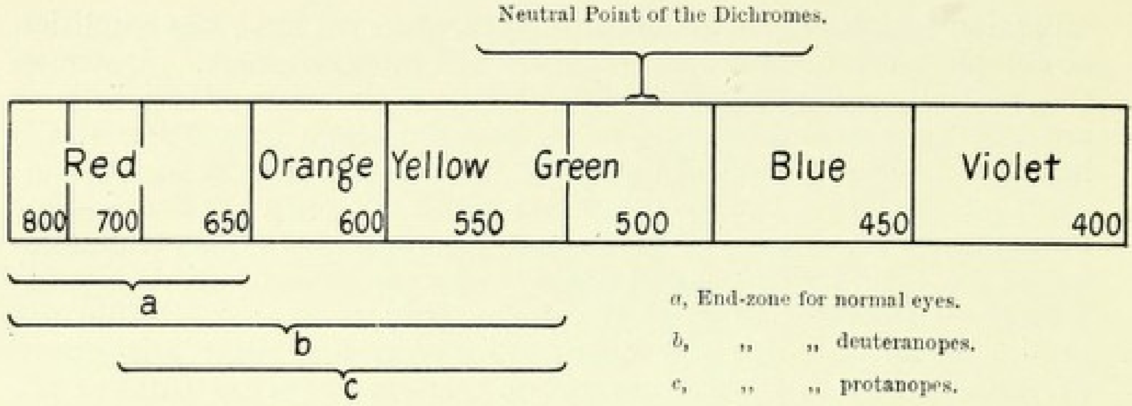

FIG. 24.—Spectrum for normal trichromes and dichromes (NAGEL).

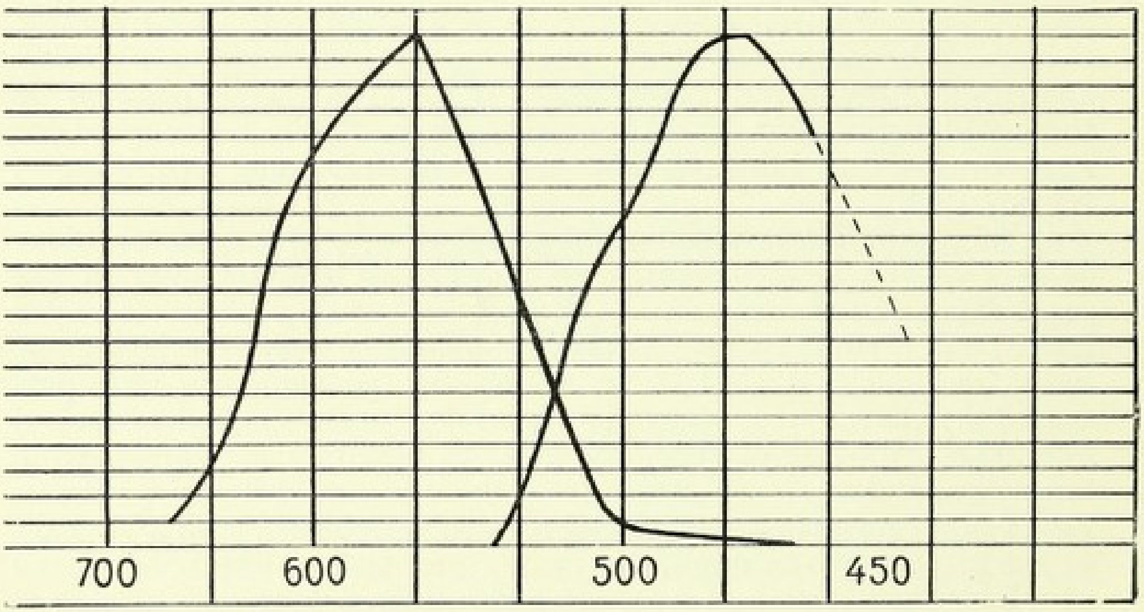

FIG. 25.—"Gauge curve" in protanopia (KÖLLNER).

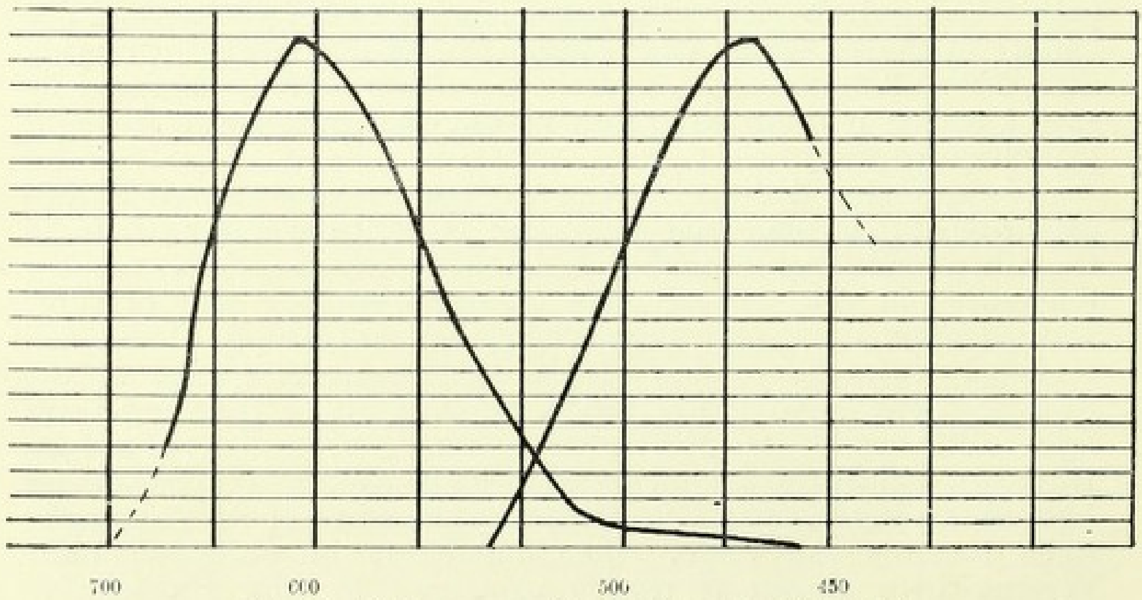

FIG. 26.—"Gauge curve" in deuteranopia (KÖLLNER).

hypothesis. In the first case the first component of the colour system is absent, and in the other it is the second; the first group is called protanopia, and the second group deuteranopia (v. Kries).

To the dichrome the spectrum not only appears as consisting of tints of two colours differing in quality, but between the two there is the so-called "neutral point," which appears grey. In the two groups of red-green blindness this point varies in position. To these dichromes, light which appears to the normal eye either blue-green or of a particular purple tone, will appear grey, so that a colourless match will be made of blue-green and purple (blue-green-purple confusion).

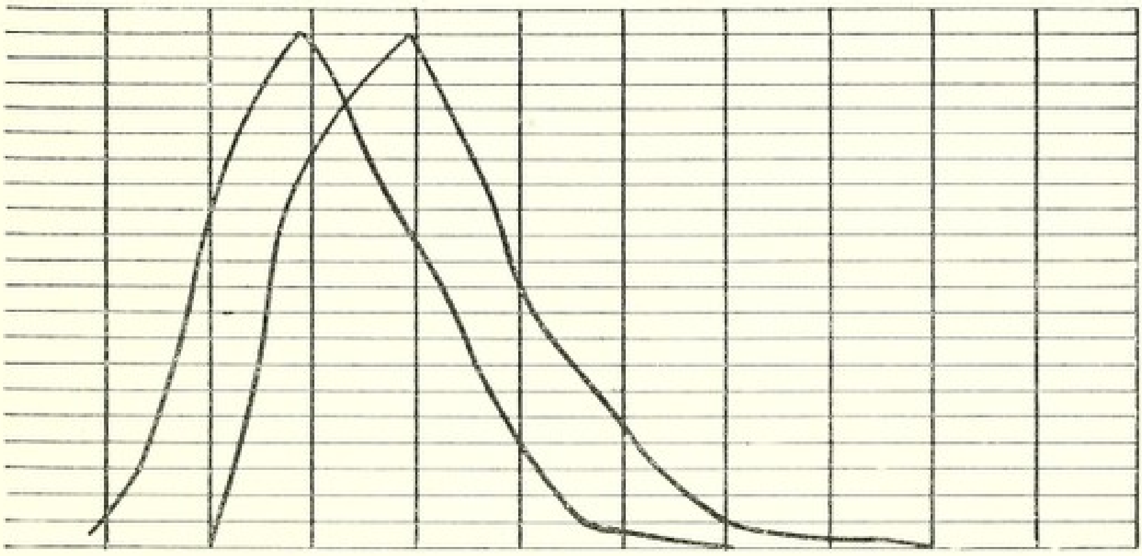

Fig. 27.—"Gauge curve" in tritanopia (Köllner).

Blue-yellow Blindness.—The blue-yellow colour-blind are much rarer than the red-green; see their "gauge curve," fig. 27, No. 3. In this group the third component of the colour system is wanting (tritanopia). These persons can readily distinguish red and green, but they confuse blue-green with blue, orange with purple, yellowish-green with blue-violet, greenish-yellow with violet-rose; to them the yellow of the spectrum appears colourless.

Monochromatic Colour Systems.—The totally colour-blind are much rarer than the red-green blind; their vision only provides a quantitative differentiation of light, and to them the world around appears as a photograph would to us. The associated phenomena provide the principal interest in total colour-blindness, and we have considered it advisable to treat of them in another chapter (Chapters IV and V).

Anomalous Trichromatopsia.—A much more common form of colour defect is provided by that anomaly which was first recognized by the English physicist, Lord Rayleigh. This investigator[1] found that a red-green yellow match, which was recognized by the majority of people, was only accepted by others when the relative proportion of red and green in the blend was considerably altered. Although Lord RAYLEIGH considered that these persons in general had good colour vision, further investigation has shown that they are defective to a considerable degree, and that they should be considered as "colour defectives" with regard to the railway and military services.

Their colour system is trichromatic, that is to say, three homogeneous colours are necessary for them, as for the normal, to match all the colours of the spectrum. The intensity curves for the stimulation values of the three components throughout the spectrum differ from the normal. There is, in fact, an anomalous trichromatic colour system (KÖNIG).

The original group of the "deuter" anomalies, *i.e.*, those persons who require more green in the RAYLEIGH equation mentioned above, can have attached to it a group of "prot" anomalies[2] in which the blended lights in the equation appear to the normal as too red. As far as relates to congenital defects the third possibility of anomalous trichromatopsia has not been established. COLLIN and NAGEL,[3] during the course of recovery in an acquired violet blindness, found a condition which probably corresponded to such a "trit" anomaly. GUTTMANN[4] considered that a case under his observation was one of deuteranopia and violet anomaly.

The condition of the anomalous trichromes, as tested by RAYLEIGH'S method, varies regarding the degree of their defect; while some will only require a very slight change in the blending proportions of the two lights others obtain matches with green and yellow (deuteranomalies), and others with red and yellow (protanomalies). It is certain that these "extreme anomalies" are not dichromes, for it is impossible for the former (deuteranomalies) to produce a colour match between red and yellow, or the latter (protanomalies) between green and yellow, which would occur were they dichromes. Blue-green, and purple, too, will not appear alike and colourless. Such an extreme case of green anomaly is recorded in the observations of SCHUMANN[5] on his own colour system. These extreme cases, just as all the anomalous trichromes, show variants and sports of the normal trichromatic colour-system, in contrast to which the dichromes must be considered as reduced varieties.

VISION OF THE COLOUR-BLIND.—The expression "colour-blind" applied to congenital colour defects may lead to error, for it may only be a case of partial colour-blindness, and those better designated as partial colour-blind, have definite sensations of colour

[1] *Nature*, xxv, 1881.

[2] LEVY: Inaugural Thesis, Freiburg, 1903.

[3] *Zeitschr. f. Sinnesphys.*, xli.

[4] *Ibid.*

[5] First Congress of Experimental Psychology, Giessen.

corresponding, *e.g.*, to red and green. The expression red-blind for protanopes and green-blind for deuteranopes is not a fortunate one.

Those who have suffered from a defective colour system from their earliest infancy find themselves compelled to fit their colour sensations into a nomenclature based on a normal colour system, and to employ different colour names for sensations which are qualitatively alike, but mostly differing quantitatively. To the colour defectives, in a smaller degree, however, than to the blind, there is that same incongruity between surrounding actualities and the ideas evolved from the reaction of the coloured objects around on the normal eye.

Information of considerable value can be derived from individuals who have normal colour vision in one eye and a colour defect in the other. Unfortunately, such cases are rare; one was recorded by v. HIPPEL.[1] The red-green blind eye appeared to perceive white light in the same way as did the normal. What the normal saw as "red" light was greenish-yellow to the other. As such cases are so rare we must fall back on conjecture in our endeavour to picture the world as seen by the colour-blind. For the most exact psychical analysis by a colour-blind person will hardly convey to us any definite information concerning his colour sensations.

Certain conclusions regarding colour sensation can be made by closely noting the errors to which a colour-blind person is liable. According to NAGEL the following are the possible mistakes in red-green blindness. Confusion of:—

(1) A bright red: with a dull yellow, or brown, olive-brown, greenish-yellow, olive green, dark orange.

(2) Orange: with a fiery red, brick red, yellowish-green, yellow.

(3) Yellow: with bright red, brick red, orange, yellow.

(4) Yellowish-green: with bright red, brick red, orange, yellow.

(5) Green: with greyish-yellow, greyish-brown, greyish-pink.

(6) Bluish-green: with grey, also white and pink.

(7) Pink, carmine: with grey, bluish-green, brownish-green.

(8) Greenish-blue: with whitey-blue (watered blue), pale violet.

(9) Blue and violet appear similar.

(10) Red-violet (mauve solution of potassium permanganate) with pale violet and pale blue.

As there are far fewer qualitative differences in colour to the colour-blind, they attempt to bring their sensations into line with the general mode of expression, by means of the secondary characteristics of the coloured objects. They have learnt to make better use of small differences in brightness and saturation for the purpose of colour diagnosis. Their skill in doing this must not, however, be expressed thus: "The colour-blind have an exceptional development

[1] *Arch. f. Ophthal.*, xxvi.

of the light sense,"[1] for such a view can easily lead to error in considering the light sense, and still more the adaptation as supernormal. It is well known that such is not the case.

A peculiarity of the dichromatic eye particularly indicated by NAGEL,[2] must here be noted. He described the colour system of a locomotive driver,[3] whose macular vision showed all the peculiarities of a dichrome, while in his full field he had well-marked trichromatic vision. NAGEL was able to demonstrate a similar condition in his own eye ; he was a typical deuteranope in the macular area, but showed a complicated visual system for objects with a visual angle of over 6°; with a 10° object the dichromatism disappeared. NAGEL found this peculiarity in thirty dichromes whom he examined specially for it. In dichromes (protanopes and deuteranopes) in the full field, the recognition of green was more uncertain than that of red, but with a large area green produced a contrast while red did not.

This explains the tendency in the colour-blind to approach close up to coloured objects, or to hold anything coloured close to their eyes, although they are not short-sighted. Great attention must be paid to this point in examining the colour-blind, or else the conclusions drawn will not have the greatest possible accuracy.

ANALYSIS OF THEIR OWN COLOUR SENSATIONS BY DICHROMES. —I take the following analytical note from the interesting exhaustive investigation which JERCHEL[4] undertook at my instigation into the question. How far is the study of medicine influenced by red-green colour-blindness? "In my earliest childhood my mother noticed that, in spite of her pains in the matter, I had great difficulty in learning the names of the colours, and made many mistakes in them. I could not tell the red from the green counters when playing halma, particularly by lamp light. After careful search I could not find a red tennis ball or a reddish-brown glove lying on the grass, and conspicuous to everyone from a distance, though I was in the immediate vicinity. When I went in search of strawberries in the woods my harvest was always much smaller than that of my companions. All the colours in my paint box were rapidly used up; 'green' alone I never used. Meadows and trees were alike painted 'red.'

"The red of the German infantry, from which I obtained the definite 'red' impression, I took as a criterion of 'red,' and impressed it firmly on my mind. All the other colours, 'darker or lighter red,' were, according to my sensations, further removed from this 'red' of mine than many of the colours which were said to be 'green.' In the same way I never developed a definite perception of the colours brown, orange, and violet. Brown and orange appeared to be a darker, or even a brighter, perhaps a dirty red ; violet as a brighter and rather dirty blue. The most elusive colour

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[1] *Cf.* RÄHLMANN : "Farbensehen und Malerei," Munich, 1902.

[2] *Zeitschr. f. Sinnesphys.*, xliv. [3] *Ibid.*, xli.

[4] Inaugural Thesis, Munich, 1912.

was green. For the term 'green' was applied to a number of colours which appeared to me to be entirely different, and according to my sensations had no relation to each other whatever, and it still is an enigma to me what the 'green' of the normal eye represents.

"As I was reared in the country, I had many opportunities of observing the various colours in Nature; my older brothers and sisters, who were normal, and knew my colour defect, drew my attention to many changes in colour, and I can still distinctly recollect the astonishment I felt at their designations of colours.

"To me the colour of grass was very closely allied to 'red,' a rather washed-out red; generally, when the grass was young, rather brighter than the 'brown' glove and the 'red' tennis ball; old grass or foliage appeared darker than 'red' objects. Yet I could not find even the approach to a colour difference between the grass-colour on the one side, and the 'red' 'orange' or 'brown' on the other, as I readily could between the 'grass-colour' and the 'yellow' or 'blue.' The 'green' of the paint box appeared to me to have no relation whatever to the 'green' which I saw in Nature.

"The colour of a forester's uniform was to be classified as 'blue' or 'grey.' Between this 'green' and the 'grass-green' (or 'red') I could see no connection; I even considered this 'green' to a certain extent as the contrast colour of the grass 'green.'

"It is quite impossible for me to define the colour sensation of a revenue officer's uniform. The colour perhaps appeared as a mixture of 'red' with a rather bright 'black,' by gathering dusk or lamplight, the colour was 'black.' At all events, it appeared fundamentally different from the grass 'green,' and the foresters' 'green.'

"Many other colour designations of normal people roused my astonishment; that, for example, there should be so marked a contrast between the 'red' tennis ball and the 'green' meadow, similarly between the 'red' painted meadow of mine and the real colour; or, between the red wild berries and the green leaves; the power also of others to recognize as 'brown' or 'orange' colours which appeared 'red' to me; and their description of the beauty and variety in the colours of the rainbow, which appeared to me as a lustrous streak of yellowish-red like the red glow of sunset.

"In the course of years both I and my relatives lost interest in my colour defect. Then, though certainly without any definite colour sense, I impressed on my mind the colour-designations of the objects I met in my daily life and in Nature, and slowly learnt to distinguish the colours by observing differences in brightness and saturation, and other minor points. I progressed so far that mistakes became ever rarer in my designation of colours, and as a result my defective colour sense affected me and my surroundings less and less, and I imagined that my colour sense had improved, and by continual practice was approaching normal.

"I then came to term the grass, the leaves of trees, fruit, especially when young—it was then termed 'green fruit'—and the unripe berries as 'green,' and I forgot to note that I really saw the 'green' fruit as 'yellow' or 'yellowish-grey,' the 'green' strawberries as 'white' or 'whitish-grey.' I learnt that ripe strawberries were 'red,' and finally forgot that I could make no distinction in colour between the 'red' strawberries and the 'green' grass. I learnt further that when an apple had acquired its ripe colour it was no longer 'green' but 'rosy-cheeked.' Also that from the young 'green' wine grapes, in their ripe stage the 'red' wine would be made; that in autumn the dark vineyard, and the darkened leaves in the woods with their peculiar sheen should be called 'red.' My own sense told me that the poppy was red. I learnt that so many flowers and roses, which I did not take to be red, were to be called 'red' or 'pink,' and others green, yellowish-green, &c. I impressed the differences in brightness and saturation on my mind, and by attention to these points I generally gauged the colour rightly, but without being sensible of the differences which normal persons perceived by their specific colour sensation, while I declared the colour from other criteria.

"The naming of colours of animals was easier for me than in the case of plants. Only certain colour designations were used for all varieties and breeds. Though the colour of the Leonberger[1] sporting about in the meadows appeared to me to be brighter than that of the grass, with a yellow shading, and although it appeared to me to be more like the grass colour than that of 'brown' beer, I naturally never called it 'yellowish-green' but always 'yellowish-brown,' for I learnt that dogs were never 'green.' In the like manner I learnt that cows and horses should be called 'red' or 'brown,' though I had no correct sensation of the colour. The tree-frog, on the contrary, was green, though it appeared to me to be more like 'yellow.'

"A dog with a dull dirty colour, which, under other circumstances, I would probably have considered 'green,' with my knowledge of colour-bearing animals I rightly called 'grey.'

"I even succeeded to a certain extent in distinguishing the coloured lamps of the street cars. It was always distinctly easier to distinguish by their saturation differences the similarly coloured placards which in the daytime indicated the route. By custom I distinguished 'violet' as lighter than 'blue,' also yellow, orange, green, and red in ascending degrees of brightness at a distance of 20 m. These distinctions were easily upset by atmospheric changes. If I went to another town and saw lamps of the same colour, but of different shape and brightness, I had to learn these new signs afresh. In the same way I succeeded in recognizing the colour of tinted wine glasses. The light green glasses of my parental home appeared yellow to me, the red ones as of a darker colour which I would as readily have termed 'red' as 'green,' but which were easily distinguished. Glasses of similar colour, but of different

[1] Leonberger—a dog, a cross between St. Bernard and Newfoundland (T.).

shape and colour saturation in other houses I often confused, tending to mistake the darker ones for the red.

"My defective colour sense has never caused me material difficulty or inconvenience. My drawing-master at school soon stopped me from painting, on account of gross errors in colouring, but this was no hardship to me. The difficulty of distinguishing between copper and nickel coins in the dark, or in badly lighted shops, has often put me in the unpleasant situation of having given a 2 pfennig piece for a 10, or a 10 as a 2."

COLOUR VISION OF ANOMALOUS TRICHROMES.—We have to thank GUTTMANN,[1] who is one of the group himself, and NAGEL, for throwing special light on the anomalous trichromes. "These persons on systematic examination show a number of variations from the normal which are peculiar and common to them all :—

"(1) Contrasted with the normal they have a lowered sense of difference in the colour tones corresponding to the region of the sodium line of the spectrum, but an increased sense of difference for the greens.

"(2) They depend upon the intensity of the coloured stimulus, inasmuch as it is only with an optimum stimulus that they can be certain in their judgments.

"(3) They are dependent on differences in luminosity, as these are often more obvious than are differences in colour tone.

"(4) For the recognition of colours they require a considerably greater visual angle.

"(5) A much longer time is required for the recognition of colour.

"(6) Coloured stimuli exhaust them more quickly.

"(7) They have a considerably stronger simultaneous contrast than the normal.

"These symptoms may react on each other in the most diverse manner, but a defect in the colour sense will always result from their combined action." (GUTTMANN.)

COLOUR WEAKNESS.—Although on the one hand the anomalous trichromes and those with a "weak" colour sense are considered as identical (GUTTMANN), NAGEL protests against such a view. He is convinced[2] that there are typical symptoms of a "weakness" in colour sense (uncertainty in the recognition of green, and of colours when the visual angle is small, inability to pass STILLING'S colour test), even when examination with spectrum lights shows a colour system corresponding to the normal trichromatic. Conversely, anomalies in the matching of red-green and yellow may be present without the ordinary symptoms of "weakness" of colour sense (KÖLLNER, ROSMANIT). The relationship between "weakness" in colour sense and anomalous trichromatopsia is extremely important, particularly with regard to appointments in the railway service. A case of "weakness" should be refused, in spite of a normal RAYLEIGH equation. If there is no demonstrable "weakness," but

[1] First Congress of Experimental Psychology, Giessen, and *Zeitschr. f. Sinnesphys.*, xlii. and xliii.

[2] *Zeitschr. f. Sinnesphys.*, xlii.

an abnormal RAYLEIGH equation, a railway servant already in the service may be retained, but an applicant should be refused.[1] I personally have never seen a case with an anomalous RAYLEIGH equation, who did not show slight uncertainty in greys and greens, particularly when tested with EVERSBUSCH's signal lantern, or with STILLING's pseudo-isochromatic tables.

INDIVIDUAL PECULIARITIES OF THE NORMAL COLOUR SYSTEM. —In his treatise "On Colour Sense and Painting," RÄHLMANN refers to individual variations in the colour sense, and says that the differences in the mode of expression in colour, and the peculiarities of artists correspond to definite peculiarities in their colour systems, and, conversely, the contradictory opinions of critics can be better understood if we refer them to differences in their sensations. In a series of investigations RÄHLMANN showed that in 30 per cent. of the cases examined the colour system differed from the normal. This percentage, which exceeds so enormously that of all other records, is explained according to HEINE and LENZ ("Über Farbensehen besonders der Kunstmaler," 1907), by RÄHLMANN's method of investigation. The extent and limits of the different colours were marked out on a spectrum of 1½ to 2 metres in length, a test in which the difficulty of determining the limits of colour are so great that no valid normal for colour sense can be deduced. HEINE and LENZ gave curves which represented the wave lengths corresponding to different colour sensations in different individuals. The quantitative differences thus shown were not considered by these two authors as indicative of material differences in the colour systems of the different individuals; they were much more inclined to side with GOETHE, who was opposed to RÄHLMANN, and in a criticism of DIDEROT's "Researches on Painting" said: "To avoid uncertainty and wrangling, we can and must admit that all normal eyes see all the colours and their relations to each other approximately alike, for this idea of unanimity agrees with the records of experience." The variations in colour interpretation and colour expression amongst painters are an expression of their individual art and their emotional state; in general the colour sensations of the painter do not differ from the normal.

DIAGNOSIS OF COLOUR-BLINDNESS.—In investigating the colour sense care should be exercised that it is done in good daylight, the eye examined should not be "out of tune" for colour, and the coloured fields should not be shown under too wide a visual angle. It is as well not to ask the names of the simple colours, for thus a colour-blind person, who has learnt to dissemble by relying on secondary evidence, may escape detection; we should much rather be guided in our decision by the information which the examinee supplies, as to the similarity or dissimilarity of coloured fields which are qualitatively and quantitatively different. The ideal is naturally a spectral apparatus, but the cost is so high that it is not every institution which can afford one.

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[1] KÖLLNER: "Störungen des Farbensinnes." Berlin, 1912.

HERING's apparatus for investigating the colour sense[1] is a good substitute. The field is divided into two parts, one is filled with a green light variable in its intensity, while in the other not only can the illumination be varied in intensity, but qualitatively the proportions of red and blue in a blended light can be altered. The apparatus will provide a continuous change in the colour tone, which cannot be obtained by NAGEL's colour lamp. In this latter apparatus we have two fields separated by a bridge; by means of two sliders various coloured glasses can be shown. There is a special adjustment by which the intensity of the two lights can be altered. KÖLLNER has recently introduced a modification of NAGEL's lamp in a cheaper form.[2]

With NAGEL's lamp two red fields, in which the intensity of the light differs, are arranged together. The normal and the anomalous trichrome will say "both are red." A dichrome whose end zone (fig. 24) extends into the red, yellow, and green of the spectrum will readily consider the differences in intensity as evidence of different colours and name them accordingly. Further a match of bright red with bright red is shown, to convince the patient that a match can be obtained. If this match also occurs when yellow and red are shown together—in other words, if by varying the intensity it is possible to match red and yellow—the case is one of dichromatopsia. Two fields, yellow and red, appear to the anomalous trichome as contrasts (yellow appears green, though it would be at once called yellow if red be absent). Both the dichromes and the anomalous trichromes will match blue-green with white by varying the intensity (KÖLLNER).

Besides these forms of apparatus designed for the matching of colours, there are simpler means of showing prepared confusion colours. I might mention STILLING's pseudo-isochromatic cards, which show spots of varying saturation of colour. The confusion colours for the colour-defectives form numerals which cannot be read by such defectives. But there may be difficulty in reading them even with a normal colour sense, and this raises a doubt as to whether we are dealing with a normal or a pathological colour sense. In conducting an investigation with the ordinary simple methods in use, it should be the rule not to rely on results by one method only. For in every single method—*e.g.*, NAGEL's coloured cards and the tables of COHN—uncertainties occur in diagnosis.

NAGEL's cards (Bergmann, Wiesbaden) show spots arranged in rings; the individual spots show colours differing in quality and quantity. The cards are to be selected which (differing in brightness of colour) are only green, or red, or grey; this is quite impossible for the dichrome. A second series is arranged with a view to the increased sense of contrast in anomalous cases; if then brown beside red appear green, a case at first considered as a weakness in colour sense passes into the class of anomalous trichomatopsia.

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[1] GRÄFE-SÄMISCH: "Handbuch der Augenheilkunde," iv, 1.

[2] KÖLLNER: "Störungen des Farbensinnes," 1912.

Cohn's cards for testing fine variations in colour sense (Berlin) are a test of contrast colours ; on a dark purple field are black forks, which appear green by contrast. If the forks are recognized, normal colour sense is certainly present (Nagel, Collin) ; but a negative result is, however, no evidence of a colour anomaly.

I have carried out a great number of investigations of the colour sense, and am convinced of the advantages of the following method : I first place the examinee before my colour table (fig. 28). Under glass and a detachable wooden lid is Nagel's first series of cards arranged in a circle ; by turning the disc the positions of the

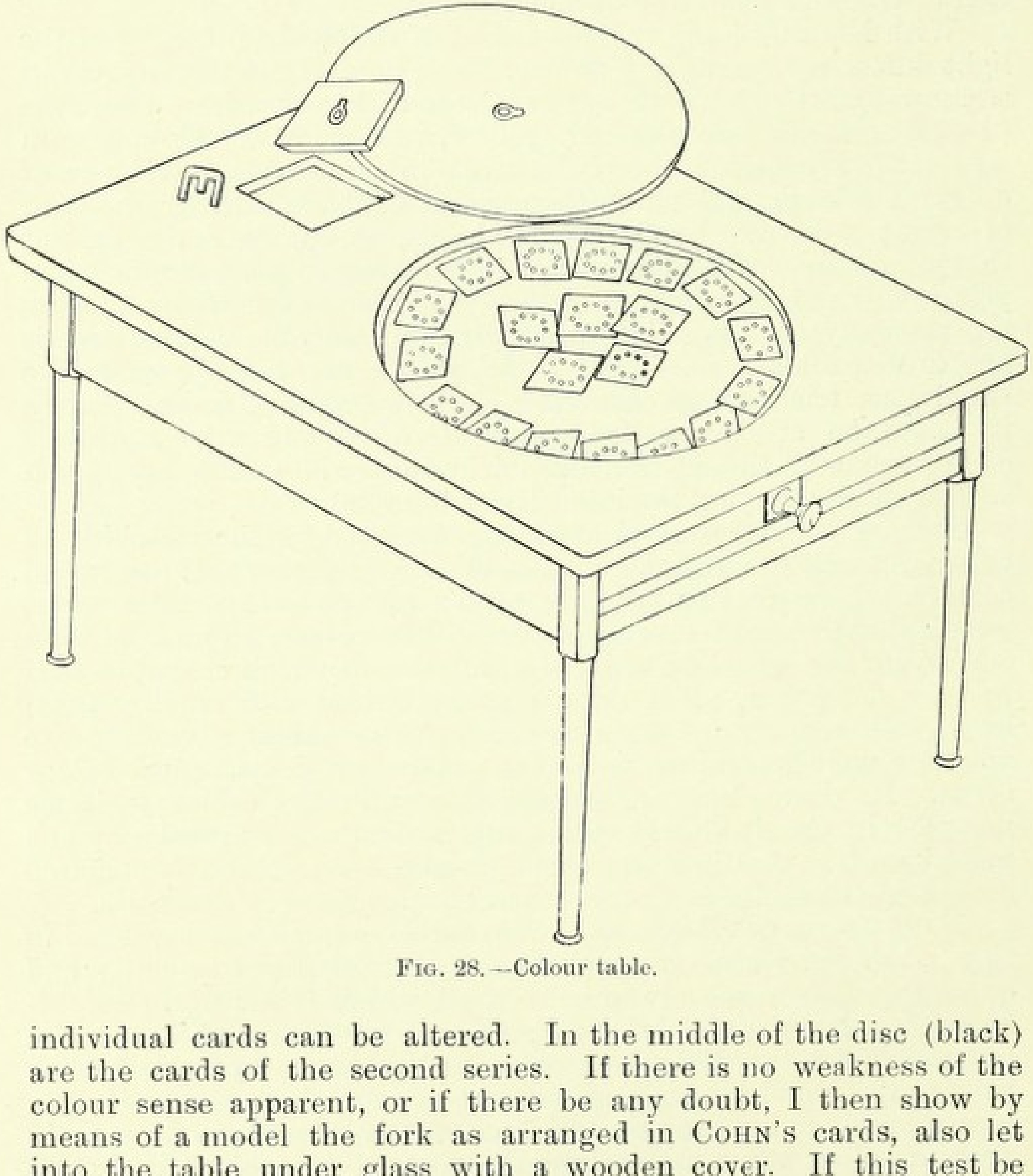

Fig. 28.—Colour table.

individual cards can be altered. In the middle of the disc (black) are the cards of the second series. If there is no weakness of the colour sense apparent, or if there be any doubt, I then show by means of a model the fork as arranged in Cohn's cards, also let into the table under glass with a wooden cover. If this test be passed the result of the first test can be verified in a more desirable way, though generally an opinion will already be formed as to whether normal colour vision is present or not. If Cohn's test does not give a definite diagnosis, I take the candidate to the Eversbusch lantern.[1] There is always an element of uncertainty about the tests in which the colours have to be named ; nor can much faith be placed on a practical test "on the line," as was formerly conducted for railway candidates on their own ground, when a plentiful supply of secondary aids to recognition was available. The EVERSBUSCH lantern shows the signal lights in different degrees of saturation and more particularly at different visual angles, and in unaccustomed surroundings; and I cannot remember a single instance of a marked colour defect which was not disclosed by the lantern. The final decision as to whether normal colour sense is present or not, I give after examination with NAGEL's anomaloscope. This apparatus is constructed to supply the match between sodium yellow on the one side, and lithium red and thallium green, either singly or mixed, on the other.

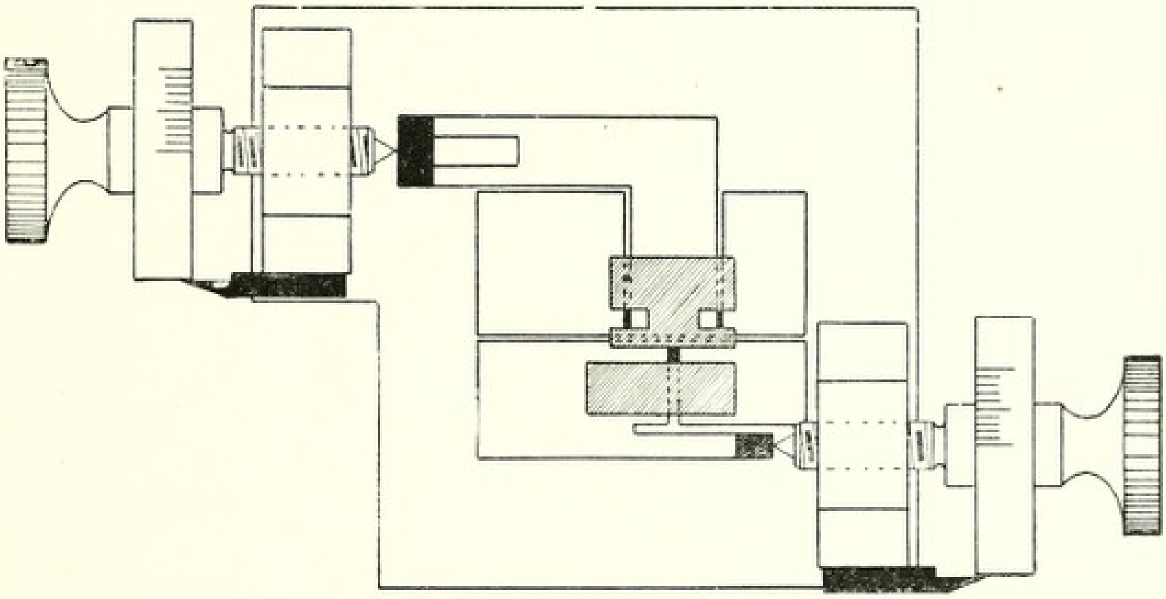

FIG. 29.—Anomaloscope (after NAGEL).

A circular field is divided into two halves by a horizontal line and viewed through an ocular, one half is supplied with Na-yellow and the other with Li-red and Th-green, either singly or mixed. The back portion of the apparatus, which lies in front of the source of light, is shown in fig. 29. There is a lower slot, variable in width by means of a screw, through which light enters and meets a prism in the apparatus in such a way that yellow light alone passes on to the observer's eye ; the two upper slots which vary in width as reciprocals of each other, supply red and green light.

The following is the method of applying RAYLEIGH's test (KÖLLNER):—

(1) First expose the red light and try if a match can be obtained by varying the intensity of the yellow. If such be the case then we have either dichromatopsia or an extreme degree of protanomaly.

[1] *Arch. f Ophthal.*, l.

(2) The yellow is arranged at the number found in a normal to the RAYLEIGH equation. Variations in the red-green blend of about five divisions of the scale correspond to individual peculiarities; greater variations indicate anomalies. It should be noted that in the anomalous matching, the intensity of the yellow should be frequently altered.

(3) The red-green mixing screw is adjusted for the anomaly (10 to 15 points lower, and about 10 points higher than normal) and the yellow altered to match.

(4) Green is arranged in the upper field, and attempts are made by varying the intensity of the yellow to obtain a match. If such be possible then the case is one of dichromatopsia or extreme deuteranomaly; the former when (1) is possible, the latter when (1) fails.

The foregoing remarks on the diagnosis of colour-blindness refer to the commoner form, red-green blindness. That exceptionally rare form, blue-yellow blindness, can be diagnosed by means of HERING'S apparatus, the comparison of colours with the colour top, or by means of STILLING'S cards, if a large spectrum apparatus is not available.

HEREDITY OF COLOUR-BLINDNESS.—It is well known that red-green blindness is hereditary; there are no records concerning the hereditary factors in blue-yellow blindness. Although it appears probable that we have the well-known type of heredity, in which alternate generations are omitted, and the defect is handed on by an unaffected daughter from a colour-blind grandfather to the grandchild, NAGEL[1] notes several families in which no generation was omitted. According to MAUTHNER, the possibility of a unilateral colour-blindness does not seem to have been considered in the construction of genealogical trees; BECKER found this unilateral condition in a woman, and v. HIPPEL has described a case of unilateral red-green blindness (*vide supra*). An observation by MAUTHNER[2] is interesting on the question of heredity; he reported a noble family in which for generations blindness was hereditary; some of the family were born blind or became blind later from nerve affections. The amaurosis had died out at the time MAUTHNER wrote his book (1899), but in the adult males he could still see its traces in red-green blindness.

IMPORTANCE OF COLOUR-BLINDNESS. PAINTING. — Colour-blindness is an absolute or relative bar to certain occupations, copyists, colour-printers, lithographers, tailors, painters, workers in mosaic, weavers and carpetmakers. We can hardly imagine a painter who was a marked dichrome or still less a monochrome. Nevertheless, we often hear of colour-blind painters, and LIEBREICH[3] reports one who would correctly reproduce the colour of a red roof in the sunshine, but would paint the shadows green. This case, as

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[1] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xli.

[2] "Farbenlehre," Wiesbaden, 1894.

[3] "On Defects of Vision in Painters," 1881.

also another reported by HIRSCHBERG,[1] was considered by GUTTMANN [2] to be a colour defective (anomalous trichrome). Such colour defects are not an absolute bar to painting, for GUTTMANN reports on a painter with a green anomaly who was considered an exceptionally fine artist. "Many of his paintings are found in private and public galleries; he has gained many distinctions and is widely known."

COLOUR DEFECTS IN MEDICAL MEN.—A physician with a colour defect will usually have reduced powers of diagnosis. Delicate differences of colour in the exanthemata, or in the fundus oculi escape him or can be seen with difficulty; he has great difficulty in finding red stained tubercle bacilli in a smear, and those chemical tests in which colour reactions occur can hardly be available to him (methyl-violet test for gastric juice, GMELIN's test, the diazo reaction, acid estimation with phenolphtalein). W. A. NAGEL tells that he was very anxious to become an ophthalmic surgeon, but his father would not give his consent on account of his dichromatopsia. We need only point out the severe examination of candidates for the Kaiser Wilhelm Akademie in Berlin, in which the colour-blind are rejected as medical students.

If the physician knows of his colour-blindness, he can neutralize the effects of his defect by perfecting the secondary powers. The influence of colour defects on medical study is held by JERCHEL to be exaggerated. Specialities such as surgery, gynæcology, and psychiatry less urgently require a colour sense than dermatology, pathology and ophthalmology.

The importance of colour-blindness in medical practitioners must be mentioned in another relationship, and that is with regard to their knowledge of colour defects. The ignorance of medical men, who have passed their examinations, concerning colour and colour defects is unbelievable. We learn much from NAGEL's observations when he refers to doctors who conduct colour tests in the most fallacious and abridged manner after methods of their own. Would it not be valuable to examine railway surgeons as to their own colour sense? Would it be asking too much of them if, before obtaining their post, they had to furnish a proof of qualification, such as State doctors (*Bezirksärzte*), though qualified, must have; or as the doctor, before he opens a dispensary, must show that he has taken out a practical pharmacy course? In such a way the torpid interest of the medical student, who unfortunately hears so little of these matters, would be aroused for questions of the physiology and pathology of the senses. Colour-blindness should be a bar to the study of chemistry, just as it is legally for pharmacy (*Apothekenbetriebsordnung*).

RAILWAY AND MARINE SERVICES.—Defective colour vision is of the greatest importance in the railway and marine service. HOLMGREN performed a great service in warmly and successfully urging the necessity of a colour test for railway servants after an

[1] *Arch. f. Anat. u. Phys.*, 1898.

[2] *Zeitschr. f. Sinnesphys.*, xlii, xliii; also *Die Umschau*, xiii, 1.

accident in Sweden (Lagerlunda, 1875). It is difficult to say how many railway and marine accidents have been due to colour defects, as driver and stoker have generally been killed, and the evidence regarding their colour vision to be found in their records often left much to be desired, at least in former times. NAGEL[1] reported in 1906 that amongst 300 railway servants who had previously been examined at least once, he found 5 per cent. of typical colour-blindness; a record which shows how necessary is a severe, uncompromising examination by the doctor. When so often we hear from the colour defective railway men that they can tell the signals, and when in a known locality they may do so from secondary means, we should think of NAGEL's record of himself—he was a deuteranope: "In large stations I can recognize with certainty the red and the white lights close together, provided the lamps are not too far away (say 100 m.) In the case of lamps at the end of a long station, about half a kilometre distant, I make an extraordinary number of mistakes. It then becomes a pure guess. The differentiation of white from green lights is very uncertain even at shorter range." Just as in the case of typical dichromatopsia, so anomalous trichromatopsia excludes from the railway and marine service; their symptoms cause great uncertainty in the rapid recognition of small signals (see the work of FEILCHENFELD[2]).

COLOUR DEFECTS AND MILITARY SERVICE.—What we have just said applies also to the marine and railway troops. In the other arms and branches of the service, colour-blindness has an importance, for many coloured signals and flags are used, and their correct recognition is necessary, as is the meaning of coloured objects in the field (*e.g.*, the enemy). Although it is generally a body of men having always a preponderance of normal colour vision, who have to recognize these coloured objects, all scouts and officers should certainly have a normal colour sense.

COLOUR VISION OF CHAUFFEURS.—A recently repealed Bavarian ordinance enacted that drivers of motor vehicles must not only have perfect eyes with normal acuity, but also a normal colour vision, and it was essential for the observance of this law that in the various colours of the green landscape other coloured objects (persons, railway signals, &c.,) should be very conspicuous, as colours have been variously used for wayside sign posts.[3]

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[1] *Zeitschr. f. Sinnesphys.*, xli, "Fortgesetze Untersuchungen," &c.

[2] *Arch. f. Augenheilk.*, l.

[3] Geheimrat EVERSBUSCH has recently published a dissertation on "the eyes of motorists."

CHAPTER VII.

ACQUIRED DEFECTS IN THE COLOUR SENSE.

Temporary Alterations in Colour Sense.—When a normal colour system is temporarily placed under such conditions as are analogous to congenital dichromatopsia, that condition is not experimentally reproduced. It is possible, by absorption, to evolve a state which resembles such a colour defect, but an exact examination will show that a trichromatic system is still present. If one looks through a yellow glass the spectrum is shortened at its short wave end, the commonly used blue object of the perimeter will seem green, and the yellow object will appear paler. Examination with spectrum light will at once show points of difference from a dichromatic (tritanopia) colour system.[1]

Transference of a Trichromatic into a Dichromatic Colour Sense.—Based on an examination of his own condition, W. A. Nagel[2] reported the experimental transference of a trichromatic into a dichromatic colour system. Using his full field he could not make the same dichromatic colour matches which obtained for the foveal region; he was, however, able to do so if the eye was previously exhausted for red and orange coloured lights. After Nagel had worn a bright orange-red celluloid shield for half to one hour, the eye in the full field appeared as a typical deuteranope. Nagel reports, concerning the alteration in vision, "It was a most peculiar sensation to see, for the first time, one's surroundings in the same way as from the reports of others a dichrome appears to do, but as I personally have never experienced, absolutely without any red. Red objects, even though they were of great size, appeared exactly as they previously did to macular vision, according to the shade of red as brown, yellow, grey, or blue." A similar extensive change in colour vision—though not to the same degree, nor as a complete transference to dichromatopsia—was produced by Nagel in an anomalous trichrome; its duration was from one to five minutes. From these observations Nagel considered that the results communicated by Beck, Burch and others on the "Production of Colour Blindness," could be explained by the view that the effects obtained by these authors were essentially due to anomalous colour systems.

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[1] König: *Zentralbl. f. prakt. Augenheilk.*, 1888.
[2] Physiol. Gesellschaft zu Berlin, Sitzung 15, iii, 1907.

NAGEL'S colour system[1] can be obtained by complete dark-adaptation as well as by red exhaustion; then it was not possible to see even large red surfaces as red. NAGEL considered that an admixture of the complementary cyan-blue arising from the stimulation of the rods (Chapter V) must be the cause of this disappearance of red. The red paper did not appear to be red, when along with the red rays it also reflected rays producing the impression of dulness; a filtered red light, however, actually did appear red even after dark adaptation.

A periodical variation in the normal colour system is shown by the fact, which was known to GOETHE,[2] that the colour of the simultaneous and the successive contrasts differ from the complementary colour; this will occur under the ordinary test conditions. If the components of the psycho-physical apparatus "under the influence of the prevailing illumination have become, so to speak, tuned in an artificial key." In an eye adapted to daylight, the successive contrast colour corresponds to the complementary colour varied by the addition of a certain amount of red and blue. TSCHERMAK was able to prove experimentally by means of an artificial yellow adaptation that the contrast colour differed from the complementary in the manner of a yellow adaptation. In these contrast tests the pure complementary colour can only reasonably be expected to appear when the eye is "tuned to a neutral pitch" (HESS) and not when it is "chromatically out of tune." In considering the colour dissonance of the visual organ when the eye is adapted for bright light, TSCHERMAK considers that along with a definite colour in daylight there is also an elective absorption in the media of the eye; but the mutual relations of these two factors appear undefinable; the chromatic dissonance of the eye under the influence of daylight must show itself by a blue-red addition.

CHANGE IN COLOUR SENSE DUE TO YELLOW DISCOLORATION OF THE LENS.—A well-marked alteration in the colour sense is caused at different periods of life by variations in the colour of the lens. HESS,[3] whom we have to thank for his exhaustive researches in this field, computed that the increasing yellowness of the lens with advancing years caused an absorption of the blue rays in daylight to the following extent: at 25 years 21 per cent.; at 45 years 25 per cent.; at 55 years 66 per cent.; at 66 years 75 per cent.; and at 78 years 85 per cent. There is thus a gradual weakness for blue light, which is not obvious to the person affected. The defect must be of the same nature as the previously mentioned restriction of colour vision which occurs when one looks through a yellow glass. A similar colour defect (not dichromatic), quite characteristic when the eye was examined by

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[1] *Zeitschr. f. Sinnesphys.*, xliv.

[2] TSCHERMAK: Über das Verhältnis von Gegenfarbe, Kompensationsfarbe u. Kontrastfarbe." v. PFLÜGER'S *Archiv.*, cxvii.

[3] *Arch. f. Augenheilk.*, lxiii and lxi.

the colour top, was observed by HESS to disappear when, at the request of a patient, he extracted a lens which still had relatively good vision. This acquired weakness of blue vision is of some practical importance, for silk-dyers who are about 60 years of age can no longer produce the finer shades, as they mix too much blue in their colours. An objection has been taken to the Mater Dolorosa of Titian that there was such a "frightful" blue colour in it; according to HESS this coloration is explained by the absorption which we have discussed. The fact that in later work by the same artist this appearance is not obvious, can be readily explained by the assistance of his students, or by repainting at a later date. Some artists have attempted to correct this defect by working by a light which is very rich in rays of short wave length (arc light).

OTHER DEFECTS IN THE COLOUR SENSE DUE TO ABSORPTION.—Hæmorrhage into the vitreous and into the anterior layers of the retina can also cause a disturbance of the colour sense, due to an elective absorption of light. When, for instance, the bleeding has occurred at the macula, the patients see at this spot a red patch in which the colour of a blue pigment will appear green. The sudden occurrence of "*mouches volantes*" is often recorded in high myopia, where central apoplexies are common; the bleeding is profuse and will neither allow red nor other coloured light to pass on to the neuro-epithelium, which is itself otherwise damaged. In such cases, therefore, red is not seen. A colour defect resembling blue-yellow blindness is sometimes seen in icterus. HIRSCHBERG[1] demonstrated an icteric staining of the refractive media by ophthalmoscopic examination in daylight, and considered the shortening of the spectrum at the violet end, which occurs in this affection, to be an absorptive phenomenon. Others consider that the yellow vision in icterus is due to damage to the retinal elements[2] (*see* Chapter V). If in a case of violet blindness the spectrum shows a dichromatopsia, then a physiological disturbance of colour vision is present; but in this defect it is not always possible to separate the physical origin (absorption phenomenon) from the physiological and pathological, in fact, in violet blindness both causes are often acting together.[3]

ACQUIRED TRITANOPIA. — Yellow - blue (violet) blindness is recorded as being present in cases of retinal detachment.[4] MAUTHNER, in 1881, demonstrated that it occurred in disseminated choroiditis. SIMON[5] (1894) particularly referred to this form of acquired colour-blindness, and expressed his astonishment at the general ignorance that an affection of the cones could produce a yellow-blue blindness. SIMON considered that the characteristic

[1] *Berlin. klin. Wochenschr.*, 1885. No. 23.

[2] SIRÉN: *Skand. Arch. f. Phys.*, 1907.

[3] KÖLLNER: *Zeitschr. f. Augenheilk.*, xix.

[4] LEBER in GRÄFE-SAMISCH'S "Handbuch der Augenheilkunde."

[5] *Zentralbl. f. Augenheilk.*, 1894.

sign of the condition was that the blue object in the centre of the perimeter appeared green, and the yellow then appeared white. A KÖNIG[1] made use of the spectroscopic proof of a dichromatic colour system in the affection in question. Recently violet blindness has been investigated by KÖLLNER, and thoroughly described in its variations.[2]

SYMPTOMS OF VIOLET BLINDNESS.—Frequently, but not always, sufferers from acquired violet-blindness become aware of the defect by observing violet or green spots in their field; such a chromatopsia is often present before or after any changes are seen with the ophthalmoscope. KÖLLNER reports having observed green vision weeks before a detachment of the retina occurred, and has had complaints of this subjective colour disturbance for a year after the re-position of the detachment.

Though some patients complain that green (unsaturated colour) appears black, or that blue appears similar to green (KÖLLNER'S patient said that blue hyacinths appeared green to the affected eye), in other cases these complaints are not heard. The colour defect may not be disclosed by some of the colour tests. NAGEL and COLLIN'S[3] patient could pass the HOLMGREN wool test, and the STILLING card test without mistakes. He suffered from a serous œdema of the retina resulting from a contusion (Berlin opacity) and by other tests could be shown to be blue-yellow blind in the affected eye. SIMON considers it a characteristic sign that the blue-yellow blind when examined with the perimeter call the blue object green and the yellow white. Their defective colour vision is still more obvious in the spectrum. All the colours appear as varieties in saturation of red and blue-green; and, as in the congenital forms, there is an intermediate neutral zone. In individual cases the yellow appeared lilac or violet (in such cases KÖLLNER showed that there was no absolute proof by spectrum light of a dichromatic system). Could such cases have been absorption phenomena?

ACQUIRED "TRITANOPIA."—KÖNIG and KÖLLNER conducted a quantitative estimation of the relative amounts of long and of short wave light in a large number of cases of acquired blue-yellow blindness. Examination of the curves graphically representing these amounts shows that both authors are agreed as to their value, and also that these curves agree with those obtained in congenital tritanopia. There are good grounds for considering that in the acquired blue-yellow blindness the same reduction form of the normal trichromatic colour system occurs, as is the case in the congenital forms (tritanopia).

KÖLLNER considered that he must raise a protest[4] against such analogous reasoning, as he could show in the acquired form a special condition of the red-green and yellow equation of spectrum colours (RAYLEIGH'S test). He showed that these patients introduce

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[1] "Verhandlungen der physikalischen Gesellschaft," Berlin, 1885.

[2] KÖLLNER: "Die Störungen des Farbensinnes," Berlin, 1912.

[3] *Zeitschr. f. Sinnesphys.*, xli.

[4] *Ibid.*, xlii.

too much red into the red-green mixture. According to v. KRIES's comparative investigations into the quotients of the mixture in healthy and in diseased eyes, the equation varied if the test light lay at different distances between the blending lights. KÖLLNER therefore considered that absorption could be excluded, and an atypical colour system must be postulated. In control examinations[1] later with coloured glasses he found that the variations due to sources of error in the technique were not inconsiderable, and came to the conclusion that the condition in question could be considered as due to absorption. Consistently with this we find that defects in the RAYLEIGH test occur as congenital abnormalities without the ordinary tritanopia being present, and that the defect cannot be found in every case of acquired tritanopia. For the present we cannot unreservedly reject the view that the conditions found in a case of acquired tritanopia when subjected to the RAYLEIGH test are not due to an alteration of the two first components.

STATE OF THE FIELD.—Blue-yellow blindness mostly shows itself in the centre of the field, and does not necessarily stand in direct relation to the changes which are visible in the fundus with the ophthalmoscope; this fact was particularly noted by SIMON. This appears to argue an increased vulnerability of the site of most acute vision (HAAB); but exceptions are found to this rule, without there being a satisfactory explanation of the phenomenon. In a case of injury by a splinter of iron KÖLLNER reports the occurrence of blue-yellow blindness in a ring-shaped area around the macula. May this not have been due to a similar cause to that which I advanced for an analogous condition in commotio retinæ[2] (the protection of the macula by the anchoring of the nerve entry in the retina and choroid)?

OCCURRENCE AND SIGNIFICANCE OF ACQUIRED TRITANOPIA.—Acquired tritanopia occurs in detachment of the retina (as a rule, KÖLLNER[3] demonstrated its occurrence in 88 to 90 per cent. of the cases), in optic neuritis, retinitis (albuminuric, &c.), in short, in those processes where changes occur in the retina.

It appears that a serous œdema of the membrane is essential for the appearance of the phenomenon. According to KÖLLNER, tritanopia has this diagnostic value, that it supports the presence of a true neuritis rather than a pseudo-neuritis; and is in favour of a syphilitic neuritis rather than one due to an accessory sinusitis, in which till now only a disturbance of the first two components of the colour system has been demonstrated. By the addition of red-green blindness, blue-yellow blindness may lead to total colour-blindness and to amaurosis; very often it is very transient and rapidly disappearing; BAYER[4] has noted the fugitive character of this symptom.

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[1] *Zeitschr. f. Augenheilk.*, xix.

[2] *Klin. Monatsbl. f. Augenheilk.*, xliv.

[3] *Zeitschr. f. Augenheilk.*, xvii.

[4] *Prager med. Wochenschr.*, 1882, viii.

The Association of Tritanopia with other Visual Disturbances.—Seeing that tritanopia occurs in diseases of the neuro-epithelium, it is clear that disturbances of the adaptation and hemeralopia will often be associated with it. But there are cases in which the adaptation is unaffected. And, conversely, in acute hemeralopia disturbances of the colour sense can be found, but only by reducing the illumination; these show a certain resemblance to tritanopia.

Tritanopia and hemeralopia, according to what has been discussed, can be freely considered as parallel disturbances in function when occurring in the cases mentioned (Köllner).

If a tritanopia be added to a red-green blindness, whether congenital or acquired, then a monochromatic (colourless) vision will result. In two such cases the particular form of the congenital defect in the red-green sense, which was present, could be diagnosed from the variation in brightness of the different regions of the spectrum; in a case of König's the curve corresponded to the long wave curve of a protanope, and in Köllner's case to a deuteranope.

Acquired Red-green Blindness.—Acquired tritanopia can be easily brought into line with the view that the organ for the perception of colour has a tripartite composition, and it shows an analogy to the congenital form; but in acquired red-green blindness, which has been longer known and is much more common, the correspondence is not valid to the same extent. This colour defect begins without showing an immediate stage of deficiency or reduction; in its course it shows an involvement of the blue-yellow sense, and it ends in a defect of both colour senses. Although the most significant stage of this colour defect, that of red-green blindness, can be recognized as a dichromatic system, a subdivision of its progress, such as Köllner gives, on the basis of the congenital defects, cannot be considered as based on the analogies of the cases, though in practice it is useful.

Results of Light Mixture in Red-green Blindness.—The first stage is characterized by the fact that trichromatopsia still is present; but in the Rayleigh test there is a wider margin of variation in the red-green mixture. The range in which matches are made increases towards the green, while the delimitation is sharper towards the red. Whenever a match is made between red and yellow, the dichromatic stage has been reached, and this gradually passes into the monochromatic, *i.e.*, all the colours of the spectrum are seen as variations in saturation, and grey in colour.

While the gauge-curves of any tritanopic colour system, whether congenital or acquired, are always comparable, a similar investigation of acquired red-green blindness[1] will show curves which in no way correspond to the type of the protanope or the deuteranope. The peaks of the two curves are generally fused into a central rise; this fusion Köllner was able to trace graphically by repeated

[1] *Zeitschr. f. Augenheilk.*, xxii.

examinations of a case of acquired tritanopia to which red-green blindness was added.[1]

THE VISION OF THE RED-GREEN BLIND.—In cases of acquired red-green blindness the sight is better than in congenital cases, for those affected have the recollection of their former colour vision, and as the colour defect does not occupy the whole of the field, they are able to compare the impressions received by the affected and the unaffected portions of the field, and analyse the sensations. HERING[2] has designed an apparatus for use in unilateral affections, by means of which it is possible to make comparisons between coloured fields, which are brought close together, and are each perceived monocularly.

It has thus been recognized that when all the colours of the spectrum become paler, three of them are distinguished by retaining their colour tone, while all the others change towards blue and yellow; these three colours are green, yellow, and blue. A fourth colour acts in the same way as these three, but is not found in the spectrum, a purple blended from spectrum red and violet. It has further been shown that the colour vision of the red-green blind is dependent, within wide limits, on external surroundings; according to the saturation of the colour and the intensity of the light, and even the size of the object, will the same colour be sometimes recognized and at other times missed.

ACQUIRED RED-GREEN BLINDNESS AND THE THEORIES OF COLOUR VISION.—The normal colour vision in the periphery[3] of the field resembles that in acquired colour-blindness. Although the other colours change their tone, such is not the case with the four invariable colours which form the two pairs of complementary colours. The extreme limits of the field are totally colour-blind; then follows a red-green blind zone in which only blue and yellow are recognized, and most internally is the normal colour sense. The colour stimuli and the corresponding colour field limits are greater or less according to the saturation of colour, the strength of the light, and the size of the object.

From these facts we can readily appreciate the inference that in red-green blindness we have to deal with a pathological extension of the peripheral colour vision over the whole field. It cannot be denied that acquired red-green blindness is much more easily brought into line with a four colour theory than with the view that there are three associated components, and we must agree with HESS when he says that the condition of colour vision in the periphery, as also that in acquired red-green blindness, cannot be explained on the YOUNG-HELMHOLTZ theory, but is consistent with that of HERING.

While tritanopia occurs in affections of the retina, red-green blindness, on the other hand, is found in diseases of the nerve connections and centre. It is, therefore, in no way strange that the

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[1] *Zeitschr. f. Sinnesphys.*, xliv.

[2] *Arch. f. Ophthal.*, xxxvi, 3.

[3] HESS: *Arch. f. Ophthal.*, xxxv, 4.

results obtained by mixing lights do not show a defect or affection of the first two components of the colour sense, either alternately or simultaneously, provided we accept v. KRIES's zone theory. How the grouping together of these triple component terminals can occur in a nerve connection arranged in accordance with the four colour theory is just as obscure as is the condition of the periphery of the field (*see* Chapter VI). We are entitled to assume that the conduction along the nerve tracts to the centre of those colour sensations which correspond to the two first components is bound up with that integrity of the nerve-fibres which is necessary for the passage of differentiated stimuli. WILBRAND and SÄNGER[1] speak of increased resistance in the nerve-fibres. But why the first two components are especially picked out and suffer greatly, and, on the other hand, why diseases of the retina particularly affect the third component, are questions which cannot be satisfactorily answered if we accept the view that the percipient apparatus is built up of three components.

CLINICAL SYMPTOMS OF ACQUIRED RED-GREEN BLINDNESS.—In comparison to the reduction of visual acuity, the subjective changes in colour vision are not well marked; the most prominent characteristics may be lost as the defect is not present in all parts of the field. It naturally shows itself earlier and is more troublesome in those persons whose occupation is concerned with coloured signs. SCHIRMER[2] tells of a patient with optic atrophy engaged in a draper's shop, whose visual defect showed itself by a difficulty in recognizing green cloth. M. BENEDIKT,[3] who first recorded the defects in the colour sense in nerve lesions, reported that a case of his would call a red rose green, or the green leaves of the trees yellow; he noticed a dependence of the pathological colour-vision on the conditions of the test, and he reported that a patient when shown pink coloured stripes at a distance of two fathoms called them lilac, but when they were close called them pink. From the results of interrogating patients, it appears that the reddish colours are first lost; these results cannot be made to agree with the objective evidence, and, according to KÖLLNER, are easily explained in that an alteration of red into yellow constitutes such a striking change in common objects. Patients often state that oranges appear like lemons; the distinction in colour between gold and silver, and between copper and nickel coins is often only made with difficulty, and unpleasant mistakes readily arise.

THE OCCURRENCE AND SIGNIFICANCE OF ACQUIRED RED-GREEN BLINDNESS. — Acquired red-green blindness is found in every possible disease of the optic nerve, its tracts and their prolongations, and the occipital cortex; it occurs equally in inflammatory interstitial processes and in simple atrophy. According to the fundamental lesion the colour defect may be permanent or transitory. The latter is the case in those processes, such as toxic

[1] "Neurologie des Auges," iii.

[2] *Arch. f. Ophthal.*, xix.

[3] *Ibid.*, x.

amblyopia, and the visual disturbances in neuritis due to nasal sinusitis (*see* Chapter IV), which generally prove amenable to treatment, provided their duration has not been too long, and a suitable therapy has been adopted. When the colour-vision returns the symptoms disappear in the inverse order. BENEDIKT's observations are interesting; he noted that the colour defect disappeared on faradization, though the result was but temporary.

THE RELATION BETWEEN VISUAL ACUITY AND COLOUR DEFECT.—A series of exact observations is necessary in deciding the question whether a colour defect of the form we are discussing, is progressive or regressive. Special attention should be paid to the relations which are found to occur between visual acuity and colour defect, and which can be appreciated from the following table by KÖLLNER:—

Visus $1-\frac{1}{3}$	Matching by the RAYLEIGH test shows no change.
,, $\frac{1}{3}-\frac{1}{4}$	The red-green mixture gradually increases in breadth.
,, $\frac{1}{4}-\frac{1}{6}$	Thallium green and sodium yellow now appear the same, but sodium yellow and lithium red are markedly in contrast.
,, $\frac{1}{6}-\frac{1}{10}$	Pure yellow completely matches pure red.
,, $\frac{1}{40}-\frac{1}{60}$	Stage of complete colour-blindness.

DIAGNOSIS OF RED-GREEN BLINDNESS.—The diagnosis of acquired red-green blindness generally presents no difficulty. Its earliest onset is not always recognizable with certainty, on account of the absence of a sharp delimitation of normal colour sense, and the relative frequency with which individual variations occur in it. One of the best methods is by taking out the field, and plotting out any defects in the centre or the periphery by means of small coloured test objects (*see* Chapter IV).

It appears very desirable to have at hand a certain quantitative test of the degree of the affection, but unfortunately none of the methods recommended for this purpose have received general recognition of their scientific value. BULL's (Christiania, 1882) colour plates may be mentioned, or the cards of colour saturation by KOLBE (Petersburg and Leipzig, 1885). These charts show series of colours in numerous variations of saturation and that chart which is correctly recognized gives the measure of the (qualitative and) quantitative colour vision of the patient. LANDOLT's chromatometer[1] consists of a rotating disc, and by varying its colour sectors variations of the shade of colour are attempted; we shall further mention the method recommended by DONDERS,[2] using the minimal retinal image, and formerly much in vogue. The records of variations in colour sense obtained by these methods do not surpass in delicacy the evidence obtained by repeated perimetric examination at frequent intervals; this last method still surpasses all others in the recognition of the extent and the variation of colour defects in the field.

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[1] *Korrespondenzblatt f. Schweiz. Aerzte*, 1878.

[2] *Arch. f. Ophthal.*, xxiii.

CHAPTER VIII.

THE CHROMATOPSIAS.

Chromatopsia.—By the term chromatopsia we understand disturbances of the colour sense, which are evidenced by the whole field—or more rarely a part of it—appearing to be suffused by a definite colour tone. In these cases we do not have to do with a defect or absence of the normal trichromatic colour vision, as in the congenital or acquired colour defects; rather have we an addition to the chromatic sensations appreciated as the colour in question even in the dark. The meaning of chromatopsia will be readily grasped if a coloured glass be worn before the eyes and the particular discoloration taken as the basis of the colour impressions received from surrounding objects. The best known form of chromatopsia is erythropsia, or red-vision, which sets in when the eyes have been dazzled, and the xanthopsia which results from the absorption of a definite poisons, santonin.

Erythropsia.—Red-vision often occurs after a march over snow mountains of a definite height above the sea level. Fuchs[1] recalls the following from Schaubach's "Deutschen Alpen." "The party, after climbing the Grossglockner and a long march over snow, had again reached the rocks. All felt somewhat dazzled. Schaubach handed over to his guide a large piece of beautiful red quartz which he had found. Next morning in the valley, when he wished to surprise his companions with his prize, it proved to be as pure white as the driven snow."

Erythropsia was formerly considered to occur almost exclusively after cataract operations, but Fuchs directed attention to the relative frequency of the phenomenon; on the occasion of an excursion up a peak 2278 metres high in Styria, he made the following observations: "The mountain was covered to a low level partly with the last winter's snow, and partly with a fall of the previous day, so that I had to travel for four hours over the snow before reaching the hut near the summit. In the morning there was a light fall of snow, and the whole day was so dark that the sun could not be seen, nor, indeed, was vision possible more than twenty paces before me. There was no question of glare, and I left my snow glasses in my pocket. After entering the hut, several minutes were occupied in shaking off the snow. When I

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[1] *Arch. f. Ophthal.*, xlii.

looked around, everything appeared bathed in a deep purple light—a square opening leading into a dark inner room, which should have appeared black, alone was of a somewhat saturated green. My attention was diverted from a closer examination of the phenomenon by the arrival of other tourists who immediately expressed their astonishment at the same phenomenon. In a few minutes the appearance vanished for all of us, nor did it return during our occupation of the hut. I suffered no inconvenience in my eyes, but next morning awoke with a most uncomfortable, burning sensation of the skin of my whole head, which was red and swollen, peeling completely in the next few days." With regard to the particular shade of the erythropsia,[1] FUCHS compares it to Bengal fire, and the scarlet lychnis (*Lychnis chalcedonica*); v. REUSS[2] states that there was a definite cinnabar red in some cases, and certainly in others more of a purple-red colour—erythropsia and porphyropsia. In the colour phenomenon brightly coloured objects appeared red, and darker ones in the contrast colour green. The condition may last for a few moments, or even for many hours.

OCCURRENCE OF ERYTHROPSIA.—The fact that erythropsia readily occurs in aphakia has long been known to ophthalmic surgeons. The absence of the lens can only produce a condition favourable to its development, as all cataract cases do not exhibit the phenomenon.

An observation by v. REUSS should be noted in this connection. This author recorded the occurrence of erythropsia a year after a cataract operation; it occurred at the menstrual period, which was always associated with headache and pains in the back. In fact, many of the recorded cases show a definite influence of nervous irritation on the erythropsia. An abnormally large pupil (mydriasis or coloboma) will predispose an eye to the occurrence of erythropsia just as aphakia does. The immediately exciting cause of the phenomenon is practically always a strong exposure to light rich in ultra-violet rays. It is easy, therefore, to understand the fact mentioned above that persons who are quite healthy can readily suffer from erythropsia when travelling over snow at great altitudes, where the light contains an excess of short wave length rays. It must not be concluded that it is only at high altitudes that erythropsia occurs, as I have evidence to the contrary in the complaints of patients of red vision after walking on the snow-covered fields around Munich. Such cases certainly do not reach a high degree, and probably for this reason the symptoms are so seldom mentioned. FUCHS records that after cataract operation he asked a patient about some symptoms of erythropsia. The patient denied having any red vision, whereupon FUCHS made him take a walk without protective glasses over a snow field in

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[1] Literature: BIRCH-HIRSCHFELD in "Ostertag-Lubarsch," 1910; KÖLLNER, "Die Störungen des Farbensinnes," 1912; HILBERT, "Pathologie des Farbensinnes," 1901.

[2] *Arch. f. Augenheilk.*, lxii.

bright sunlight. A severe erythropsia resulted. "Every morning since my operation, I have seen this red glitter on waking, but I did not understand that that was what you meant when you asked about red vision."

CAUSE OF ERYTHROPSIA.—Nothing definite can be said about the origin of erythropsia. FUCHS considered that an optical regeneration of the visual purple was the cause. This view is supported by the fact, which he discovered, that about 10° around the point of fixation in a region which is comparatively free from cones and visual purple, the red vision is far less intense than in the periphery of the field. VOGT opposes this explanation, and has conducted an experimental investigation into the question.[1] The hypothesis that red vision depends on the formation of visual purple is untenable, as the phenomenon occurs even when the eye is acted upon by a light deprived of all its red and yellow rays, by filtration through a solution of erioviridin. VOGT'S explanation that the erythropsia is due to a prolongation of the phase of the after-image, has not found general acceptance; it has been said that he evades the real cause and does not explain it. Other authors, *e.g.*, BIRCH-HIRSCHFELD, consider that ultra-violet light, which has the power of causing changes in the ganglion cells, can also produce changes in the hypothetical visual substance of HERING, which would explain the subjective phenomenon. Another older, and, in my opinion, still an acceptable view, ascribes the cause to some peculiar state of irritation or stimulation of the visual sense nerve substance. HILBERT lays emphasis on the bodily and mental condition, and calls attention to a case of MEYHÖFER'S[2] in which erythropsia occurred after the loss of one eye, but disappeared on a successful operation on the other. The fact that V. REUSS obtained relief in this condition by the use of the faradic current has a bearing on the view that its origin is to be sought for in some peculiar and abnormal state of nervous irritation of the visual apparatus.

XANTHOPSIA IN SANTONIN POISONING.—The occurrence after the exhibition of santonin of a visual disturbance, characterized by intense yellow vision, has long been known, and has been the ground of close study and keen controversy. Xanthopsia has been compared to the vision obtained by looking through yellow glass. This comparison is valid, in so far as it relates to chromatic sensation, for in both cases there is no defective colour-system present (monochromatopsia or dichromatopsia, Chapter VII). But there is an essential difference between vision through yellow glass and xanthopsia. In the former the vision in dim light—the adaptation —is affected, and in the latter it is not (*see* Chapter V). KRIENES[3] laid emphasis on this difference, and drew the following conclusion from it: that the action of the santonin occurred in the peripheral parts of the eye, and only affected the cones in the visual apparatus,

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[1] Heidelberger ophthal. Gesellschaft, 1908.

[2] *Klin. Monatsbl. f. Augenheilk.*, 1884.

[3] *Arch. f. Augenheilk.*, xxxvii.

while the rods and the visual purple (this was confirmed by experiment on animals) remained unaffected by the toxic influence of the drug. Another view is opposed to this pre-eminent affection of the cones; SIVÉN[1] sees a support to this latter in his observation, that in santonin poisoning yellow vision does not occur centrally, that is in the foveal region.

VAUGHAN[2] at the instigation of NAGEL, conducted a fresh investigation into the action of santonin, and confirmed to some extent SIVÉN'S statements, but also found that under certain conditions of illumination even the foveal vision was yellow. That in the retinal centre in santonin poisoning there is a slight weak yellow vision is therefore established. With regard to the explanation of this fact, and also the analogous observations of FUCHS (*vide supra*), that erythropsia, due to glare, appears to be less marked in the centre than in the periphery, I would draw attention to the more active metabolism at the retinal centre due to the extraordinarily fine capillary plexus of the choroid at this site. This ensures a better nutrition and a greater resistance, as also a more rapid elimination of toxic material, with a consequent shorter exposure of the region to the toxic influence. If a dose of 0·1 to 0·5 grm. of natrium santonicum be taken, a form of violet vision will be noticed before the true yellow vision begins. The first symptom appeared to VAUGHAN as a violet tint in the newspaper print, or in the darker corners of the room. In a short time the objects outside became lighter, but they took on a peculiar discoloration like the grey appearance seen in a partial eclipse of the sun.

KRIENES thought that in this stage the spectrum was elongated in both directions. Following on this stage of hyperæsthesia for red and violet light, was a period of anæsthesia for both kinds of light. He compared this condition of the eyes to the state of the integument in the extremities; after an initial feeling of tingling and warmth, there is a numbness which persists longer. VAUGHAN'S observations oppose these conclusions, for he could not determine any lengthening of the spectral band, though he carefully tested for it in an eye adapted to bright light. The elongation of the violet end of the spectrum, stated to be of considerable moment in the early stages of santonin action, he considered to be due to the influence of adaptation to darkness acting during the observations.

When the yellow vision began VAUGHAN was able to show that violet became paler; the spectral band did not contract in its length, but did so in respect to the spread of its bright colours. The pallor affected the blue and the green as well as the violet. In the extreme red VAUGHAN observed a colour between purple and violet in tone, a most remarkable fact, for violet was not found in that part of the spectral band where it normally occurs, but at quite another place where no violet was seen by the normal eye.

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[1] *Skand. Arch. f. Phys.*, xiv.

[2] *Zeitschr. f. Sinnesphys.*, xlii.

Xanthopsia in Icterus.—The xanthopsia of santonin poisoning has a certain resemblance to the yellow vision which occurs in icterus. In this latter visual anomaly[1] Sivén demonstrated a difference between the centre and the periphery of the retina, in that the yellow vision did not affect the macular area. As in this peculiar yellow vision the adaptation is generally disturbed, without any reduction in the normal colour system, this xanthopsia can be more aptly compared to vision through yellow glass. But even in this form there appears to be some toxic action on the nervous structures of the eyes along with the physical cause.

Blue and Violet Vision.—Erythropsia and xanthopsia, as may be gathered from what precedes, are the commonest forms of chromatopsia. Blue vision (cyanopsia), violet (janthinopsia), and green (chloropsia) are much rarer. These symptoms are sometimes found in diseases of the retina and choroid (Chapter III), sometimes along with general disturbances of the nervous system in medical or surgical disease. Hilbert, who has had a wide experience of chromatopsia, reports their occurrence in the most diverse diseases.[2] He considers that the cause of the more frequent occurrence of erythropsia and xanthopsia lies in the more ready and intense impression made by the long wave colours, and hence on pathological irritation these colour sensations will be more readily induced (*cf.*, the child and the race in relation to colours [Chapter II]).

Blue Vision after Cataract Operation.—A bright blue vision frequently occurs after cataract extraction. This cold tint of the surroundings, which may actually reach the stage of blue vision, is most intense immediately after the operation and disappears at the latest in one month.[3] An idea of this form of vision can be got if a yellow gelatine screen be worn before the eye for a considerable time and then suddenly removed; immediately everything will look blue (successive contrast). As in this case so in the blue vision after cataract operation, it is obviously the successive contrast which causes the colour disturbance. The opaque lens only allows the long wave, and especially the yellow rays, to pass to the membranes in the interior of the eye, and excludes the short wave rays. If then the lens which has acted as a filter for the incoming light be removed, the short wave rays will reach the retina unhindered, and then in contrast to the filtered light the blue tone elements in the colour will be especially noted.

Chloropsia in Fundus Disease.—If a pathological fundus change is the cause of the chromatopsia, it will generally be found distributed in a clustered arrangement throughout the field (Chapter III). Green vision appears to be the important condition. The green

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[1] *Skand. Arch. f. Phys.*, xix.

[2] *E.g.*, in poisoning, *Klin. Monatsbl. f. Augenheilk.*, xlv; in medical disorders, *Klin. Monatsbl. f. Augenheilk.*, xlvi; in surgical affections, *Klin. Monatsbl. f. Augenheilk.*, xlvii.

[3] Enslin: *Zeitschr. f. Augenheilk.*, xv.

spots appear to be surrounded by red circles of contrast colour. Köllner[1] definitely states that the complaint by patients of seeing green spots is in favour of an affection of the retina and choroid (retinal detachment); chloropsia in high myopia, even when no other symptom is present, is significant of a commencing retinal detachment. In seeking an explanation of this chloropsia, we may perhaps consider that it is due to the absorptive action of a greenish exudate on the rays of light. This explanation, however, is very problematical, just in the same way as our knowledge of the origin of chromatopsia is defective and uncertain, and the true basis of chromatic sensations, their laws and material source in the nerve structures, is denied us.

[1] "Die Störungen des Farbensinnes," 1912.

CHAPTER IX.

"COLOUR-HEARING" AND OTHER OPTICAL CO-SENSATIONS.

"COLOUR-HEARING" is widely distributed. By this expression we designate the widespread peculiarity that the representation of a colour is urgently associated with an acoustic sensation. This colour-hearing is the most common special instance of those phenomena which are grouped under the term "synopsias," and which are characterized by the association, with the stimulation of one sense organ, of a sensation derived from another organ of sense. So a synopsia may occur between taste or smell, and the sensation of light or colour; between sensations of smell and representations of sounds, &c.

LIMITATIONS OF THE EXPRESSION "COLOUR-HEARING."—Colour-hearing is somewhat different from the combination of taste and smell, whose physiological separation is never quite sharp. When we eat a pine-apple and form an opinion unprejudiced by theoretical views, we have to do with one complete sensation, as when we judge experimentally of the possibility of separating taste from smell by sampling with the nose held.[1] Colour-hearing is a phenomenon which supplies an unmixed and unadulterated sensory stimulus, which, however, is accompanied by sensation derived from another sense organ.

Colour-hearing is no illusion; we are not dealing with an hallucination, for the sensation of light is always attached to a definite auditory sensation. On the other hand, there is an analogy between colour-hearing and the so-called reflex hallucination of KAHLBAUM,[2] which follows the stimulation of other sense organs; an example of reflex hallucination is found in the irritation of the larynx which occurs on hearing a hoarse singer, the tickling sensation when an impact on a sensitive spot is imminent, &c.[3] If I might characterize this colour-hearing with a word I would suggest the expression "co-sensation."[4]

COMPREHENSION OF THE PHENOMENON.—Although a large pro-

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[1] NAGEL: "Handbuch der Physiologie."

[2] *Allgemeine Zeitschr. f. Psych.*, xxiii.

[3] KRAEPELIN: "Lehrbuch der Psych.," i, S. 226.

[4] "Begleitempfindung" "Accompaniment Sensation," analogy from a musical accompaniment (Trans.).

portion of mankind feels these co-sensations, the ordinary man cannot grasp this colour-hearing, and considers any question as to his own condition to be a jest, or becomes indignant and declines to answer. On the other hand, the colour-hearer understands the position with a word; they quickly grasp the idea, as they have often made unavailing efforts to discuss the matter, and have been received with ridicule and irony. Such people rarely speak of colour-hearing on their own accord; they never attempt to tell others of their extraordinary peculiarity, which would certainly be the case if it were an hysterical manifestation.

Criticism and Reserve Necessary.—Imagination and pretence certainly play an important part in a field of research which is so completely removed from any control; a critical valuation of the answers given is incomparably more difficult than in any other field of physiological or pathological optics, and the scepticism voiced by Daubresse[1] seems justifiable up to a certain point. This author relates the case of a young Russian who saw everybody in different colours. A young lady asked him how he saw her; and after some cogitation the Russian answered "I see you yellow." As it transpired, the lady on the day he first met her had worn a yellow dress. The precautions which Daubresse urges appear to be specially apt in this case, as in the St. Petersburg salons at that time the subject of colour-hearing was much discussed, and many Russians pretended that the phenomenon occurred in their own case. Ziehen[2] also issues a warning against being too ready to accept the assertion of secondary sensory impressions, for the condition is often simulated in order to make oneself interesting.

Classification of Colour-hearing.—Henning[3] divided the synopsias into physiological and psychological photisms. The latter concedes to a brain which can only make pure abstractions with difficulty, psychological material of a certain degree of concreteness. If a colour-hearer has a definite and consistent colour impression for the vowel "a", the phenomenon, according to Henning, is physiological; but if the names of persons or the days of the week produce a colour sensation without relation or reference to the elements forming such names, then we have a psychological photism. It is presumed that associations are formed in the case of psychological photisms, whilst they are absent in the physiological (where certain definite optic nerve-fibres are co-excited); this, however, is really a matter depending on chance, and quite unimportant. If the note of a piano seems black and white, the note of a violin brown, the winter white and the spring green, the induction of the definite colour of the photism is found in psychological factors which are not difficult to recognize; but the faculty of colour hearing as such is not in any way explained thus, and remains as obscure as are the physiological photisms of Henning. If the psychological photisms are to be considered as a subclass of

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[1] *Revue philosophique*, 1901.

[2] "Lehrbuch der allg. Psychiatrie."

[3] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, x.

the "physiological," then HENNING's divisions do not appear to me to be sharp enough. I therefore prefer a division into two classes, laying less stress on the analysis of the photisms than on the individuals who are subject to the synopsias. This division, which shows very obviously in well-marked cases, is just as far from being a sharp one without intermediate forms, as is a classification of mankind into the artistic and the non-artistic.

AUDITION COLORÉE.—In the first group of the colour-hearers, definite and constant colour impressions are firmly associated with letters, numbers, names of persons, names of objects, the days of the week, dates, &c. Such individuals have not acquired or developed their peculiar talent by training. We will designate the interesting symptom of this group by the French term *audition colorée*.

INDIVIDUATION COLORÉE.—In other persons colour-hearing forms a much greater integral part of their personality. The associated colour sensations play an intimate personal *rôle*. These people clothe the whole host of congenial and uncongenial ideas in the garments of synopsias; their whole vivid spiritual life is intensely saturated with this factor; they rejoice in its power, which plays such an overwhelming part in their emotional life, and sometimes strive to develop it still further. For this group of colour hearers I prefer the term *Individuation colorée* of SOKOLOV.[1]

AUDITION COLORÉE: VOWELS.—Leaving aside the most elementary cases—where uncomfortably shrill noises, as the scraping of a pencil point, induce the colour red—and those where colour-hearing only occurs in childhood, to be lost later, audition colorée presents definite symptoms, which when tested at varying intervals always give the same result. The commonest form is that the vowels of our language are visualized in bright colours. This phenomenon was described to me by a man in a very simple way. When a vowel was pronounced loudly and emphatically he saw in front of him—on the opposite wall—a colour; this did not appear in ordinary speech, apparently because his attention was not sufficiently directed to the sounds. The vowels appeared to him:—

a (f*a*ther) grey to black.
e (p*e*n) bright green.
i (ant*i*que) red.
o (s*o*) moss green.
u (p*oo*r) yellow.
The diphthongs:—
ö (as in French n*eu*f) phosphor yellow.
ü (as oo in bloom) orange (u and i mixed).

At a concert the harmonies and chords appeared bright coloured; in minor keys the surface behind the musicians appeared green; in major tones the surface was red or yellow.

While this colour-hearer "projected" outwardly his sensations, which were only induced by vowels accentuated in a particular key,

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[1] *Revue philosophique*, 1901.

the majority of the persons whom I examined had the sensation vaguely in their heads. This regularly occurred when listening to speech. It is often reported in the literature that when the attention wandered the phenomenon disappeared. One of my colour-hearers assured me that to him the phenomenon was so usual and natural that during a conversation he paid as little heed to it as he would to the chiming of a clock, which so often passes unnoticed.

DIPHTHONGS.—The diphthongs are often seen as a mixed colour. I have reported a case of a colour-hearer to whom o appeared yellow and e red,[1] and ö the mixed colour orange. U appeared to this man green, and i yellow, while ü was a mixture of the two colours. With au, ai, eu, and ei, according to the phonetic character of the individual vowels, the corresponding colour appeared to the consciousness. In the colour-hearer we find the same results of colour mixing as we do when the stimulus is applied to the eye, an interesting fact, as colour-hearing is probably due to a central stimulation of the visual apparatus.

MUSICAL INSTRUMENTS, DAYS OF THE WEEK, NAMES OF PERSONS.—In other colour-hearers notes take a colour according to their clang, and the character of the instrument which emits them. Thus the notes of the flute are blue, and the violin red, &c. Others see different colours for the days of the week; to a colour-hearer:—

Monday was blue.
Tuesday, light blue.
Wednesday, dark yellow.
Thursday, blue-green.
Friday, grey.
Saturday, brown.
Sunday, sky-blue.

Names of persons appear coloured; and as in the case of the vowels, so the numbers are coloured. Others will associate noises with the representation of colours. The different forms of colour-hearing may occur singly or combined in the same person. The consistency of the association is always marked, as KAISER noted in the year 1882, when he obtained the same results on testing a case with an interval of ten years.

COMPARISON OF THE INDIVIDUAL CO-SENSATIONS.—It is easy to collect a mass of material referring to observations on colour-hearers, but it is difficult to reduce the mass to order. Colour-hearers will often tell of differences which they find in other persons possessing this faculty. A mother told me that she could never understand how it was that she and her daughter had quite different colour sensations on hearing the vowels. NUSSBAUMER, who was one of the first to definitely describe his own colour-hearing, reports[2] that he and his brother often played games with spoons and forks, and that the colours induced by the noises resulting did not seem the same to him as to his brother, so much so that the

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[1] *Zeitschr. f. Sinnesphys.*, xlvi.
[2] *Wien. med. Wochenschr.*, 1873.

disputes about the colours often led to quarrels. The investigations of FECHNER (1879) produced no rule of general validity in colour-hearing. The deeper notes, and the vowels with the deeper clang, were more often associated with darker colours than were the opposite acoustic stimuli. LOMMER's[1] view, that the letters when arranged according to their vibration frequency (u, o, e, i) would correspond to the colours arranged according to the vibration frequency of the ether, is far from being generally true.

The following table gives the associations which BLEULER and LEHMANN[2] found between vowels and colours, in a series of observations :—

	Blue	Black	Red	Yellow	Brown	White	Grey	Green
a (ah)	10	15	13	7	3	6	0	1
e (eh)	5	0	3	28	2	5	3	5
i (ee)	2	0	3	7	0	37	0	4
o (oh)	8	7	12	13	9	0	1	4
u (oo)	6	10	11	4	7	0	8	0

ORIGIN AND PREVALENCE OF COLOUR-HEARING. — Colour-hearing, as we have mentioned, is of frequent occurrence ; in BLEULER and LEHMANN's statistics it occurred in 12·8 per cent. of all the persons investigated. In normal and in psychopathic individuals the percentages were about equal. ZIEHEN[3] says that in general colour-hearing is consistent with a sound nervous system, but is mostly based on a neuropathic disposition. Colour-hearing occurs in the blind ; I found it in 10 per cent. of the cases in the Munich Blind Institute. In this respect it should be noted that the cases were mostly of recent blindness, and generally could see colours when very close. Nothing certain is known of the true cause of colour-hearing. STELZNER,[4] who has reported very fully on its incidence, considers that there is an abnormal association between the acoustic and the optical centres. The exact causes are of so hypothetical a nature that I would rather not go fully into the question, for, in my opinion, we would do well to approach any detailed statement of these relationships with reserve and scepticism. FLOURNOY[5] refers to association, and postulates an *association privilégée* which has been elaborated at some time under favourable circumstances, leaving irradicable traces in our nervous systems, so that one sensation will always induce the other. One sensory impression will more readily induce another if they are related, *i.e.*, if both induce the same feeling of pleasure or pain.

There is certainly no ground for supposing that the phenomena under discussion are manifestations of hysteria. Though a predisposition to these co-sensations is to a large extent hereditary (LOMMER records a family in which in three generations different forms of colour-hearing were found), I do not consider it would be

[1] *Arch. f. Psych. und Nervenheilk.*, xl.

[2] "Zwangsmässige Lichtempfindungen durch Schall u. verwandte Erscheinungen auf dem Gebiete der Sinnesempfindungen," Leipzig, 1881.

[3] "Leitfaden der physiol. Psychologie."

[4] *Arch. f. Ophthal.*, lv.

[5] "Des phénomènes de Synopsie." Paris, Genève, 1893.

correct to speak of a psychical taint,[1] for, as has been shown above, the contradictory nature of the sensations is especially noticeable in members of the same family.

INDIVIDUATION COLORÉE.—In other cases of colour-hearing, these factors have a much freer play than in the *audition colorée* which we have been considering. Persons appear to be coloured according to their character. The music of BEETHOVEN has a different colour to that of WAGNER. A colour-hearer of this type told me how the colours of surrounding objects, according as they were sympathetic or unsympathetic to him, influenced his matured decisions and mental pliability; he was delighted to have this predisposition, and anxious to develop it further, he called himself "colour-glad" with pride and joy.

Although the differentiation between *audition colorée* and *individuation colorée*, in the sense in which we have used the terms, may not be a radical one, still, in my experience the colour-hearers of the second group are so distinct from those of the former that it is right to emphasize them as a different class. In the following quotation from the records of such a colour-hearer, the essentials of a free *individuation colorée* are well seen:—

"So far as I can recollect, the first time I had a colour-sensation was when, at the age of 12, I heard TSCHAIKOWSKY'S 'Helle Nächte.' The sensation I received was of blue, as from an object thrown into blue water forming circular waves, ever anew from the centre, some higher, some lower, and on the whole a play of red or even violet light; thus was I affected by harmonies and even single notes, especially the light restrained or staccato notes, which corresponded to coloured waves. I did not see these waves everywhere; I often had merely the sensation of blue. It was a blue like the snow in the forest or in the dusk. I did not, however, experience that sensation, but had the idea of a blue quietly appearing without any desire on my part.

"Undoubtedly the harmonies determine the whole phenomenon. The note which governs the whole, the intensity with which the whole piece affects me and stirs my emotions, arouse the colour vision. A general colour tone is produced by the pitch of the music, and in this shades are induced by the individual notes and harmonies. For example, SCHUMANN'S piano concerto in A minor. In the central movement is a passage which specially affects me; I see a vivid blue. Every harmony, and each note of every harmony, alters the shade of colour; the colours leap like waves. Now I see a violet mounting up, then follows a stormy red surge, in its turn again to vanish. A short sudden wave is overwhelmed with a wide sweep of blue and emotionless calm.

"I imagine the scenes and persons of a poem, and then see the colours. I should think that were I to paint the individual scenes as I see them, it would excite laughter, yet they are beautiful. The speech, the form, the art by which the poet achieves the

[1] LAIGNEL LAVASTINE: *Revue neurop.*, 1901.

effect, the phantasy furnish the inspiration. The nicety and the exactness of the detail have no influence. In spite of all its detail, HALLER's 'Alpen' leaves me quite cold.

"In the first act of 'Tannhäuser' I often have the sensation that the lighting of the grotto does not suit the music. In the Parisian presentation a part of the grotto in the middle of the stage ought to be blue where it is red. I, therefore, shut my eyes to increase my enjoyment. Similarly, in 'Tristan,' Act II, a horrible green is often represented. I always have the sensation of 'red.'"

THE IMPORTANCE OF COLOUR-HEARING.—When we read this description, it can well be understood how HANS v. BÜLOW, in real earnest, called on his orchestra to "play red," and the professor of music, whom I have heard say that he thought it would be better if the expressions, *allegro*, *con fuore*, *adagio*, &c., were translated by their corresponding colours; on the other hand, too, we appreciate how colour-hearing is woven into the personality of the individual, and suffuses his whole nature. Colour-hearing certainly plays a great part with artists in the inspiration of works of art. FLOURNOY tells of a painter who drew inspiration from the notes of his violin, in the search for the colours of his pictures. Mostly we hear of the utilization and development of this faculty. It is but seldom that colour-hearers are terrified at their colour sensations, *e.g.*, when, at a concert, the colour phenomenon suddenly appears to the consciousness of the person in question. The simple forms of *audition colorée* are sometimes made use of; several people have told me that they made use of their faculty for mnemonics. Certainly others could not thus utilize it. A colour-hearer told me of the confusion which she often felt between the number 3, the colour yellow, and the diphthong ei.

OTHER SYNOPSIAS.—Just as colour sensations are associated with acoustic stimuli—the most common form—so in cases they occur with smell, taste, or with painful stimuli. In most cases *audition colorée* also is present. A colour-hearer told me that the prick of a needle was red to him; another related that the lemon or its juice tasted distinctly yellow; another told that he saw blue when he smelt the perfume of a woman's hair. HILBERT[1] tells of a daughter who had the sensation of yellow when she tasted good milk. Unpleasant tastes were associated with brown, and very unpleasant ones with grey; a sweet taste was blue.

AUDITION FIGURÉE.—A further group of phenomena is provided by figure-hearing, which GALTON[2] first indicated. Many of these phenomena are certainly not of the group of co-sensations, but represent psychological problems, concerning, for example, the conception of a visual representation. In many cases the appearance of these diagrams appears to be so distinct that the French term *audition figurée* appears to me to be well chosen. A colour-hearer reported to me that—and these phenomena appear to occur mostly in colour-hearers—with the word "kreis" (a circle) he had in

[1] *Klin. Monatsbl. f. Augenheilk.*, 1897.

[2] "Inquiries into Human Faculty," 1883.

his head the definite sensation of a circle of 7 to 8 cm. in size; it was only with abstract geometrical forms that these phenomena occurred to him (circles, cubes, spheres), while the word apple, for example, or ball, produced no co-sensation. These figures are commonly found in association with the days of the week, years, numbers, and seasons, and may vary from the simplest geometrical forms to the most bizarre of figures. It is generally not difficult in well-marked cases to recognize a definite cause of origin, *e.g.*, in the case of the seasons, and the well-known graphical representations in the atlases.

THE IMPORTANCE OF THE FIGURES.—With regard to the importance of this last-mentioned phenomenon, I refer to a saying of FLOURNOY: "I feel envious of such a faculty, which must help in a most peculiar method to bridge over gaps in time, and bring objects into order."

HENNING[1] relates the case of a man who possessed this faculty, with an extraordinary power of noting dates, years, renowned names, and historical facts. He records his own words: "The unusual trend of development was towards the memory of numbers. The history books in school pleased me very particularly. Historical works with many dates I devoured with as much greed as books of adventure. And it was interesting to note that it was the numbers themselves which especially interested me. I showed no more than the usual comprehension for the grouping of the incidents and the historical summaries. I felt either sympathy, antipathy, or indifference to the numbers, and derive a peculiar pleasure in the study of whole columns of figures such as logarithms or dates."

An artist, who saw figures, when examined related to me that these symbols were of much use to her in the solution of problems; thus her sketch: "Spring Storm," earned full approval. Perhaps the pictures of KATH. SCHAFFNER[2] are to be referred to such figures. For the present such an art cannot correspond to any general sensations, for, as in the case of *audition colorée*, there is no unanimity in the co-sensations. The figures are symbols peculiar to the individual.

AUDITION COLORÉE IN THE BELLES-LETTRES.—We find in the writings of HEINRICH HEINE pictures and word associations which lead us to the conclusion that synopsias occurred to him. PACHE[3] considered that he had the faculty of *audition colorée*. As a matter of fact, several of my colour-hearers have assured me that they could picture the expression, "the triumphant red of the trumpet's note," which is found in the "Memoiren des Herrn v. SCHNABELEWOWSKY," Chapter II. The question there under discussion is the painter, JAN STEEN, who would only be recognized in a happier and freer future day. "On that bright day, when the sun shines

[1] *Zeitschr. f. Psych. u. Physiol. der Sinnesorg.*, x.

[2] "Kunstwart-Ausgabe," Munich (Callway).

[3] "Naturgefühl. u. Symbolik," bei HEINE, 1904.

through the unclouded window, and from the tower no black dull-sounding bell, but the triumphant red of the trumpet's note announces the lovely hour of noon." This certainly sounds like colour-hearing; and shortly before this we find in the same sense a similar comparison, where this same metaphor is used: "When the religion of pain is extinguished, and the religion of joy tears away the gloomy mourning emblems from the rose bushes of the earth, and the nightingale at last dare pour forth with triumph her long-hushed ecstasy."

I would exercise just as much reserve in indicating this passage as evidence of HEINE'S colour-hearing, as I feel in seeing a synopsia in the following passage from the "Florentine Nights": "Sweet pineapple odour of courtesy! What wholesome refreshment dost thou bring my soul, which in Germany has gulped down such fumes of tobacco, such smell of cabbage, and such uncouthness."

In the romance writings of E. T. A. HOFFMANN the following passage occurs in "Kreisleriana" (a letter from the orchestral conductor, Kreisler, to Baron Wallborn): "I was wearing a coat which I had bought in great ill-humour over the failure of a *trio*, and whose colour was in C flat minor; I, therefore, to mollify the beholders, put on a collar in E major colour." In "Don Juan" also: "Unwillingly my eyes closed, and a glowing kiss burned on my lips; but the kiss was like a note long denied to the eternal thirst of desire," and "Your *trio* is a prayer which rises to heaven in pure and glittering rays."

STEINERT[1] has contributed an enormous mass of evidence relating to these pictures and expressions in romance. In many of the instances I am sceptical as to whether they have anything to do with the co-sensations in question. The following from TIECK'S "Zerbino":—

"The Flutes:

"Sky-blue is our spirit,
To the azure does it lead,
Soft enticing chords
Mingle with those other notes."

This recalls to me a modern book, "Über das Geistige in der Kunst,"[2] whose author, as his own statement shows, was free from *audition colorée*, but still spoke of the relationship between the flute and blue notes.

Do not the romanticists, who represent the intangible by the tangible, often picture dimly conceived relationships in a material form? To show that colour-hearing was by no means a generally recognized phenomenon at the time of the romanticists, I quote from "Vorschule der Ästhetik," by JEAN PAUL: "The sensual picture should have a sensual plasticity, but not reality. The

[1] "LUDWIG TIECK und das Farbenempfinden der romantischen Dichtung," Dortmund, 1910.

[2] KANDINSKY, Munich, by Piper, 1912.

phantasy of the connection of the two most dissimilar senses, the eye and the ear, is grasped with difficulty. TIECK not only makes the colours resound—which, though venturesome, may be possible, for from the visible arises the invisible spirit of effect—but he also makes notes glitter, which demands even a bolder leap."

GOTTFRIED KELLER.—GOTTFRIED KELLER'S example shows how careful we must be in concluding from poetic evidence the existence of a definite faculty for colour-hearing. In the Zurich novel ("Landvogt von Greifenstein") we are told how LANDOLT "could not obtain the effect without the help of a jews' harp. With a smile, he explained the action of such music as the mixture of delicate colour tones, and seizing the toy instrument, which lay on a table amongst a thousand other objects, he set it to his lips and drew from it a trembling, faintly breathing phantom which at one moment threatened to die away; then, softly swelling, flowed into another." . . . "'Do you see,' he cried, 'how the light grey passes into the dull copper-red?"

BLEULER and LEHMANN tell us that KELLER, when asked if he was a colour-hearer, was extremely astonished, and knew absolutely nothing of *audition colorée*. In the source which KELLER used for the novel (DAVID HESS'S "Biography of Landolt," 1820), we find, on the other hand, the following: "LANDOLT often played on the jews' harp, and considered that, not merely in all kinds of music, but especially in the fine tones of this simple instrument, was there a particular association between harmonic variations and colour tones whereby the finding of the best gradations of hue was assisted.[1]

Audition colorée is very frequently found in the later lyric poets (STEPHEN GEORGE and his circle, DAUTHENDEY, HOFFMANNSTAL).

The following sonnet is by the Frenchman, RIMBAUD:—

> "A noir, E blanc, J rouge, U vert, O bleu ; voyelles,
> Je dirai quelque jour vos naissances latentes,
> A noir corset velu des mouches éclatantes
> Qui bourdonnent autour des puantes cervelles."[2]

This poem is certainly not derisive as is often held, but is evidence of the *audition colorée* of the poet. Reserve should be exercised in deciding on co-sensations in the later writers. OTTO ERICH HARTLEBEN, in his novel "Bibamus," puts the following into the mouth of a composer: "I have this new white voice; you remember the white wail of Dodine, and that dark voice in which she sinks . . . the yellow one too. And that green sound! particularly that one!" Would not he who in his "Frosch" ridiculed HENRIK IBSEN, have made fun of colour-hearing? Green is the particular colour to which colour-hearers are least susceptible, and here "green" is emphasized. Finally, I will complete by giving

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[1] "Inaugural Thesis," by NUSSBERGER, Frauenfeld, 1903.

[2] A black, E white, J red, U green, O blue; I can always tell your hidden source. A is the black garment fouled by the flies which in glittering clouds swarm over the carrion, &c.

the statement of GANGHOFER, when this poet describes his own colour-hearing.

"As KERLER played on the organ a phantasy with varying key, the whole church suddenly took on before my eyes a peculiar intense colour; everything appeared red, corn-yellow, or of a beautiful blue. This lasted a few seconds and then vanished. Generally I only saw a single colour, and when it disappeared everything was natural as before. But sometimes, with rapid variations in the music, during which I saw the colour, the colour itself changed equally rapidly and glowed even more strongly.

"It was so indescribably beautiful that a delightful glow pervaded my heart and soul. This colour vision increased in later years when good music influenced me more. I have never yet been able to determine any law and order in the appearance of this phenomenon.

"There are a few musical pieces in which I always see the same colours. When I listen to the 'Rheingold' there always comes an instant in which the whole stage is filled for several seconds with a glowing golden yellow. If I play the first *trio* of HAYDN with my children, the music sheet towards the end of the first movement appears a dull red-violet, which, when we go on without a break into the *adagio cantabile*, changes into a deep steel blue. In the *allegro non troppo* of the symphony in C minor of BRAHMS, which I have now heard three or four times, I saw every time the same scarlet red. Once I saw in this colour a broad expanse of sky, with drawn out clouds of flaming scarlet, over which a tall female form clad in scarlet appeared to float.

"All emotional music changes into pictures before my eyes, and for seconds or minutes I seem to hear the music no longer.

"These scenes and colours appear more frequently with the music of BEETHOVEN and SCHUMANN. Formerly they also occurred with WAGNER. But this power which WAGNER'S music once had over me has been lost for some five years." (From GANGHOFER'S life history of an optimist, "Book on Childhood" pp. 306, 307, and 308.) The latter part of this statement is not a co-sensation (*audition colorée*), but is a co-perception (music phenomonen). We will return more fully to this in Chapter XII.

CHAPTER X.

BINOCULAR VISION AND ITS DISTURBANCES.

VISION WITH TWO EYES.—In a work on physiological optics[1] appearing as late as the year 1864, at the commencement of the chapter on "Vision with Two Eyes," we can read the following: "The reduplication of the organ of vision has apparently no great importance in vision, for such an organization is not absolutely necessary for sight; the one-eyed see, and the two-eyed can see with one eye. The duplication has therefore some entirely different motive; maybe for external symmetry, or from the greater complexity and functional perfection of the organ of vision, or as a greater protection from the effects of injury, or to ensure an increased field of vision, or some other similar reason."

The author attributes some purport to binocular vision, were it only that thus the blind spot of one eye is neutralized by the visually active corresponding area on the other side. But amongst the many motives which he brings forward in favour of binocular as against monocular vision, he fails even to mention that one which appears to us to be the most important—stereoscopic vision. Yet at that time (1864) the fundamental work of E. HERING had appeared (*Beiträge zur Physiologie*, Heft I to V[2]).

A work by L. PANUM anticipating this and called "Physiologische Untersuchung über das Sehen mit zwei Augen," was printed in the year 1858.[3] The celebrated work by WHEATSTONE[4] in 1842 recorded investigations on stereoscopic vision, and provided some insight into binocular vision with solidity.

I. BINOCULAR VISION IN DEPTH. VISION WITH TWO EYES. —The theory of identical points in the retina (which was known to JOH. MÜLLER, and even before the time of HALLER) was amplified by PANUM, who showed that the important postulate in this theory was that each pair of stimuli which fell on identical or corresponding points in the retinæ, would always and under all circumstances be perceived as one; the correlate postulate that two impressions which fall on two spots which are not identical will always and under all circumstances be perceived as double, had

[1] H. SCHEFFLER: Braunschweig, 1864 and 1865.

[2] Leipzig, W. ENGELMANN, 1861 to 1865.

[3] Kiel, "Schwerssche Buchhandlung."

[4] In POGGENDORFF's Annals.

been refuted by WHEATSTONE'S investigations. For in stereoscopic vision two materially different retinal pictures are, by the vision of the two eyes, perceived as one, and it is impossible for all parts of the two separate pictures which are thus fused to fall on corresponding points in the retinæ. PANUM amplified the conception of identical points in the retina by assigning to each point a corresponding circle in the other retina described about the point as centre ("circle of sensation"). The actual conception of depth or solidity in two-eyed vision (stereoscopy), according to PANUM, is due "to a specific power inherent in the act of binocular vision," and according to him is brought about by the "difference in the position of contours which are brought into relation to each other by two-eyed vision."

HERING, in the works which we have already referred to, distinguishes projections in height and breadth arranged similarly in the two retinæ; he considered, however, that there was another system for space and depth arranged in the opposite way. While the projection values only gave a picture in two dimensions, those for space or depth gave the third dimension. The two eyes—"the double eye"—are inherently so organized that the simultaneous stimulation of corresponding longitudinal rows of elements in an appreciably similar manner and for the same time produces the impression of straight vertical lines in one and the same frontal plane. The stimulation in pairs of 'librate'[1] linear series of elements which do not correspond, produces impressions projected before or behind this plane. Nasally dissociated lines give the impression of remoteness and temporarily dissociated lines the impression of nearness."[2]

Fig. 30 will elucidate this: a and a_1 are corresponding points as are B and B_1. Simultaneously stimulated (*e.g.*, a and a_1), the impression is produced of a point in the frontal plane passing through the point fixed. If a and B_1 be stimulated the sensation "nearer than the fixed point" is produced, for the point B_1 in regard to a_1, the corresponding point to a is temporarily dissociated, the simultaneous stimulation of B and a_1 produces the sensation of "further than the point fixed," for a_1 is nasally dissociated with respect to B_1, the corresponding point to B.

The following relation exists between these points in vertical lines over the whole retina: simultaneous stimulation of the linear series corresponding to the points mentioned, will cause the sensation of "vertical line in the frontal plane drawn through the fixed point" (basic plane), or "before" this plane, and "behind" it respectively.

Only images with a horizontal separation produce stereoscopic effects; those separated vertically do not. This remarkable longitudinal "strip-like arrangement on the retina" of the stereoscopic function can be referred back to the horizontal separation of the

[1] "Librate," from libration (lat. *libra*) as used in astronomy (T.).

[2] TSCHERMAK: PFLÜGER'S *Archiv.*, xcviii.

two eyes. If our two eyes were placed one above the other then the strips on the retina would be arranged horizontally. To fully understand this, consider the following experiment: Two strong lenses are placed before a screen, they are separated horizontally and project on the screen two sharp images of a flame which is placed before them on the same level. A rod held vertically before the flame will appear in the image of the left lens as on the left side of the flame, and in that of the right lens as on the right side of the flame. If now, by means of a strong prism brought in front of one of the lenses, the two images of the flame are united into one, the rod will then appear both on the right and on the left of the flame. If the rod be held horizontally it will only be recognized as a line, which, if it be short, may appear dissociated as to its vertical limits.[1]

II. Central Visual Axis. Vision With Two Eyes.—In vision with two eyes, and their co-ordinated action, localization in breadth is of quite as fundamental an importance as is that in depth. We have shown above that the stimulation of two identical or corresponding points produces a single sensation, but we have said nothing

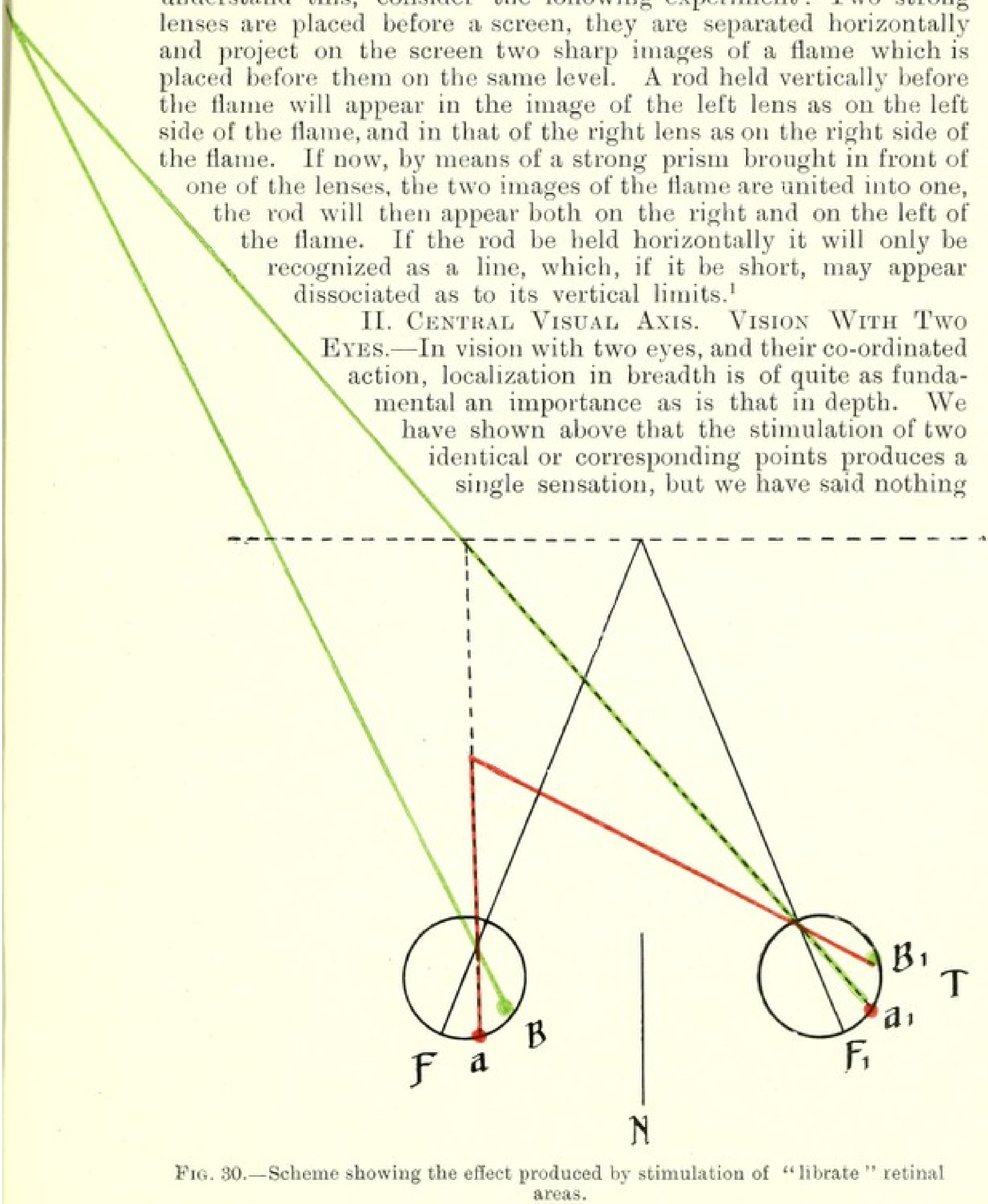

Fig. 30.—Scheme showing the effect produced by stimulation of "librate" retinal areas.

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[1] Lohmann: "Zur Frage nach der Ontogenese der Raumanschauung," *Zeitschr. f. Sinnesphys.*, xlii.

of superficial projection, with relation to the two eyes. SCHEFFLER, previously mentioned, represents this condition in the following way: When a point "a" is fixed, the axes of both eyes are directed towards it; we see the point in the middle line of the angle of convergence, the axis of "the head."

HERING[1] symbolizes the co-operation of the two eyes by a comparison with "a Cyclopean eye." "The head, or more exactly, the place where, with reference to the object viewed, we imagine our head to be, forms the centre of projection and of the lines of pro

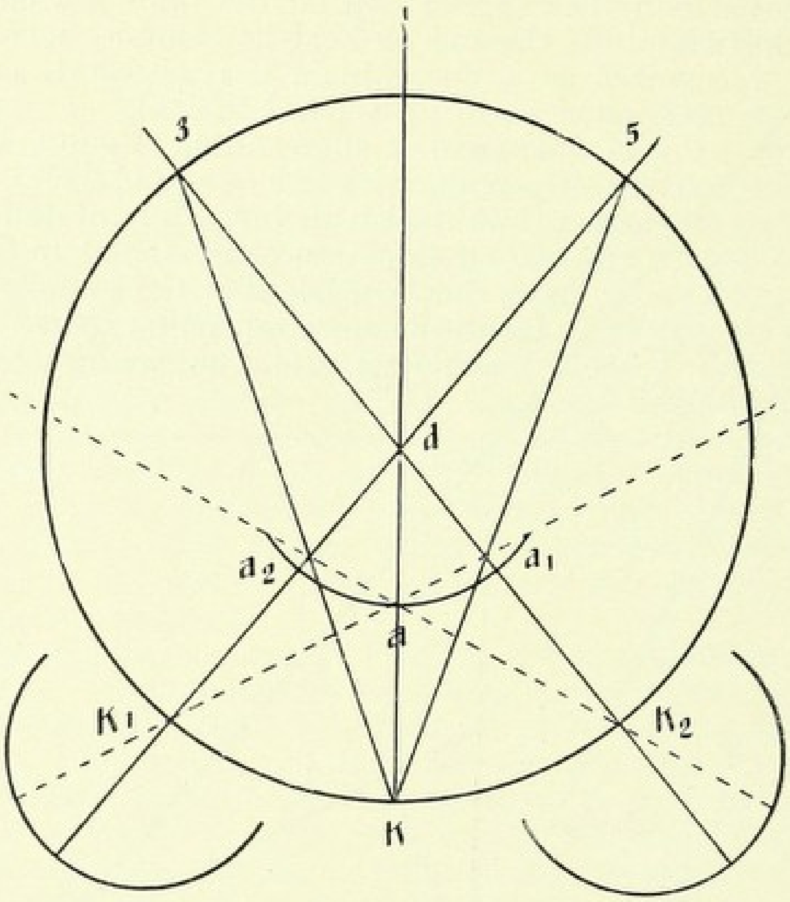

FIG. 31.—Position from the Cyclopean Eye (after Hering).

jection. We can imagine the visual axis of the right eye to be superimposed on that of the left so that every pair of corresponding lines coincide. We can consider the centre of this simple bundle of lines to be placed in the middle between the two eyes, so that all the lines in the bundle which belong to the central longitudinal sections of the retinæ lie in the middle line of the head." If the retinal pictures from any object fall on spots which are not identical, or rather which are not within PANUM's "circles of sensation," then the image will be double. The position is given by HERING from the Cyclopean eye as follows (fig. 31):—

$$\angle\, dK_2a = \angle\, dKa_2, \text{ and } \angle\, dK_1a = \angle\, dKa_1.$$

[1] HERMANN: "Handbuch der Physiologie," 1879.

On fixing "d" "a" appears in crossed diplopia at a_1 and a_2. HERING states that this exact fixation of the double images is only schematic; for the localization of the double false images is due to the retinal sense of position, and hence to experience. The scheme is only rigidly accurate with regard to the direction of the false images, those of "a" must lie on the lines K3 and K5.

I have attempted to determine experimentally the angular displacement of the physiological double images.[1] Half of one eye's share in the binocular field was screened off, so that it was only visible monocularly; a registering needle was placed in this area (being monocularly and therefore singly seen); another needle out of the line of fixation was seen double, the registering needle was placed in the same plane as the false images, so that their angular displacement was measured. The monocular value thus found showed that each eye saw the false image of the other eye at an angular deviation from its own visual axis. Further investigation showed that in binocular vision the line of vision of the right and of the left eyes coincided, and this common line lay in the median line of the head. In the language of physics, the common visual axis formed the resultant of the two lines of vision. As the experimental results briefly indicated above show that the analysis of the double images also indicates the duplex nature of the perceiving organ, I concluded that the central common visual axis of HERING'S Cyclopean theory, and the double images grouped at an angle to it, were not the attributes of a sense stimulation, but of a central combination, a psychical synthesis.

HERING'S NATIVISM.—In my opinion this last conclusion is of importance because, in combination with certain considerations which will be given later, it shows that the actual conditions obtaining in two-eyed sight, in the elucidation of which HERING has performed a lasting service, admit of an interpretation of the organ of vision different from that corresponding to this author's views.

HERING considers that the "sensations of space" are essential attributes of the retina; as we have seen already, they show a congenital longitudinal segmentation, arranged in a contrary manner to the sensations of depth in the two retinæ. HERING looks upon space-vision as congenital, but in its primitive form there is "no appreciation of far and near, which first develops when the ego is contrasted with the visible image."

According to HERING, in fully developed space-vision "the visible space, as an integral whole, is differentiated from the ego." The sensations of space have a quantitative value relative to the sense of remoteness of the basic plane. "The localization of the basic point is dependent partly on the sensations of space aroused in the sensorium by the dominant retinal pictures and partly to the re-presentations, derived in some way or other from experience, which we make of the position of the point fixed; these experiences may be derived from the past, or merely from the movements of the eye as it closely scans the visual field (*Physiol. Beitr.*, v., p. 345).

[1] *Zeitschr. f. Sinnesphys.*, xliv.

From these extracts it is clear that HERING's standpoint is not purely nativistic; to fully explain the details of our space vision he must borrow from experience, and that too of the particular individual. In answer to the objection that HERING's explanation of sensations of space had no real foundation, HILLEBRAND[1] seeks to establish the following: "Objects in the greatest proximity must be sought for close to the visible parts of the body (the nose and the forehead). When, therefore, I speak of an absolute localization of the basic point, I mean not a localization with reference to true space, but one which refers to the visual field . . . the 'absolute localization' of the basic point is in fact not absolute, but obviously a localization relative to one's own body." According to HILLEBRAND, those points on the retina on which the nose and the forehead are pictured, are also important bases for sensations of depth. The position of the basic point depends on them, and the sensations of depth in the meridional bands are not related to this basic point, but to those peripheral retinal points. Such a point of view may be valid for vision in ordinary circumstances; but it cannot be considered so for HERING's sensations of space, as these are present when the stimuli are points of light in the dark.[2]

EMPIRICISM.—The opposed ideas of vision, "Nativism" and "Empiricism," are due to various schools of general philosophy. The English philosopher BERKELEY[3] referred all vision to experience. H. v. HELMHOLTZ must be mentioned as a particularly strong supporter of "Empiricism." He would attach all the phenomena of vision to other "antecedents such as the simple psychic activities, certainly themselves requiring further elucidation, but still present and important." The essence of empiricism is found in the following: "The impressions of the sense organs are signs to our consciousness, and it is left to our intellect to learn their meaning."

The "sense of innervation" of the eye-muscles in convergence is the chief factor to be considered in binocular vision; but other factors derived from experience occur in the vision of solids.

WUNDT conducted researches to show the influence of accommodation and convergence on the sensation of depth; HILLEBRAND[4] found fault with his experiments, as they did not elucidate the possibility of muscle-sensation, nor was vision from separate points or other acquired elements excluded. He himself investigated the influence of accommodation and convergence, making monocular observations by means of black cards, which were movable in front of a white background; he came to the conclusion that the muscular sense had by no means the delicacy which was attributed to it, and that it conveyed the sense of depth only to a very limited extent, which was far from absolute.

I consider that we can rightly urge against HILLEBRAND's view that such experiments do not contradict an hypothesis which

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[1] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xxvi.

[2] LOHMANN: *Zeitschr. f. Sinnesphys.*, xliv.

[3] "Theory of Vision," London, 1709.

[4] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, vii.

postulates that sensations and experiences as an accumulated whole produce the impression of solidity. Imagine a case: Consider the question as to whether a horse could turn a merry-go-round. Because the animal was unable to move all the constituent parts of the apparatus on sandy ground, it could not be concluded that its strength was insufficient to turn the merry-go-round when properly erected.

Factors of Experience.—Before we come to vision with transversely dissociated retinal images, which is most important in the vision of solids, I would like to call attention to some facts concerning experience which are of importance in our estimation of space. I would first call attention to the experiments of Stratton.[1] For many days he wore an optical instrument which threw re-inverted images of all objects on the retina. He suffered great confusion on the first day, but on the second was becoming accustomed to the unusual visual conditions; this facility increased from day to day until he finally again saw all objects upright.

The great influence of experience on vision is shown in the so-called apparent movement in stereoscopic pictures.[2] If a person be standing still in the foreground of a plastograph picture, an apparent movement is observed when the observer's head is moved to the side. If an actual person were standing on the street and we made the movement, the image of the person would make an apparent movement in the opposite direction, due to change in parallax; the failure of such an apparent movement would only be explicable if the person moved in the same direction as the observer.

The apparent movement of the person is thus readily understood,[3] and the principle is exactly the same as underlies another example of apparent movement.[4] Moving about a room and keeping the eyes fixed on a portrait which is painted with the gaze of the subject fixed on the observer, the impression is conveyed that its gaze follows one's movement.

It is beyond all doubt that the factor of experience plays a great part in vision. This is best shown in judging distances, in which secondary empirical factors influence judgment to such an extent. If we stand on the seashore 50 metres from the surf, the sea appears to be of great extent; the shore, on the contrary, as a comparatively narrow strip, although it is seen at an angle of about $87\frac{1}{2}°$ as against the $2\frac{1}{2}°$ of the sea. Filehne[5] considers that we "attenuate" the shore; and he looks on this "horizontal deepening" as a true psychic act. In this connection it may be remembered how perspective drawing in a picture will

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[1] *Psychological Review*, 1896 and 1897.

[2] Heine: *Arch. f. Ophthal.*, lxi.

[3] Another explanation, Weinhold, *Arch. f. Ophthal.*, lviii.

[4] Straub: "Der Platz des Bewusstseins in der Theorie des Sehens," Stuttgart, Enke.

[5] *E.g.*, *Arch. f. Phys.*, 1910.

give the impression of depth. V. ASTER[1] studied the conditions under which this impression of solidity was given by drawings in two dimensions. He came to the conclusion that the impression of solidity in a rhombus was communicated by the horizontal line, which assisted the "passage to the third dimension." This "successive grasp" of the horizontal is brought about by the appearances presented by such objects as really do extend in depth. A horizontal rod lying in the mid plane of the head, by binocular vision only appears single at the point of fixation, the rest of it is seen double; according to V. ASTER the double images further induce fixation, and thus the rod and the eyes will in a sense travel in depth.

THE CONDITIONS UNDER WHICH DEPTH IS ESTIMATED MONOCULARLY AND BINOCULARLY.—While it will not be denied that the last examples can be referred to the psychic side of vision, the opinion is general that true binocular vision (vision with librate impressions) is something different, namely a sense-perception corresponding to the view of HERING, which we have given above. This idea is especially emphasized by HEINE.[2] Others, on the contrary, take the view that monocular vision of solids only differs in degree from binocular. PANUM lays stress on this.

With this suggestion we can return to the astonishing sense of solidity which can be obtained by the monocular stereoscope which the firm of ZEISS have put on the market under the name of "Verant."

MONOCULAR PARALLAX.—The view that there is no essential difference between monocular and binocular vision of depth is advocated by STRAUB.[3] He relates that in making an ophthalmoscopic examination with one eye, when he wishes to determine a difference in level by parallactic movement, he suddenly receives the composite sensation of view in relief. The impression of depth can be obtained from the monocular observation of stroboscopically displayed figures; but in such cases—and this is against STRAUB—there is not that complete certainty as to extension in space (whether nearer or farther) which binocular vision yields. STRAUB replies to this objection that the peculiarity of the test caused this inferiority, as contrasted with stereoscopic observation. The important fact which is established is that monocular parallax gave a convincing representation of a body in three dimensions. STRAUB also refers to the work of GUILLOZ,[4] who, alternately stimulating each eye by the alternating halves of stereoscopic pictures, produced vision in solidity, though the interval extended to one second, and successive not simultaneous fusion was taking place. KRUSIUS[5] records the results of the alternate exhibition of stereoscopic halves. If the eye was occluded 35—10 times per

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[1] SCHUMANN: "Beiträge z. Analyse der Gesichtswahrnehmungen," iii, 1909.
[2] *Arch. f. Ophthal.*, lxi, li.
[3] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xxxvi.
[4] Soc. d. Biologie, 1904. [5] *Arch. f. Augenheilk.*, lxii.

second, "orthostereoscopy" (HEINE) resulted when the eyes were used alternately, but only a flat picture was seen if only one eye was in use. On the other hand, with an alternation frequency of 10—1·5 both with the one eye and with the two, a flickering image was perceived.

PSYCHIC FUSION OF MONOCULAR VISUAL IMPRESSIONS.—Regarding the "psychic fusion of incongruous retinal images,"[1] I am impressed by the demonstration that the horizontal libration of the two monocular images, resulting from the horizontal position of the two eyes, in combination with other elements, can very well be considered as the empirical factor in the ontogenesis of spatial impressions.[2] I have already emphasized the congenital nature of the disposition of the two eyes and their delicate central connections. But the melody which is produced by this orchestra—vision in solidity—is a psychical act. Consider fig. 1; the associative and productive connections indicated by the black lines will evolve the perception of solidity with greater certainty when librate impressions from both optical centres can be turned to account. If there be no parallel centres, as is the case in monocular vision, the impression of solidity can only be of moderate intensity. I have previously shown that the combination of the two eyes (Cyclopean eye) resulting from a psychical synthesis, as recognized in the law of the central common visual axis, can be broken down by special methods of examination; similarly in the phenomenon called "the strife of the two visual fields" we possess a key explaining the nature of the psychical activity in vision of solidity.[3] This "strife of the fields" is nothing else than our consciousness of the swaying of psychical activity first towards the image from one eye and then successively to that from the other. Generally the percept resulting from these incongruous visual impressions is so built up that it lies above the limits of the fusion frequency—if the analogy may be allowed—of the strife of the fields.

TESTS OF BINOCULAR VISION AND ESTIMATION OF DEPTH.—The best apparatus for testing the binocular estimation of depth is that provided by HERING's drop test. The person to be examined places his face in the front end of a tubular screen, opposite the other end of which, and at some distance, a bead is suspended by a vertical thread. Before or behind this bead small balls can be dropped, and the examinee has to say where they have fallen; the surface on which the balls drop must be covered with a cloth to deaden the sound. A very useful apparatus has been designed by TSCHERMAK (made by POLLAKEIT in Halle). In this, by means of a screw, a third rod is to be brought into the same plane as two other rods, which can themselves be moved in relation to each other. For very exact examinations the "Haploscope" of HERING[4] is used.

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[1] ELSCHING: Verein z. Verbreitung natur. Kenntnisse, Vienna, 1906.

[2] *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xlii.

[3] *Ibid.*, xl.

[4] Description—HILLEBRAND: *Zeitschr. f. Psych. u. Phys. d. Sinnes.*, v.

Each half picture, reflected by a mirror, is movable around an axis going through the centre of rotation of the eye, and can be moved nearer to or farther from the eye.

THE MONOCULAR CONDITION.—In discussing the pathology of binocular vision we must first consider the monocular condition, which, when suddenly occurring (by loss through disease or accident of one eye or its vision) produces a temporary but considerable visual disturbance. The appreciation of depth in any manipulations at short range will be seriously diminished, as will one's confidence in walking (particularly noticeable in going up steps). Workmen such as skilled mechanics or fitters, to whom the instant recognition of depth is necessary, may be prevented by the loss of binocular vision from following their trade. In general, we can say that the one-eyed soon become accustomed to monocular vision, and soon learn by parallactic movements of the head, or from experience stored up of the position of objects behind each other, by differences in illumination and perspective, &c., to develop a very considerable and practically useful power of monocularly estimating difference in depth. This last observation was frequently brought forward as evidence that monocular and binocular vision only differ in degree, and it is still so used. The fact which is here referred to is, however, no strict proof of this statement, for it does not show that the empirical use of parallactic movements of the head, with the other expedients, reproduce the direct binocular impression. Further, the one-eyed would fail with HERING's drop test, which postulates simultaneous two-eyed vision. VERWEY[1] conducted experiments on the precision of the estimation of distance by means of monocular parallax, and came to the conclusion that a direct representation of distance is possible by monocular parallax alone; that such vision alone, however, was always a poor makeshift for binocular estimation of depth. Of all the "psychic" factors which must be taken into account in vision of depth, this has the greatest utility to those who have but one eye.

To investigate the conditions governing monocular estimation of depth, an apparatus is essential, which, while utilizing signs of empirical value, bases its action on some symptom-complex which really can be supplied by monocular observation. Such an apparatus has been supplied by PFALZ;[2] this "stereoscoptometer" consists of three rods which can be moved about by fine adjustments and carry on their tops variously coloured balls. The patients must say whether the balls are on the same level, or one in front of the line of the other two, &c. This apparatus is very handy, and will tell whether a good and practical monocular power of estimating depth has been acquired, and if the "habit of monocular vision" has been developed. According to PFALZ one-eyed people possess a sufficiently good appreciation of depth for industrial purposes, if their error is less than $\frac{1}{4}$ to $\frac{1}{2}$ cm. when $\frac{1}{2}$ metre in front of the apparatus. This latter assurance is very valuable when we have to

[1] *Arch. f. Augenheilk.*, lxvi.

[2] *Klin. Monatsbl. f. Augenheilk.*, xlv.

give an opinion on a case, for it is customary to assess the loss of an eye at a compensation of 33 per cent., but after the "habit of monocular vision" is acquired, only 25 per cent. is allowed. While some authors, *e.g.*, FISCHER,[1] voice the opinion that a test with PFALZ's apparatus is unnecessary and fallacious, because the data of importance to the examinee in his occupation are only accessible to him in the place where he works, and also because the test described demands a certain degree of intelligence, others are still more convinced of the value of a stereoscoptometer test, for though it can be taken as generally true that after one to two years the person has become accustomed to monocular vision, yet the capability of learning the monocular estimation of three dimensions will be favourably or unfavourably influenced by personal elements, such as age, mental alertness, &c.

ESTIMATION OF DEPTH AND UNILATERAL DEFECTS IN VISUAL ACUITY.—In considering the question of good binocular vision, particularly in its legal aspects, it is important to note the degree of visual acuity which it necessarily demands. Agreeing with the views of other investigators, PFALZ[2] reports that when refraction was equal in both eyes and there was no squint, a good binocular estimation of depth was present provided the vision of one eye was $\frac{1}{10}$ or more, that of the other being normal. AXENFELD[3] considers that with a unilateral reduction of the visual acuity to not less than $\frac{1}{6}$ in one eye, good binocular vision can be assumed without special testing.

APHAKIA.—In aphakia, when the absence of the lens results in a lowering of vision to less than $\frac{1}{10}$, the power of binocular estimation of depth[4] is lost. The field of the aphakic eye is of value, however, in the interest of the binocular field. When there is a squint, however, the blurred image of the eye without the lens may lead to troublesome diplopia, and HESS[5] considers that extraction is contra-indicated when there is a paralytic strabismus in a cataractous eye, if the other eye be healthy.

In the Universitäts Augenklinik in Munich a patient with an aphakic squinting eye was examined for a medical opinion; when a red glass was held before the eye (deviating 7°) diplopia resulted; and when the examination was repeated at different distances the separation of the images was found to correspond to the angular deviation of the eyes. For other reasons the possibility of these double images having a disturbing influence had been negatived and the decision arrived at that "habit" was developed (with reduction of compensation). The patient, however, stated that, especially when luminous objects were looked at (bright borders or glowing pieces of iron), he was confused by obscure diplopia. We

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[1] *Monatsschrift f. Unfallheilkunde u. Invalidenwesen*, xiv.

[2] *Ophthal. Klinik.*, 1898.

[3] Tenth International Congress, Lucerne, 1904.

[4] SCHMIDT-RIMPLER: *Wein. med. Woch.*, 1899.

[5] "Erkrankungen der Linse" in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde," ii.

could not advise a reduction of the compensation, and considered the double images to be still a disturbing factor; although a medical expert opinion might argue them away, the injured man, though he only saw them in the exceptional cases mentioned, still was psychically affected by them.

PARALYTIC SQUINT.[1]—A confusion of binocular vision occurs when there is a sudden restriction of the motility of one eye, so that it does not move with that congenital and acquired aptitude in an identical manner with the other, and with a similar relation to objects around. Externally this affection shows itself by the abnormal position of the eyes suddenly giving the person an unusual appearance; a squint develops.

The patient, who is not aware of this defective position, will be extremely annoyed by the occurrence of uncomfortable, and at first extremely confusing, diplopia. They often find out instinctively, or may have been advised, that the troublesome double images and the confusion in orientation will disappear at once if one eye be covered up. It is in this way that ocular giddiness is distinguished from auricular or central, for in these latter the closing of one eye or both produces no relief from the symptoms.

THE DOUBLE IMAGES.—We must pay some attention to the double images which are caused by the paralysis of one or more muscles. Passing over other and older explanations, I would call attention to the remarks on identical points in the retinæ and the central common visual axis (*vide supra*), and trace the origin of the double images as follows:—

The central common visual axis, according to HERING, lies in the middle line of the head; it can be imagined as the resultant of the fusion of the two visual axes (the line joining the macula to the nodal point of the eye); it may also be considered as the line bisecting the convergence angle. This common axis, on which external objects are projected, will remain the same, when by a sudden paralytic squint one eye is torn from its customary sensory association with the other, and their subjective community of relationship is deprived of its sensory support. The psychical faculty concerned with reasoning and deduction does not take into consideration the paralysis of one or more muscles; it responds to the nerve impulses which reach the centres for the eye muscles as usual, and to the sensory impressions from the eyes, the whole being fitted into the customary scheme of arrangement. The visual impressions from both maculæ will be projected together on the common visual axis in the middle line of the head. In the correct direction the patient will see the object fixed with the healthy eye, and at the same time in the same direction another picture, which is not intentionally fixed, but corresponds to the paralysed eye. Naturally, we cannot speak of seeing the two foveal impressions in the same way and to the same degree, as the basis for a binocular vision of depth with three dimensions has been removed.

[1] GRÄFE AND BEILSCHOWSKY in GRÄFE-SÄMISCH'S "Handbuch der Augenheilkunde, ii."

As the conscious and intent fixation of an object with the sound eye immediately, or very rapidly, produces an accentuation of the visual impressions formed by the object in this eye, the confusion of vision which results from the complexity of the muddle will be easily understood when we consider what has preceded. The conditions must be looked at more closely along with the diagram shown in fig. 32. The point fixed *a* is represented on the macula (F_2) of the sound eye only; in the paralysed eye its image

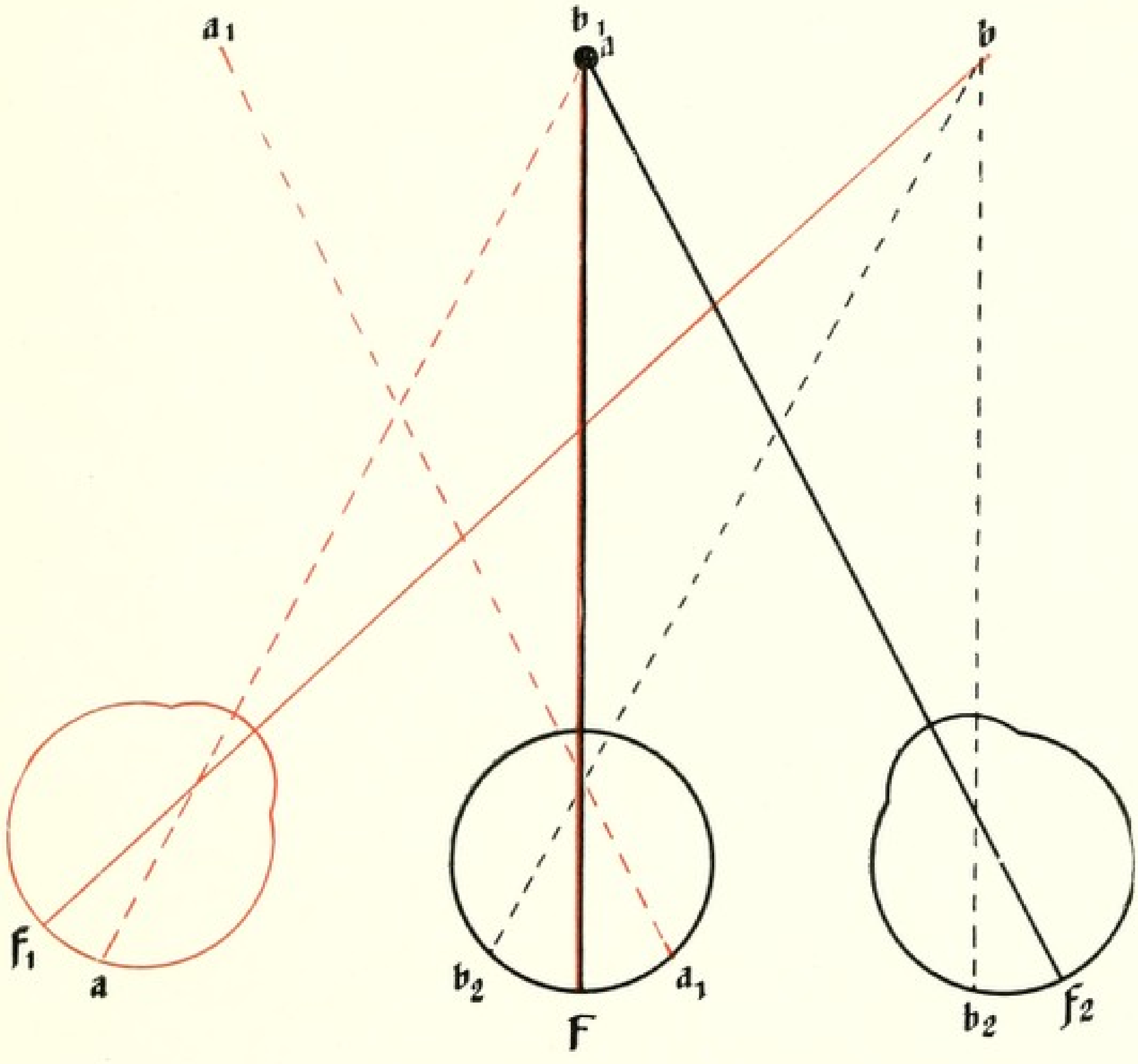

FIG. 32.—Diagram explanatory of double images.

falls on a spot *a* on the retina excentric and corresponding to the angle of the squint. At the macula of this eye another point *b* is represented, which in the sound eye forms an image on an opposite excentric point on the retina. If we now indicate HERING'S "Cyclopean" eye in the middle, *F* corresponds to the point *a*; this visual impression corresponding to the macula of the sound eye, has associated with it the equally sharp visual impression of *b* in the paralysed eye; while the weaker excentric sensory impression of the point of fixation in the paralysed eye, will be localized in the direction towards *a*. The diagram shows how the images of the two eyes, to a certain extent, will be placed sideways over each other, and will confuse and conceal each other. If one object, by reason of its size or illumination, stands out from its surroundings, so that even its excentric image in the paralysed eye overcomes all other impressions which this eye receives (even those of the macula), then out of the jumble of objects the person with the paralysed eye will receive the definite impression of double images.

ABSOLUTE LOCALIZATION.—Just as the diplopia of a paralytic squint results from the relationships of the two eyes in the consciousness, so another defect occurring in paralytic squint—the disturbance of absolute localization—is due to the motor and nervous associations of the apparatus of the eyes. Absolute localization (localization of an object with relation to the body) can be tested in the following manner: Place the patient before a board, and with a horizontal screen exclude from vision the lower part with the hands, &c. If a vertical line be now drawn on the board, and the patient be asked, while freely fixing the line with one eye, to produce it with a chalk under the screen, a continuous line should be found when the screen is removed. This is not the case if the patient has a muscle paralysis. The lower line will then be displaced sideways from the upper, and the error will be greater according as the eye is looking in the direction of action of the paralysed muscle.

BIELSCHOWSKY[1] concluded from his investigations (in opposition to LANDOLT), that the angular degree of defect in localization on fixation with the paralysed eye was equal to the secondary deviation. The secondary strabismic angle, which is greater than the primary deviation of the affected eye, occurs when the sound eye is covered and the affected eye is used for fixation. To effect this fixation a considerably greater innervation is necessary on account of the paralysis.

The sound eye under cover, receiving the same innervation as the affected one, deviates strongly in or out. The disturbance of absolute localization, shown by false movements of touch, results from the innervation impulse and corresponds with a position which the unaffected eye would take up without any restriction from the paralysis (secondary angle of deviation).

In certain cases, where the paralysed eye is the "leading" one, a variation of this defect is seen, and within certain limits a correct localization is possible with the paralysed eye. A. GRÄFE found that some qualification specially favourable for vision was the reason for the paralysed eye being used for fixation, while the sound one deviated secondarily; the further observation that though the refraction and the visual acuity of the two eyes were the same, still exceptionally the affected eye would be used for fixation, was explained by this reference "that in certain conditions the closer approximation of the double images resulting from the

[1] *Ber. der Ophthal. Gesell.*, Heidelberg, 1906.

primary deviation is more confusing than the wider separation which occurs in the secondary deviation." In a case where the refraction and the vision were equal in the two eyes, I have been able to show that the cause of the fixation being persistently in the paralysed eye was the inability to close it ; the patient could shut the sound eye or both eyes together, but could not close the paralysed one alone. When in these exceptional cases an adequate localization is developed by custom, the defect in tactile movement is found on the unparalysed side (*Spastische Localisationsstörung*, SACHS).

SUPPRESSION OF THE DOUBLE IMAGES.—The diplopia at the onset of the affection is extremely confusing, but even when the paralysis does not improve, the individual becomes accustomed to this vision. The general rule is that no new association of the retinal pictures is developed, but the impressions from one eye (generally the deviating one) are suppressed.

EXCLUSION AS EVIDENCE OF THE STRIFE OF THE FIELDS.—Suppression will be readily understood if we recall the phenomenon of "the strife of the fields," readily apparent when objects of different colour and contour are presented to each eye simultaneously; the consciousness alternately accepts first the one and then the other object. If we carefully consider the matter[1] we will see that this strife is always occurring in the physiological double images of daily life ; this is more readily seen in hyperopes than in other refractive states. As the conscious innervation corresponds with the localization by the unaffected eye, a gradual sensory accentuation of the impressions of this eye over those of the other eye will be produced, as we have already seen. Being thus better equipped in the strife, the image of the unaffected eye will gradually triumph over that of the affected one ; and its permanent triumph is shown in the suppression of the visual impressions of the latter.

VISION IN CONCOMITANT SQUINT.—In the case of the common non-paralytic (concomitant) squint, the question as to the nature of the vision with respect to the combined action of the two eyes, has long been freely discussed hypothetically, but only in recent times has it been made the ground of exhaustive investigation, and its actual conditions better understood. The advocates of nativism or empiricism each looked on vision in squint as the touchstone or proof of their particular theory ; JOH. MÜLLER considered that the basis of such vision lay in a congenital alteration of the identical points of the retina, while A. GRÄFE referred it to an acquired abnormal identity. The work of BEILSCHOWSKY[2] and TSCHERMAK[3] has placed our knowledge of the vision of squinters on a deeper and broader foundation.[4]

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[1] LOHMANN : *Zeitschr. f. Psych. u. Phys. der Sinnesorg.*, xl.

[2] *Arch. f. Ophthal.*, xlvi. and l.

[3] *Arch f. Ophthal.* xlvii., also *Centralblatt f. prakt. Augenheilk.*, Nov. 1902.

[4] Review, HOFFMANN in Spiro, Asher, "Ergebnisse der Physiologie," 1912.

Method of Investigation and Classification Recommended by Tschermak.—For the exact subdivision of squinters—and they differ greatly, as analysis shows—the angle of the squint and the nature of the localization must be determined, and a comparison of the two made. According to Tschermak, this examination is best carried out by means of the after images of a tubular

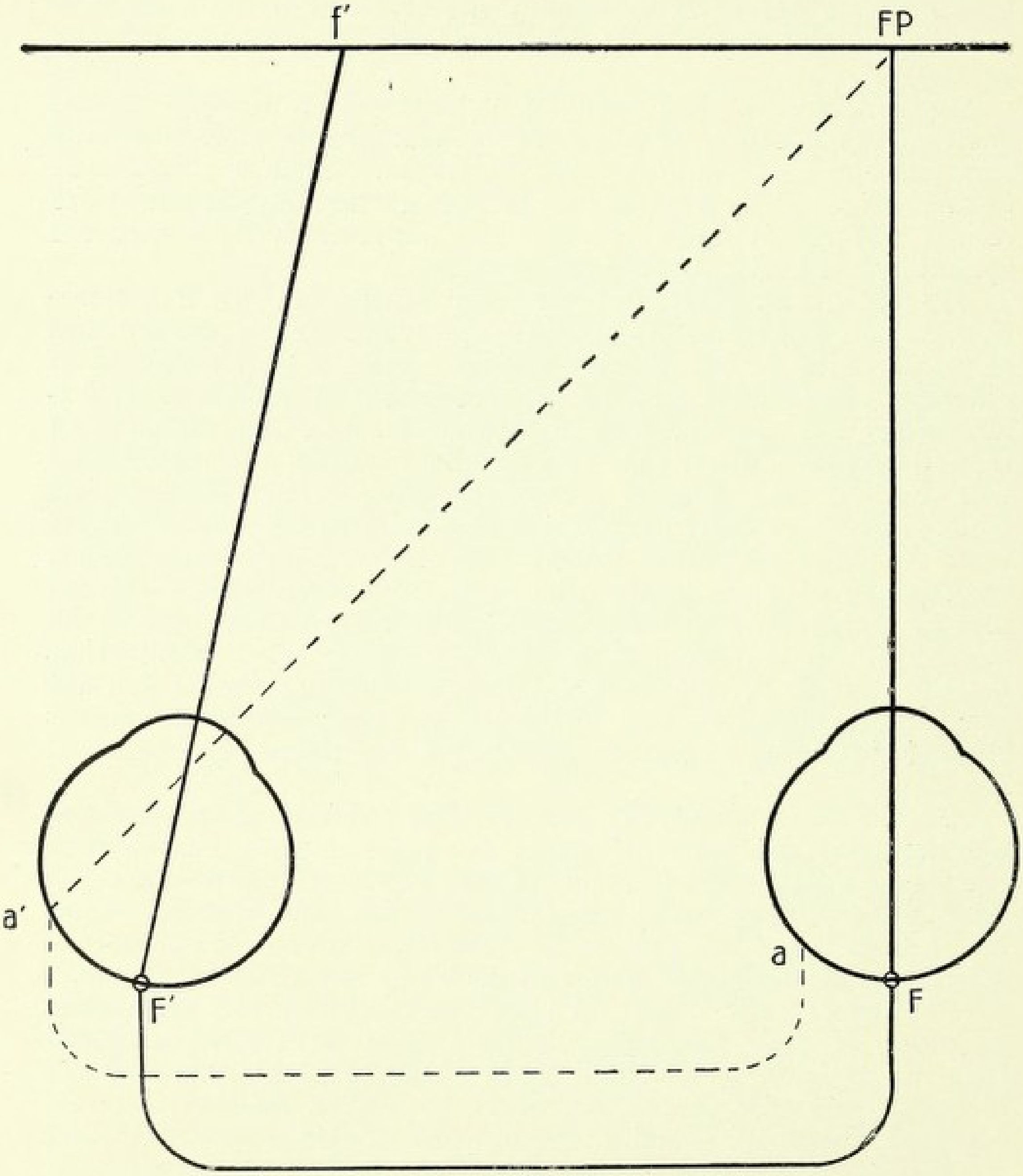

Fig. 33.—Normal retinal correspondence in squint (Tschermak).

incandescent lamp, which is used to excite at the macula of the squinting eye a persistent negative after-image, and the angle of the squint is determined by fixing the zero of a Maddox tangent scale by the leading eye; both eyes being open, a test object such as a pencil is introduced into the field from the side to which the eye is squinting, until the entoptic image of the filament and the (exogenic) point of the pencil coincide. This point and its linear separation from the fixation point supply the data for the angle of the squint.

By testing the localization, it has been shown that a number of squinters possess the normal correspondence of the two retinæ. If by means of the luminous filament we produce in one eye a hori-

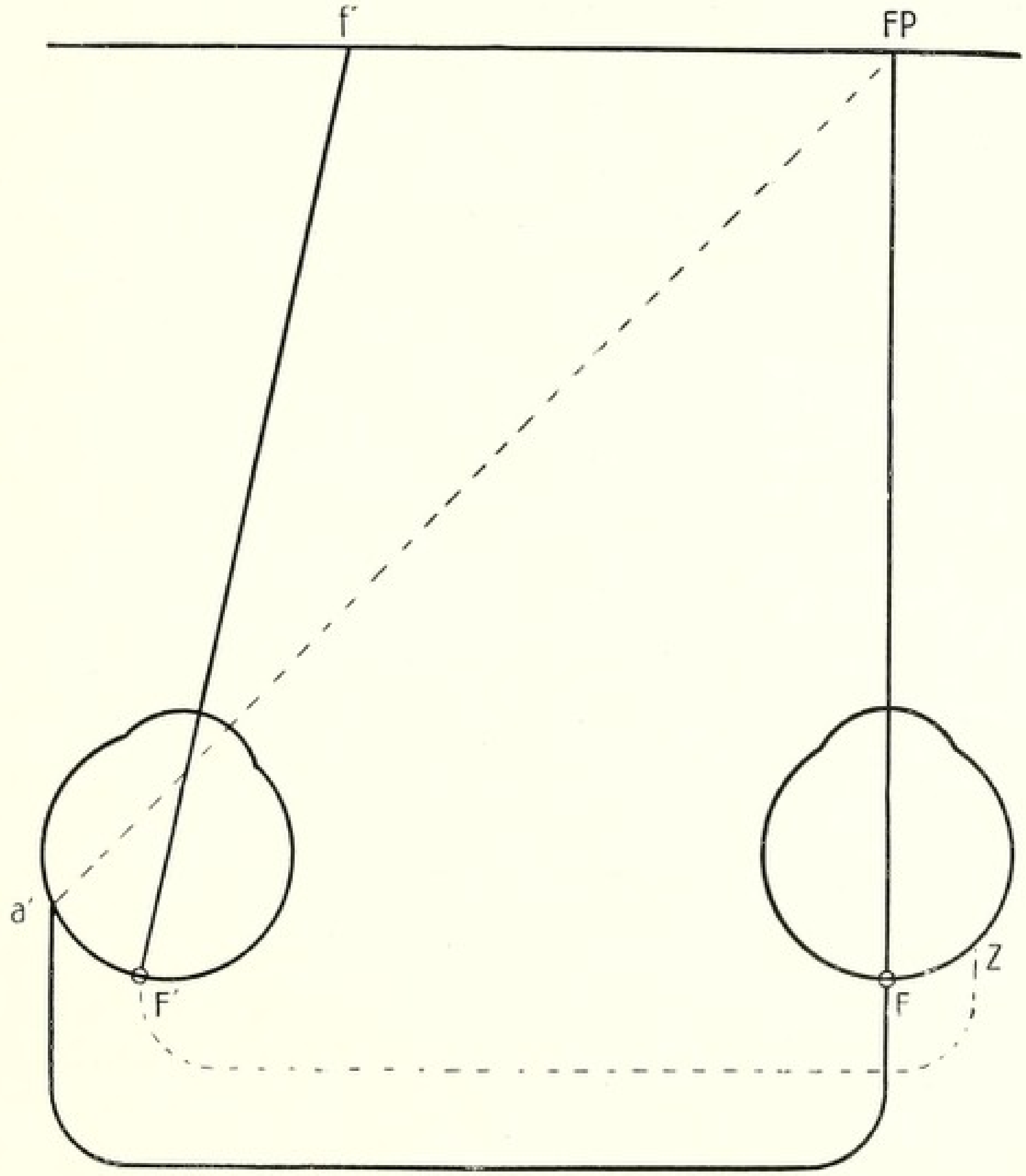

FIG. 34—Abnormal harmonic retinal correspondence (TSCHERMAK).

zontal (transfoveal) negative after-image, and in the other a similar vertical one, and then look at a vertical white sheet, such cases would show a regular cross. In spite of the motor anomaly there is here normal sensory correspondence (fig. 33). If the retinal after-images do not form a cross, a new relationship between the two retinæ must have developed (an "anomalous community" of visual axes). This anomalous community may be in harmony with the angle of the squint or not. If the angle of the squint and the angle of the anomaly coincide, then we have harmonic anomalous vision (fig. 34), if they do not correspond then we have disharmonic anomalous vision (ADAM) (fig. 35).

TSCHERMAK considers that the latter cases of anomalous community of visual axes are due to the fact that the correspondence which is found is the remains of a former harmonic anomalous community of visual axes.

It is clear that in the first and the third groups the image of the squinting eye must be suppressed, and only in the harmonic form

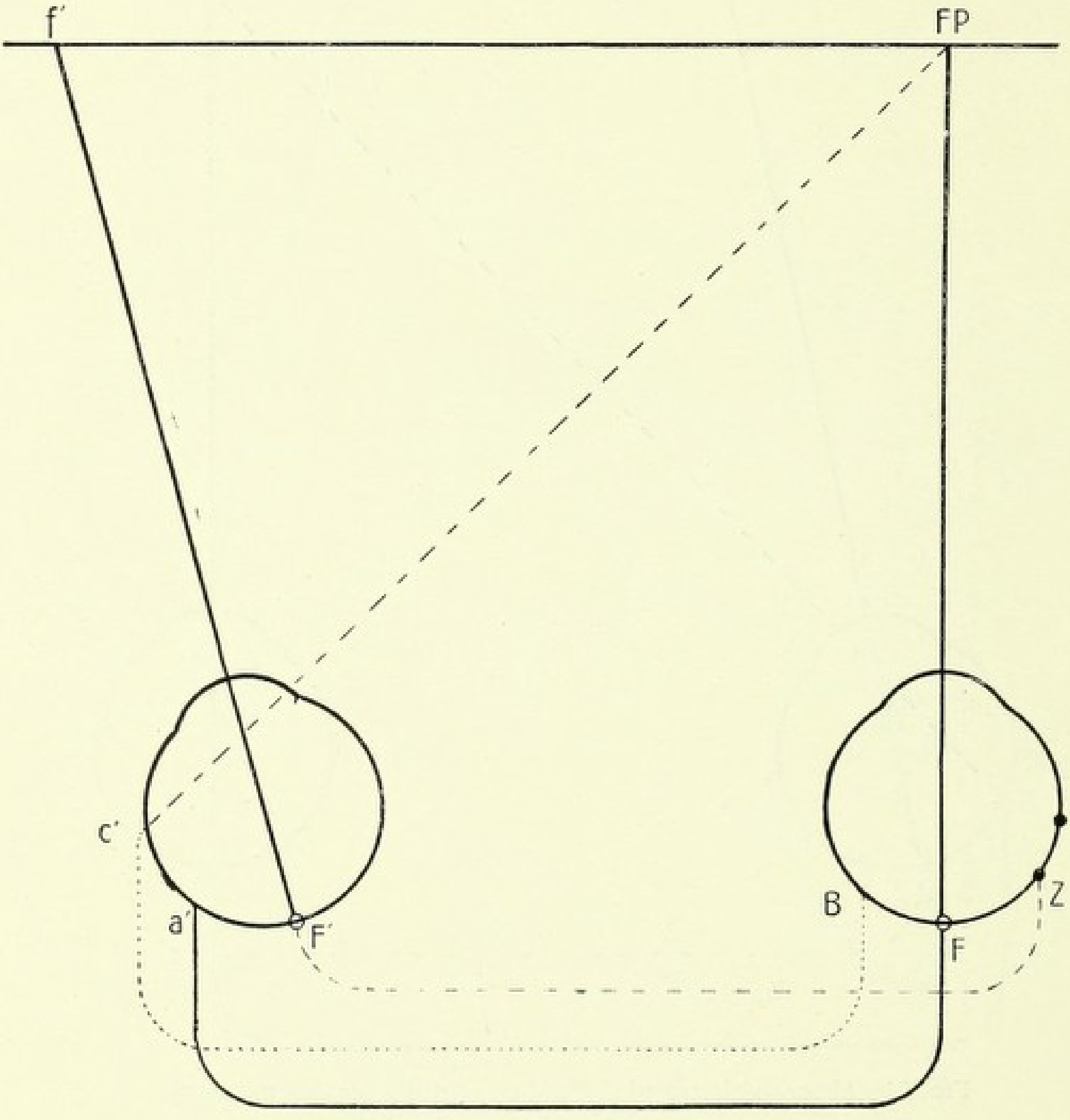

FIG. 35.—Abnormal disharmonic retinal correspondence (TSCHERMAK).

can we speak of binocular vision. As to the relationship of the various groups to each other, I will quote ADAM's figures :[1] In 100 squinters this author found 66 whose localization was of the anomalous type, and of these only six were disharmonic.

The binocular vision of these harmonic types is far from being

[1] *Zeitschr. f. Augenheilk.*, xvi.

the same as that of normal binocular vision. Mügge[1] found that it was only developed to the extent of seeing unlike amblyoscope pictures as a group; much more rarely was there a fusion of parts of the same picture presented as stereoscopic halves; and he only found one patient with a low grade of stereoscopic vision.

Normal and Abnormal Correspondence.—According to Bielschowsky, there is an essential difference between normal and abnormal correspondence. (1) The anomaly angle varies in the latter; it is not a constant and varies with different methods of test. (2) There is absence of a tendency to fusion, the variations of the angle of the anomaly which was so fully and thoroughly studied by Schlodtmann,[2] must not be considered as a tendency to fusion. The fact that Mügge with the amblyoscope demonstrated a breadth of fusion of 10° in a patient must be borne in mind. (3) There is loss of estimation of depth; Mügge's observation is an exception to this. (4) There is a dissimilarity and want of strife between the images produced in the two eyes.

Though the abnormal common visual axis must be considered as variable in comparison to the normal, still in my opinion there are no grounds for considering the common visual axis as essentially congenital in the nativistic sense.

In view of what we have already considered, the acquired abnormal correspondence of the retinæ can be considered as a psychic faculty just as is the sense of depth, and naturally when the association of the individual elements is the normal congenital one, the function is more accurate. In my opinion, it is the existence of this anomalous common axis, in spite of unfavourable conditions and relations, which proves that a functional co-ordination, though variable, can be attained, and furnishes evidence of a psychical faculty which, as we have already indicated, is to be found in creative and reproductive processes.

Conditions in Squinters after Operation.—After operation there are three stages in which vision differs[3]:—

(1) The absolute predominance of the anomalous localization; after a successful operation double images ("paradoxical diplopia") may still occur. This is generally not the case, for as Ohm rightly shows, anomalous projection is much more common than confusing diplopia.

(2) In the second stage there is a conflict between normal and abnormal localization. Ohm demonstrated in three of the cases in his series that there was monocular diplopia and binocular triplopia. Bielschowsky's investigations on monocular diplopia first gave an impetus to exact critical examination of the conditions of the two retinæ in squint. The diplopia is to be explained by the projection of the object according to the acquired localization, and also according to the congenital sense of space in the retina. The duration of this stage varies; it may last for days, weeks, months, or even years.

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[1] *Arch. f. Ophthal.*, lxxix. [2] *Ibid.*, li.
[3] Ohm: *Arch. f. Ophthal.*, lxxviii.

(3) The predominance of normal localization. Binocular estimation of depth must be acquired with difficulty; it is doubtful whether complete normal binocular vision will be acquired. OHM certainly takes this view. MÜGGE, on the other hand, is sceptical and leans to the view, which is also voiced by SCHWEIGGER:[1] "In squinters who have acquired a new relationship between their two retinæ, the normal binocular vision will not be learnt after operation." This sentence baldly stated is not quite correct, but experience, such as that of MÜGGE and ADAMS, shows that TSCHERMAK'S conjecture is valid; those with a harmonic anomalous localization, especially when there is a certain degree of perception of depth, have a smaller chance of developing the normal relations of the two eyes, an important fact in prognosis, as a cosmetic success may mean an extremely persistent functional disturbance.

ORIGIN AND IMPORTANCE OF AN ANOMALOUS COMMON AXIS.—We have no certain knowledge of the origin of the anomalous common axis. While some would see in the squinting posture the primary and chief cause for the incidence of an anomalous axis, MÜGGE holds the view that some defect in the arrangement of the normal correspondence is a necessary precedent to that relationship of the two retinæ which is the means of obviating diplopia. According to MÜGGE, the inefficiency of these congenital arrangements is proved by the long persistence of the abnormal relationship, and by the fact that amblyoscopic exercises appear to produce only an incomplete binocular vision. One of the chief factors in the occurrence of the anomalous common axis is to be found, according to BEILSCHOWSKY, in the fixity of the strabismic angle (strabismus concomitans). It is only in extremely exceptional cases that abnormal relationships will be developed in the two retinæ in cases of strabismus paralyticus (A. GRÄFE).

PRESENCE AND ABSENCE OF FUSION IN CONCOMITANT SQUINT.—The chief accompaniment of the defective retinal correspondence is a defective fusion. WORTH[2] has clearly shown that this is so in concomitant squint. By fusion is meant the impulse to binocular unification, such as is shown in the stereoscopic union of two half pictures, though they are brought together or separated, the eye maintaining binocular single vision by following the movements of the pictures.

WORTH found a defective fusion faculty in every squinter, best marked in cases of strabismus alternans with good central vision in each eye, and he considered that defective fusion was the origin of the squint. KRUSIUS[3] showed that there could be a defect in fusion without any squint, and placed fusion in the trio—squint, fusion, amblyopia—in a sense giving it the central position, considering that it was the important etiological factor in the production of squint and amblyopia. WORTH'S view is of the greatest importance, for

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[1] *Arch. f. Augenheilk.*, xxix.

[2] "Squint, its Causes, Pathology and Treatment." London: Bale, Sons and Danielsson, Great Titchfield Street, W. Price 6s.

[3] *Ophthal. Gesell.*, Heidelberg, 1908.

the therapeutical results which follow fusion training have proved such a valuable addition to our procedure in concomitant squint.

Training the Fusion Faculty.—For the training of the fusion faculty Worth has provided an apparatus (the amblyoscope, fig. 36) by which, in any position of the eyes, simultaneous stimulation of the foveæ can be achieved, and the visual objects can be very considerably displaced. Figures and pictures are used which take into account the different degrees of fusion. In fig. 37 three pairs of such figures are shown. The first pair does not provide a true fusion of the images, but simultaneous vision of dissimilar objects ; the second provides for the fusion of single partial pictures into a complete whole. And for the third and most difficult degree

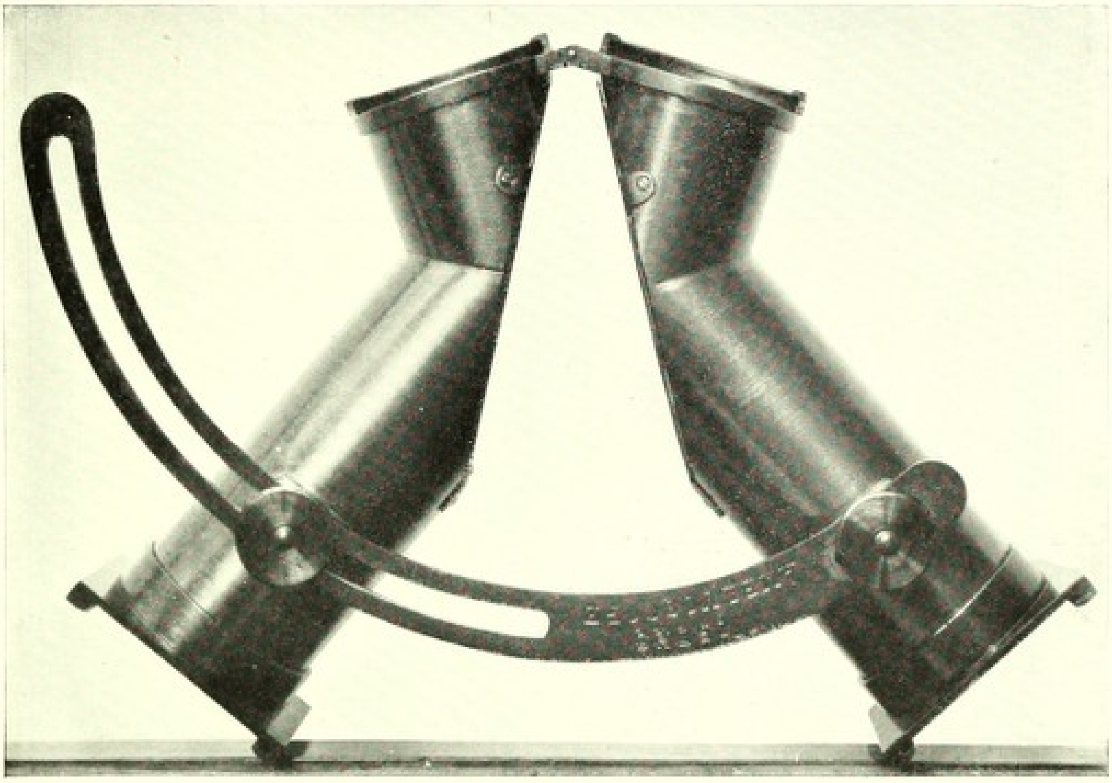

Fig. 36.—Amblyoscope (Worth).

of binocular vision—vision of solids—the third pair of pictures is adapted.

Krusius recommends an amblyoscope with variable illumination, having the advantage of rendering fusion exercises possible in those individuals to whom simultaneous vision of the objects shown is not possible.

With respect to the results obtained by amblyoscope training we must not theorize too freely, and must remember Bielschowsky's statement in the discussion on Krusius's communication. He showed that a defective basis for binocular vision (abnormal retinal correspondence, fusion defect) is not present in every case of concomitant squint, but that " even after the squint had lasted for years, immediately on the position of the eyes being restored to an approximation of the normal, binocular vision occurred, without any fusion training being necessary; in this case the basis of the squint was an anomalous position of rest, with a completely normal fusion mechanism."

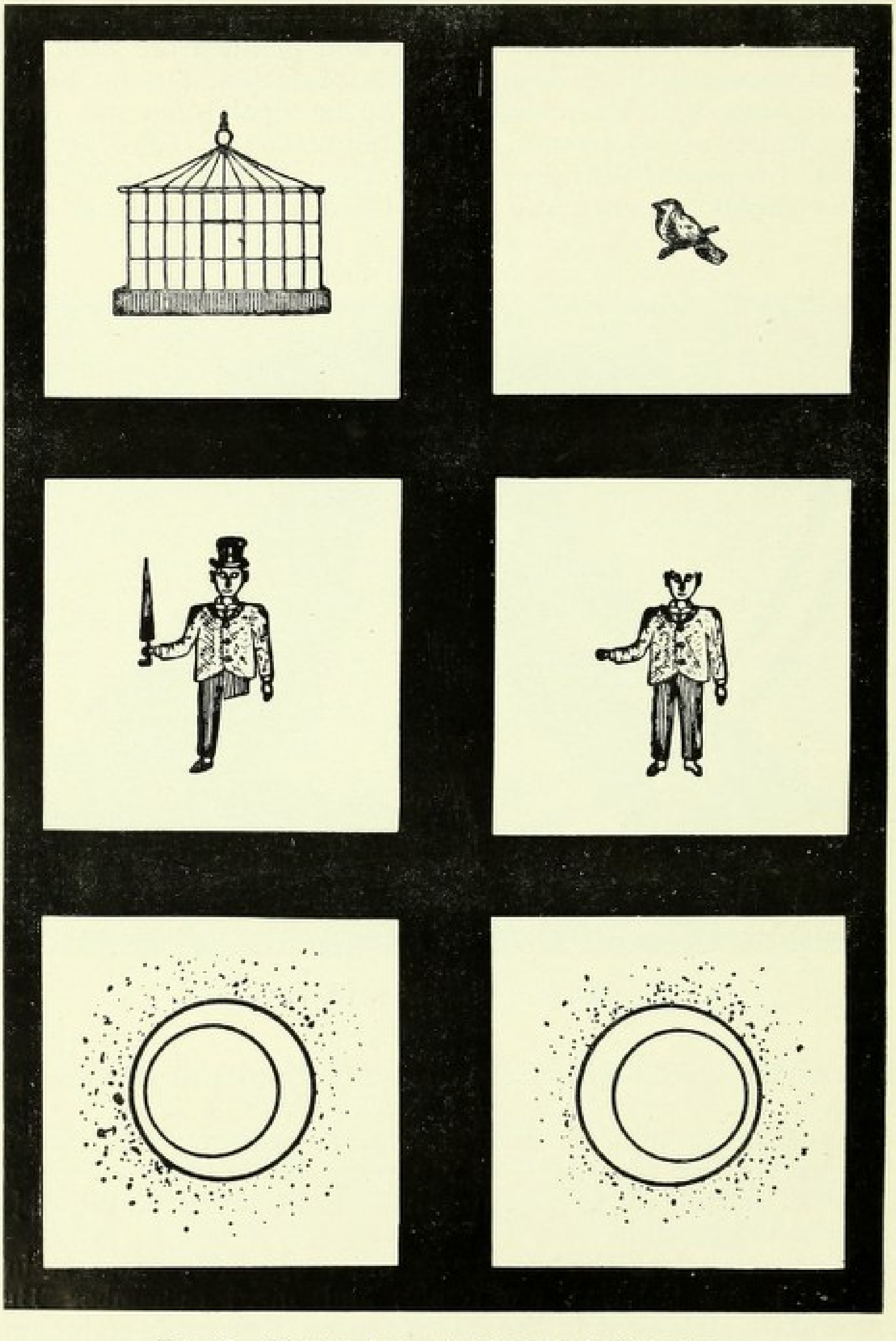

Fig. 37.—Pictures for use in Worth's Amblyoscope.

Not long ago I had the opportunity of examining such a case, operated on in the private clinic of Professor Eversbusch; I will give the history, as it shows that the rule—that those squinters who have normal retinal correspondence have the best chance of a good functional result after operation—needs certain reservations. The vision was good in both eyes and the hypermetropia was low (some 2 dioptres); after the operation, which cosmetically was excellent, there was such a confusion of vision that "paradoxical" diplopia was suspected.

A careful examination of the case showed that the disturbance of vision was due to the tenotomy having broken down the association of the movements of convergence and accommodation. The use of glasses for near and distant vision relieved the confusion from which this young man suffered. Binocular vision was evident at the very first attempt with the amblyoscope (even binocular stereoscopic); from the records of the case I conclude that normal retinal correspondence was present before the operation.

The patient told me that he had formerly excluded the image of the squinting eye, but that this did not always succeed; for example, if he were reading the left page of a book with the right (leading) eye, and there was a coloured picture on the other page, it would always form an obscuring image over the print which he was reading.

Amblyopia ex Anopsia.—The third symptom in concomitant squint is amblyopia ex anopsia. This must be considered as a functional loss, as a suppression. Best[1] favours the view that there is a suppression of visual perception, and this is supported by the fact that we do not perceive the shadows of our own vessels on the retina, and the evidence that the experienced ophthalmoscopist or microscopist with both eyes open only sees the object which is being examined. By perimetry of the open eye, not being used for microscopy, Best successfully demonstrated a central scotoma, the other eye having its attention directed the while to the field of the microscope. According to this idea congenital amblyopia can be considered as a permanent suppression of the region of the fovea in the strife of the fields. I must here note that in a case of congenital amblyopia in the Universitäts-Augenklinik at Munich, we were able to go a step further than this lowered condition of the fovea, and show that the periphery of the amblyopic eye prevailed. When the test was made monocularly the field of the functionally active eye was larger than when the test was made binocularly, and this "defeat in the strife" affected 10° of the field in the functionally active eye; on the other hand, a central scotoma without any anatomical signs in an amblyopia, which was absolute for blue to a binocular perimetric examination, was relative when the amblyopic eye alone was tested (*cf.* Amblyopia Congenita, Chapter IV).

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[1] *Klin. Monatsbl. f. Augenheilk.*, ii., 1906.

CHAPTER XI.

VISUAL DISTURBANCES IN DISEASES OF THE VISUAL TRACTS AND CENTRES.

The Visual Tracts.—From the eye, in which the fibres of the optic nerve spread out, there is a connection to the cerebrum, so that symmetrical halves of the fundus oculi are related to corresponding halves of the cerebral cortex. This is represented in a general schematic manner in fig. 38. The following points should be noted.[1]

Chiasma.—The fibres of the optic nerve pass backwards and inwards through the optic chiasma into the interior of the skull *via* the optic foramen and form, with the fibres from the opposite side, a crossing (semi-decussation), the chiasma. One half only of each nerve passes over, the remaining half continuing on the same side; the "crossed" fibres pass through the bottom of the chiasma, the "uncrossed" fibres through the top. In the "tractus opticus" the fibres thus mixed are continued on to the basal ganglia, the primary optic centres. The optic fibres pass into the corpus geniculatum externum, the anterior corpus quadrigeminum, and the optic thalamus.

Optic Thalamus.—The separate entrance of the optic fibres into the three ganglionic masses at the base of the brain would seem to have some functional significance.[2] Such, however, till now has not been incontrovertibly demonstrated; we must imagine the enormous difficulty attending on an interpretation of pathological anatomy, which shall be free from all objections; nor is it always possible to sharply discriminate with precision and certainty between the signs of nuclear affections and those from the neighbouring parts.

There are connections between visual impressions and co-ordinate movements, and though the latter are more dependent on the muscular sense, yet their dependence on visual impressions appears quite clearly in those cases where the common and muscle senses are lost. With their eyes open tabetics are able to maintain their balance; but with their eyes closed they sway about and are no longer able to stand upright (Romberg sign).

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[1] Bernheimer, in Gräfe Sämisch's "Handbuch der Augenheilkunde," ii ed.

[2] Wilbrand-Sänger: "Die Neurologie des Auges."

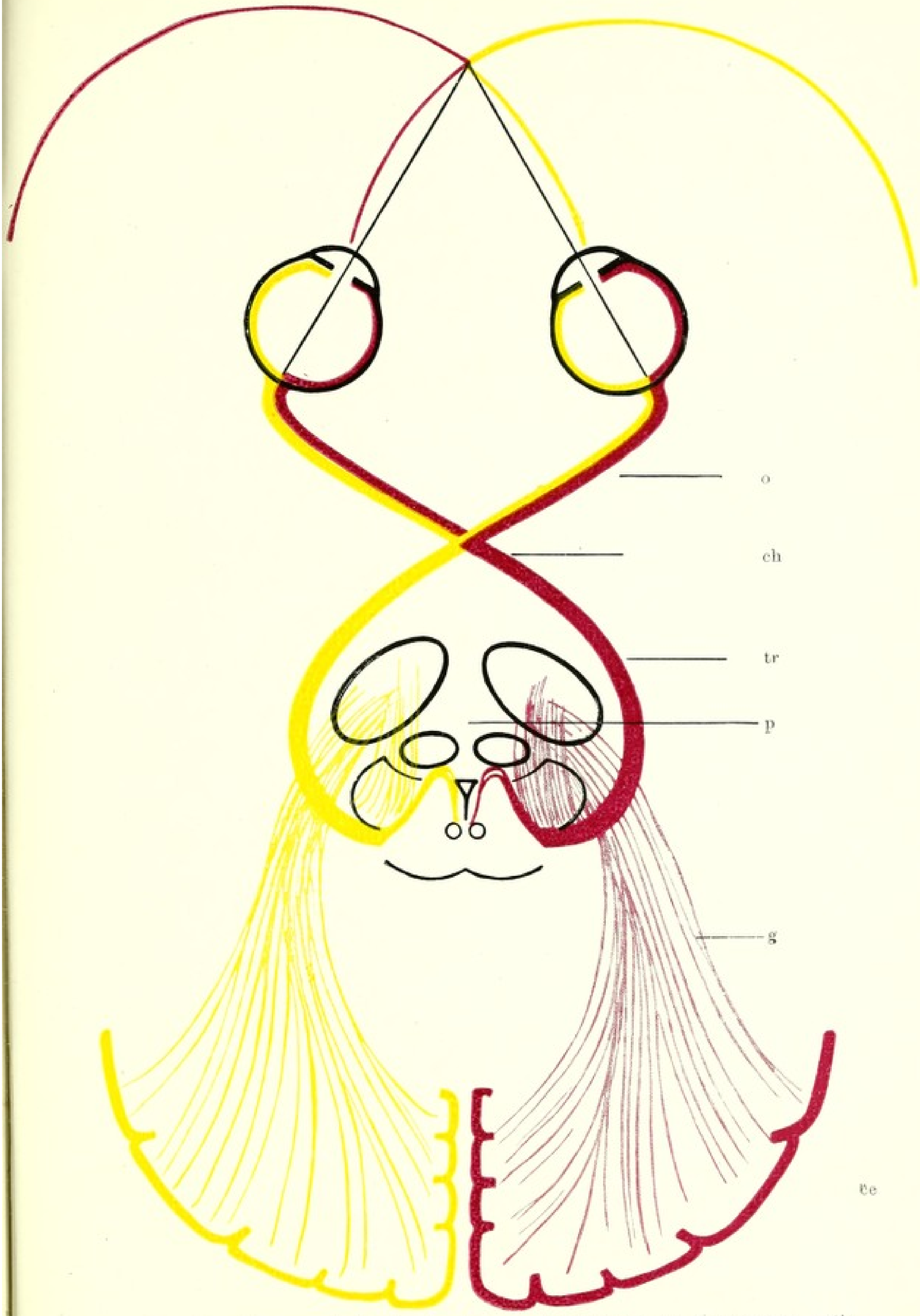

FIG. 38.—Diagram of the visual paths: o, optic nerve; ch, chiasma; tr, optic tract; p, primary optic ganglion; g, Gratiolet's bundle; ce, cerebral cortex.

We conclude that, by connections starting from the pulvinar of the optic thalamus, visual stimuli can be transferred into impulses for the regulation of the motor functions. Grünhagen considered that the optic thalamus was the central junction for the voluntary motor nerve-fibres. There is also a close connection between the optic thalamus and the cerebellum, that central organ which is so closely associated with the balancing of the body. The connection of the optic thalamus with Gratiolet's visual bundle appears to supply the path by which movement results under optical control or in accordance with estimation of distances.

Anterior Corpus Quadrigeminum.[1]—The optic fibres which pass to the anterior corpora quadrigemina are concerned with the eye movements. In lesions of the nuclei we find paresis of the upward and downward ocular movements, which are of themselves so rare that the coincidence indicates a relation between the corpora and the ocular movement. The ocular fibres for the pupil reflex branch off from the corpus geniculatum externum to the anterior corpus quadrigeminum, and turn back from there to the nucleus for the sphincter.

Corpus Geniculatum Externum.—The optic fibres concerned in vision appear only to pass into the corpus geniculatum externum. The visual fibres extend from here through Gratiolet's connection to the occipital lobe of the cerebrum.

Before we take up the two possible but disputed connections between the optic nerve-fibres and the cerebral cortex, we must bear in mind the state of affairs which obtains in hemianopsia. In many such cases of half-blindness the field shows that the line of division between its right and left halves is not vertical, but bends round the macular area in a circular, elliptical, or pear-shaped line ; in these cases we speak of a "superfluity in the field," and its presence or absence has been made the basis of an exact localization of the causal lesion either before or behind the primary optic ganglia (*vide infra*).

Wilbrand's View.—The possibility of this "superfluity in the field" occurring at all definitely proves a peculiarity in the connection of the macula to the occipital lobe. Wilbrand's hypothesis put forward to explain this fact bases this double supply on a dichotomous branching of the macular fibres in the chiasma (Heine locates the forking of the fibres in front of the primary optic centres) ; Wilbrand further considered that there was a correspondence between particular areas of the retina and of the occipital lobe, so that only a very restricted occipital area corresponded to the macula (projection of the retina on the cortex). This idea is confirmed by scotomata of the macular area only. Wilbrand described a very circumscribed injury in the occipital region due to a penetrating wound ; he found small homonymous defects in the fields of vision. Uhthoff[2] has also observed similar cases ; after a blow in one case there were circumscribed homonymous

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[1] Bach : *Zeitschr. f. Augenheilk.*, ii.

[2] Rectorial Address, 1908.

defects in the field at the fixation point; in another, where a falling brick had caused a depression of the skull in the region of the visual centre, there was a limited homonymous hemianopsia.

BERNHEIMER'S VIEW.—BERNHEIMER demonstrated anatomically that there was an admixture of the right and left optic fibres in the optic tract, and that such could not occur after the fibres had entered the corpus geniculatum externum; he supported the view of MONAKOW as to the connection between the optic nerve-fibres and the cortex. According to this author, the fibres from the peripheral ganglion cells of the retina branch, but each only connects with one, or few, of the cells of the primary optic centre; those fibres, however, which come from parts corresponding to the macula, branch, and each connects with many of the cells lying in the nucleus. According to this view there is a multiple compound connection between the macular fibres and the cortex, and thus the predominance in vision of this site is explained.

According to BERNHEIMER, clinical support to this point of view is found in the fact that cases are extremely rare in which, with a normal function of the periphery of the retina, there is a defect in the field limited to the halves of the macula. Such cases, however, have already been reviewed (WILBRAND, UHTHOFF, &c.).

In view of these facts, the hypothesis of WILBRAND and MONAKOW in my opinion can only be supported if the defects in the macular area of the field be considered as the residuum of a total hemianopsia. In this connection an observation by HAAB[1] may be quoted, referring to a central hemianopic defect in a man aged 61. "Further careful investigation showed that immediately after the onset of the affection, the disturbance was more extensive and severe; for a person who walked on the left side of the patient disappeared entirely." Taking this point of view, we have the antagonistic explanations on the one hand of the "superfluity of the field" by the pre-eminence of the macula, and, on the other, of the hemianopic defect limited to the centre, as demonstrating an increased vulnerability. These will present difficulty in comprehension on the BERNHEIMER-MONAKOW hypothesis of the connections of the visual tracts to the cerebral cortex; difficulties which will hardly be removed by postulating lesions differing qualitatively and quantitatively in their action. RÖNNE'S[2] idea is that the escape of the macula lutea in hemianopsia must be considered as the functional residue of a hemiamblyopia; in view of the actual occurrence of small central hemianopic defects, this presents the same theoretical difficulties as have been mentioned.

AFFECTIONS OF THE CHIASMA.—Affections of the chiasma or in the neighbourhood of the optic decussation (hypophysis tumours, acromegaly, cerebral syphilis, destructive processes in the sella turcica, &c.)[3] cause heteronymous defects in the fields. Corresponding

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[1] MAGNUS: "Unterrichtstafeln." Cases 24a and 24b.

[2] *Klin. Monatsbl. f. Augenheilk.*, 1911.

[3] An extremely valuable presentation of this subject by UHTHOFF in GRÄFE SÄMISCH'S "Handbuch der Augenheilkunde."

to the loss of the field on the left temporal or left nasal side there is a defect in the right field affecting the side of the same name. As we have already mentioned, the crossed fibres lie in the lower part of the chiasma and the uncrossed in the upper; the result is that processes at the floor of the chiasma result in a defect in the two nasal halves of the retinæ (temporal hemianopsia); processes destroying or compressing the roof of the chiasma destroy the function of the temporal halves of the retinæ (nasal hemianopsia). The first variety is more common; HIRSCHBERG, in an ingenious comparison, calls it "Blinker-hemianopsia." NETTLESHIP insists that the retinal defect may begin as an amblyopia, and the temporal hemianopsia gradually develop. On the other hand, UHTHOFF observed the commencement of a temporal hemianopsia as a bilateral paracentral scotoma outside the point of fixation, and states that the scotoma then showed characteristic peculiarities; it was sharply delimited by the vertical line of separation, and from this it stretched outwards. The scotoma enlarged during the five years the case was observed, and finally completely filled the half of the field.

The profound alterations of function occurring in affections of the chiasma are related in some cases to the rupture of a cyst,[1] and in others changes in the lumen of vascular tumours[2] play a part.

As RÖNNE[3] has shown, an exact analysis of the fields in heteronymous hemianopsia will yield interesting evidence of the course of the fibres in the chiasma. We know that in the nasal half of the retina the fibres radiate from the optic entry to the periphery; the distribution in the temporal half is different; here the fibres sweep above and below the macula to meet in a raphe which separates the upper and the lower temporal quadrants from each other (*see* Chapter IV). After carefully analysing two cases of temporal hemianopsia, RÖNNE concluded that crossing does take place in the chiasma, and that the uncrossed as well as the crossed bundle maintains the same position as it had in the retina.

HOMONYMOUS HEMIANOPSIA.—According to RÖNNE a grouping of the fibres takes place in such a way that fibres from identical regions of the retinæ come together; and RÖNNE is inclined to conclude from the frequent demonstration of quadrant hemianopsia in a form reflecting the "raphe" of the temporal half of the retina, that the crossed fibres attach themselves to the uncrossed. For just as a complete loss of vision to the left or to the right can occur in hemianopsia, so defects occur which are limited by the horizontal meridian through the point of fixation (quadrant hemianopsia). On the other hand, the homonymous defects may be more irregular; they may, for example, begin in the form of a sector and gradually progress to total hemianopsia, and again may recede in the opposite direction, as in the case which UHTHOFF has recorded of a hemianopsia in the progressive and regressive phases. In the homonymous, as in the heteronymous, the defect can be for

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[1] ERDHEIM: "Sitzungsbericht d. kaiserl. Akad. d. Wissensch.," Vienna, 1904.
[2] DE KLEIJN: *Arch. f. Ophthal.*, lxxx.
[3] *Klin. Monatsbl. f. Augenheilk.*, 1910.

colour or both for colour and white. According to LENZ,[1] the relative proportion of such a relative hemianopsia (hemiachromatopsia) to the fully developed form is 5 : 764. A hemianopsia may occur on both sides, so that only a small central portion of the field (the superfluous field) remains with good vision; such cases have been reported by FÖRSTER and SCHWEIGGER. This bilateral hemianopsia may only affect colours,[2] and in a complete unilateral hemianopsia there may be a colour hemianopsia on the other side.[3]

DEFECT IN VISION DUE TO HEMIANOPSIA.—The hemianopic defect in the field causes great disturbance of vision, giving rise to uncertainty, and handicapping the patients. The hemianope, when looking straight in front, is only able to see objects lying to one side, a state of affairs which greatly restricts his free movement on the streets, or in open places. This will be particularly noticeable if the patient walk along that side of the street opposite the defect in his field. It will readily be seen how a right-handed defect will greatly restrict reading and writing; the hindrance is not so great in the reverse cases. HIRSCHBERG, in a discussion, related a beautiful instance of this in a Rabbi, who was afflicted by a right-sided hemianopsia. He was unable to read German text, but read the Hebrew without a hitch. Small central hemianopic defects, according to the observations of WILBRAND,[4] cause a considerable hindrance to reading.

DISTURBANCE OF THE ABSOLUTE LOCALIZATION IN HEMIANOPSIA.—In two hemianopes I found[5] a defect in absolute localization which showed itself when an attempt was made with the arm covered to prolong a line drawn in the uncovered part of the field (*cf.* p. 150). In a right-sided hemianopsia this defect was especially pronounced if the test was made with the right hand. The idea that there is a disturbance in the connection between the left occipital lobe and the left centre for the movements of the right side of the body, must be discarded for the view that as a result of the right-sided hemianopsia a correction of the defect in localization had only developed with the left and visible arm. If by means of a blinker a field is produced corresponding to that in hemianopsia, glaring mistakes will be made in localization. The uncertainty in vision with the half monocular field is surprising, and I would compare it to that which occurs when a person who is accustomed to binocular vision attempts to make an estimation of depth with one eye. The defects in localization are partly responsible for the uncertainty in vision and movements which the hemianopes complain of; they can be explained by the hemianopsia itself, as we have shown, and they represent a disturbance of terminal origin.

DISTURBANCE IN THE VISUAL ESTIMATION OF SIZE BY HEMIANOPES.—A further visual disturbance explicable by the defect in the

[1] *Arch. f. Ophthal.*, lxxii.
[2] STEFFAN : *Arch. f. Ophthal.*, xxvii.
[3] SCHÖLER-UHTHOFF : Beiträge, &c., Berlin, 1884.
[4] *Klin. Monatsbl. f. Augenheilk.*, 1908.
[5] *Arch. f. Ophthal.*, lxxx.

field is shown in that defect in visual spacing which was first described by D. AXENFELD.[1] When a strip of paper is halved the half which lies on the blind side appears too small. AXENFELD only described one case; LIEPMANN and KALMUSS[2] conducted a series of investigations and gave detailed information as to this defect. The material available to these authors consisted of ten cases. In 81 per cent. of the cases the typical defect of AXENFELD occurred, in 10 per cent. the halves were equal, and in 9 per cent. the error was reversed. Some of the cases consistently made the error, while in others it was of such a low degree that a few tests might easily have missed it.

Regarding the explanation of this phenomenon, AXENFELD falls back on WUNDT's explanation of the discrepancy in spacing by monocular vision. The excess in value given to the upper half of a vertical (it is made too small) is due, according to WUNDT, to the fact that the inferior recti for an equal length are greater in cross section. Similarly, he would explain KUND's spacing experiment (where the nasal half had an excess value over the temporal)[3] by the greater strength of the interni over the externi. The condition here, however, is different from the vertical, for the excessive valuation lies on the side of the stronger muscle; and it is only in the exceptional cases (FISCHER,[4] MÜNSTERBERG[5]) where the opposite is the case, that WUNDT's explanation can suffice.

AXENFELD considered that in a hemianope there was a slight paresis of the one rectus internus and the other rectus externus; and went on to say that the explanation of the disturbance was to be found in the normal condition as given by WUNDT; only that here it was not the greater or less section of the muscles, but their greater or less functional activity. LOSER[6] advanced strong evidence against this; he examined a hemianope who also had a left-sided abducens paresis. The paralysed and the unparalysed eye made the same mistake.

I consider that this spacing error must be referred to the power of appreciating space-values which resides in the retina. "The elements of the outer half of the retina show a steeper gradation of locality signs than do those of the inner half; one and the same functional difference is attained on the temporal side by a smaller number of elements and by a less excentricity than on the nasal" (TSCHERMAK). KUND's spacing experiment must be thus explained. The defect in visual spacing cannot be considered as a variation of this optical illusion, for either the nasal half alone or the temporal half alone of the retina is functionally active. There is here the expression of another relation of the locality signs of the retina, namely, the fact that, in the same meridian, the

[1] *Neurol. Zentralbl.*, 1894.
[2] *Berl. klin. Wochenschr.*, 1900.
[3] POGGENDORF: "Annalen d. Phys.," cxx.
[4] *Arch. f. Ophthal.*, xxxvii.
[5] "Beiträge zur exper. Psychol.," 1889.
[6] *Arch. f. Augenheilk.*, xlv.

elements are so graded that those placed centrally are closer together for the same functional value than those more peripheral.[1]

In fig. 39 a diagram of the spacing discrepancies in the right eye is given (after TSCHERMAK), illustrating very well the objective and the subjective estimation of space. "The continuous lines

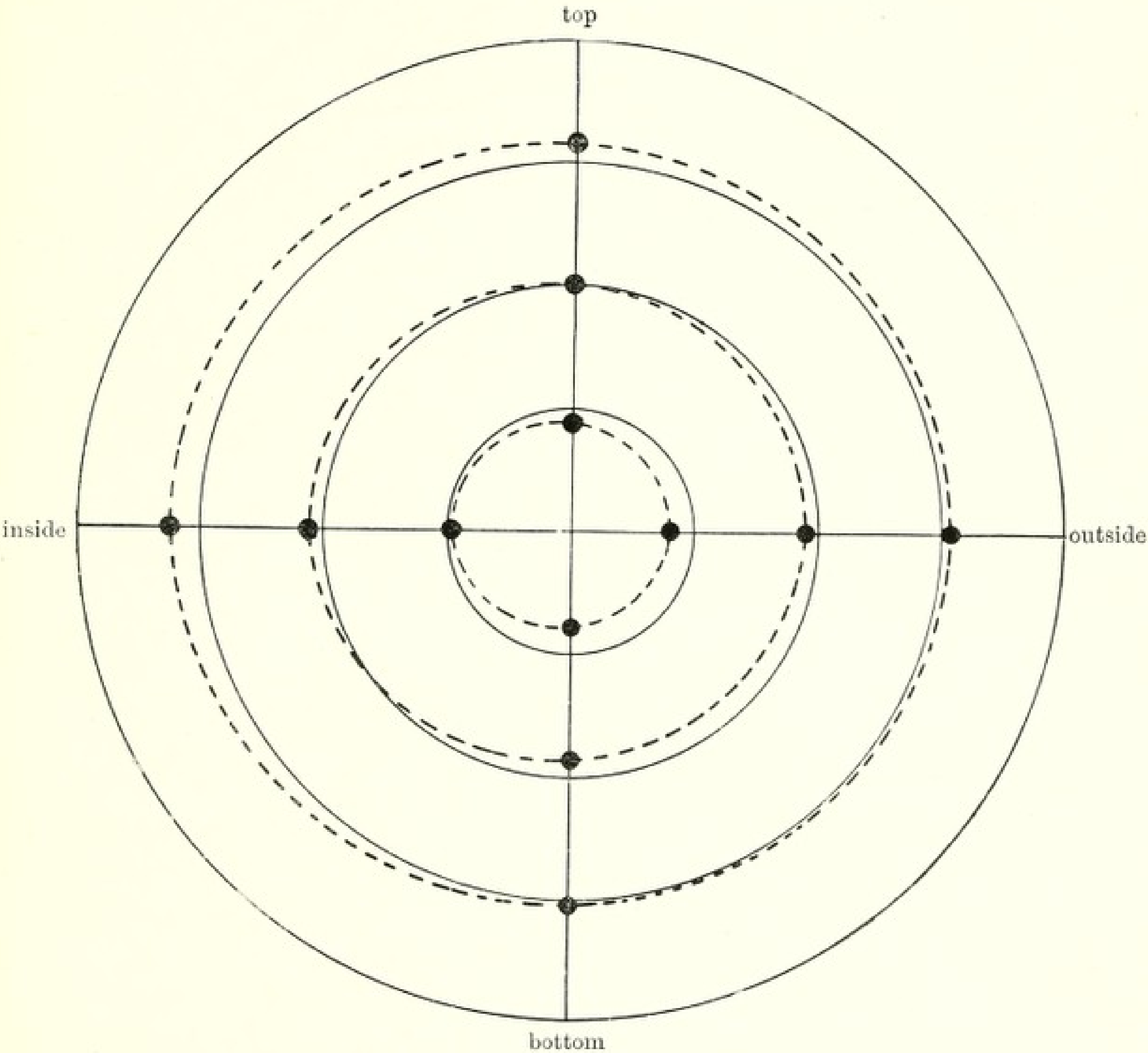

FIG. 39.—Diagram of the spacing discrepancies in the right eye.—(After TSCHERMAK).

indicate geometrical concentric and equidistant circles. The dotted lines join those retinal elements which convey the subjective impression of concentric equidistant circles."

TSCHERMAK compared this functional differentiation with a morphological one, the decentred arrangement of the individual flowers in the compositæ. I consider it is of value with regard

[1] TSCHERMAK collected literature in Spiro Aster, 1905. FEILCHENFELD: *Arch. f. Ophthal.*, lxxiv. LOHMANN: *Arch. f. Ophthal.*, lxxx. BEST: PFLÜGER'S *Archiv*, cxxxvi.

to these functional discrepancies to note the analogous anatomical conditions in the eye, as shown in the ora serrata,[1] the lesser circle of the iris, and the excentric entry of the optic nerve.[2]

VISUAL DISTURBANCES NOT DUE TO THE HEMIANOPIC DEFECT.—Along with the three forms of visual disturbance in hemianopes, whose explanation appears to be in the defect itself, other disturbances have been described, which form complications of simple hemianopsia. WESTPHAL observed a hemianope who had lost his estimation of distance and of orientation in space.[3] In this case, as also in one recorded by ANTON, the optical field of memory was probably affected, and so the perception of space, in which so many elements of representation occur, must have been altered. LENZ reports another peculiar form of visual disturbance, which can be recognized as metamorphopsia. A patient, when looking at a trade placard, saw the one end half a metre deeper than the other (from a distance of 50 metres); to another every face appeared as a caricature and all objects distorted. Corresponding to the metamorphopsia which we have considered in Chapter III, LENZ would look upon this form as due to the disposition of the cortical elements of the cerebrum. But the cause must be something different, for the essence of the retinal metamorphopsia is shown by the discrepancy between the picture regularly projected and the distorted retinal elements; this cannot be so in the metamorphopsia of central origin. Apparently we have an alteration in the factors of re-presentation; a confusion in the abstract perception prevents the impression being conveyed unaltered to the consciousness. What this alteration consists in, is at the present quite an unanswerable question.

The hallucinations of the blind half of the field (they are more rarely found in the seeing half) must be considered as complications of the hemianopsia. These hallucinations were first described by SEGUIN,[4] and were given a certain localizing value by UHTHOFF, who states that they are more common in cases where the occipital lobe or its immediate vicinity is affected; they mostly appear colourless, but occasionally are coloured.[5] UHTHOFF records a hemianope who saw on his blind side a bright road, along the sides of which were giants and dwarfs standing. Another patient of UHTHOFF'S saw by his bedside animals and persons who appeared and vanished.

ADAPTATION IN HEMIANOPSIA.—BEHR'S[6] researches show that in heteronymous hemianopsia (chiasma disease) disturbances in the adaptation of the sound half of the field can be shown at a time when no other test will indicate any change in this part of the field. In homonymous hemianopsia BEHR found a difference in

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[1] SCHÖN and SCHULTZE: "Verhand. d. phys. Gesellschaft," Erlangen, xxxiv.

[2] LOHMANN: *Klin. Monatsbl. f. Augenheilk.*, 1906.

[3] Quoted by LENZ: *Arch. f. Ophthal.*, lxxii.

[4] *Journal of Neuro-Ment. Diseases*, 1881.

[5] UHTHOFF: *Monatsschr. f. Psych. u. Neurol.*, v.

[6] *Arch. f. Ophthal.*, lxxv.

adaptation according to whether there was a tract hemianopsia, or one of central origin. In tract hemianopsia there was a disturbance of adaptation which did not occur in other hemianopsias. BEHR sees in this fact a confirmation of the view that adaptation is a reflex, and that the reflex arc is complete in the primary optic ganglia. On account of the absence of any disturbances of adaptation in cortical hemianopsia (as contrasted to their presence in tract hemianopsia), WILBRAND and SÄNGER[1] considered that the disturbance of adaptation must be due to lesions in centrifugal fibres. In my work on disturbances of adaptation[2] I emphasize, on the contrary, that, accepting MONAKOW'S view of the connection of the subcortical centres with the surface of the brain, the absence of adaptation disturbance in cortical lesions can be explained just as can the "superfluity of the field." (I must admit that this view is not too strongly supported by the evidence of clinical pathology.)

TRACT OR CORTICAL HEMIANOPSIA.—In deciding clinically with certainty the question whether a hemianopsia is due to a lesion in the tract or is central to the primary ganglia, the hemianopic pupil reaction, the superfluity of the field, and the "hemianopic prism phenomenon" of WILBRAND are made use of. The value of the evidence thus obtained is still in dispute, HEINE and BEHR[3] taking the one side and HESS and KRUSIUS[4] the other.

FLICKERING SCOTOMATA.—The flickering scotoma is a common affection of transient duration; FÖRSTER called it "Amaurosis partialis fugax." From its frequent association with migraine it has been called "*migraine ophthalmique.*" Most writers consider that the origin of these flickering scotomata lie in vasomotor changes in the cerebral hemispheres; some allege a vascular spasm, others a vascular paresis as the circulatory change. Flickering scotomata,[5] which can have various causes, were divided into the following classes by A. v. REUSS[6]:—

(1) A flickering, scintillating, or opaque cloud occupies the whole field, but has no movement; it leaves the centre free.

(2) In the vicinity of the centre of the field there is a scotoma surrounded by flashing zigzag lines constantly in movement. These lines form a circle or an arc. The phenomenon vanishes in the periphery, the lines always growing larger.

(*a*) This enlargement and disappearance may occur rapidly, the phenomenon commencing again at once.

(*b*) The change occurs slowly and is not repeated.

(3) Opaque or flashing spots appear in the field; these scintillate, but there is no zigzag movement; they disappear without enlarging either rapidly or slowly.

(4) A true hemianopsia without any lights or flashings.

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[1] "Neurologie des Auges," iii.

[2] *Arch. f. Ophthal.*, lxv.

[3] *Klin. Monatsbl. f. Augenheilk.*, xlviii.

[4] *Arch. f. Augenheilk.*, lxv.

[5] WILBRAND-SÄNGER: "Neurologie des Auges"; PICHLER: *Wien. klin. Wochenschr.*, 1911.

[6] *Wien. med. Presse*, 1876.

The third group in v. REUSS's classification can well be considered as different from the others; this (unilateral) phenomenon is better described by MAUTHNER[1] as "retinal" flickering scotomata, in contradistinction to the others which are cerebral. The fourth group, which actually is a transitory hemianopsia, was introduced into the class as they alternate with flickering scotomata.

REUSS distinguishes the scotoma as the opaque speck, which obscures what lies behind it; the speck is often orange-yellow or violet-grey in appearance. The scotoma is always negative, it is generally absolute, and often also relative (SIEGRIEST). When looked at through a coloured glass the scotoma appears of the complementary colour.[2] The form which REUSS classifies as 2b is the most common of the flickering scotomata. With regard to the course of the scintillating arch, PILCHER distinguishes a centripetal and a centrifugal form; in the latter the arch begins in the centre and enlarges to the periphery, in the former it begins in the periphery and contracts towards the centre.

In the first stage of the affection there is a central scotoma. The patient describes it as a peculiar uncomfortable disturbance; v. REUSS describes that in his own case he often felt impelled to take off his glasses and clean them. A gentleman recounted to me that he was suddenly so overcome by this peculiar affection when delivering a lecture, and was so alarmed at it, that he could hardly conclude his remarks. In the second stage the central scotoma usually disappears, and the characteristic flickering begins. The scotoma may continue inside the flickering edge and follow it as it enlarges, or, as v. REUSS describes in his own case, at the height of the attack the scotoma and the zigzag arch may not have any relation to each other.

TRANSCORTICAL VISUAL DISTURBANCES. — Mind-blindness is that state when optical sensation is intact, but a loss of memory pictures and representations has occurred. The optical field of memory is considered to be separated in the cerebrum from the field of optical sensation, a division of function which allows of the greatest possible power of perception of optical sensations, and a generous possibility of their admixture with memory images.[3] Cases of pure mind-blindness are rare; disturbances of vision in the form of hemianopsia are usually found with them. CHARCOT[4] reports a case of pure mind-blindness which was carefully observed; the patient was a man who had formerly had an extraordinary recollection of visual impressions. During his illness, when he returned to his own town, it appeared to him that he had come into a strange place. He looked at the streets, the buildings, and the monuments with the same interest as though he were seeing

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[1] "Vorträge aus dem Gesamtgebiet d. Augenheilkunde," Wiesbaden, 1881.

[2] v. REUSS: *Arch. f. Augenheilk.*, liii.; LOHMANN: *Zeitschr. f. Sinnesphys.*, xlvi.

[3] *E.g.*, ZIEHEN: "Das Gedächtnis." Berlin, 1908.

[4] WILBRAND: "Die Seelenblindheit." Bergmann, Wiesbaden, 1887.

them for the first time, then gradually his recollection returned. He had previously been a good draughtsman, but now he was unable to draw as before, and could not recognize his own face in a mirror.

VARIETIES OF MIND-BLINDNESS.—Mind-blindness may take on various forms, according to the groups of recollections which are lost. The cases where the recognition of external objects by touch and hearing remains, but is lost by vision, are called "optical aphasia" (FREUND). Alexia is another form; such patients are able to trace letters with their fingers, but are unable to name or read them. I have seen a merchant who was an extremely good calculator. He became aware of his defect by missing appointments which he had himself noted down, and reading entries wrongly. He had a quadrant hemianopsia, and was unable to read several numbers; for example, he could not read the number 153, calling it either 13 or 15, though he was still able to read the individual numbers 1 5 3 in the row.

LOSS OF COLOUR NOMENCLATURE.—The contrast between congenital colour-blindness and colour amnesia (WILBRAND)[1] consists in persistence of the sensation of colour as shown by the pseudo-isochromatic colour tables of STILLING, but the colours cannot be named. This colour amnesia may be partial; a patient of WILBRAND'S named all the colours wrongly except blue. I have recently seen a patient in whom the eyes were normal functionally and objectively as far as examination could show. But she could not name a single colour. Asked what an egg, a tree, or a leaf looked to her, she could as little tell the colours as she could name the pigments themselves when shown. Red alone was recognized correctly, and the colour of the blood was given as red. The diagnosis of the disease could not be definitely made, as the patient had a severe attack of a definitely hysterical nature.

LOSS OF SPATIAL REPRESENTATION.—Mind-blindness in which there was a loss of spatial representation has been described by HARTMANN[2] and KRAMER[3]. In KRAMER'S patient after an apoplectic stroke there remained a disturbance of the power of recognition by sight, which showed itself in a very serious diminution in the power of appreciating perspective in pictures; the recognition of solid objects, and the projection of stereoscopic pictures appeared to be less affected.

CONGENITAL WORD-BLINDNESS.—Mind-blindness is occasionally congenital. The importance of the correct recognition of such "word-blind" children on the part of the schoolmaster is obvious. UHTHOFF reports a patient who had complained from his youth of the difficulty in reading, so much so that it was easier to learn the lesson by heart than to read aloud from the manuscript. The fundamental congenital anomaly is probably in the brain in the vicinity of the

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[1] "Opthalm. Beiträge zur Diagnostik d. Gehirnerkrankungen," Wiesbaden, 1884.
[2] "Die Orientierung," Leipzig, 1902.
[3] *Zeitschr. f. Psych. u. Neurol.*, 1907.

gyrus angularis, or in the association fibres between the occipital pole and the centre for speech.[1]

SIGNIFICANCE OF MIND-BLINDNESS.—Similarly to those disturbances which appear of a more practical importance, mind-blindness will destroy the value of life to those who have enjoyed an existence rich in phantasy based on visual memory pictures. The total loss of visual sensation from peripheral disease or destruction of the visual paths or centre alone will not produce a condition parallel to the disturbance in mind-blindness. For such "blind" in the night of their affliction can save a whole world of memory pictures, which are withheld from the mind-blind, just as they are from those born blind or those blind from earliest infancy, to whom such a treasure is denied, but the affliction is greater to them than to these latter for "none but a king can mourn the loss of a crown."

[1] *Cf.* BÜTTNER in "Gesundheitswarte," ix, 12.

CHAPTER XII.

MEMORY PICTURES; ASSOCIATED AND FALSE OPTICAL PERCEPTIONS.

MEMORY.—With our visual impressions is always mingled a mass of "reproduced material," serving the elaboration of the complete percept, and rendering possible remembrance and recognition. "Memory," which is evolved out of this material reproduced from our store of sense impressions, and plays such an important part in our psychic life, our concepts, ideas, memory pictures, and fancies, is a phenomenon essentially due to the persistence of impressions which have been received by the sensory centre affected; just as an impression will remain in wax, or a folded cloth will resume the same folds when moved.[1] HERING speaks[2] of memory of living matter, and of matter in general.

THE EMBODIMENT OF MEMORY PICTURES.—The site of the complicated and multiple dispositions for the evolution of memory has been placed in the human cerebral cortex, not coinciding with the centre for the visual sense. A special centre, the field of visual memories, is presumed, separate and distinct (*see* Chapter IX). The recollections here stored up will be brought forth as images and shadowy memory pictures, if in the play of fancy or in dreams, this one or that arises into consciousness; they are generally only aroused as vivid sense images when a new sense impression arrives from the periphery.

OPTICAL AFTER-IMAGES.—The phenomena known as after-images must be distinguished from memory images, the former being due to the persistence of the visual stimulus in the peripheral organ, the eye. In physiology positive, negative, and complementary coloured after-images are distinguished; and in them a definite succession of phases can be determined (HESS). The colours do not all disappear with equal rapidity, but vary considerably. The optical after-image often modifies the sensory impression, as, for instance, when "irradiation" causes confusion. URBANTISCH[3] observed the branches of a tree in the after-image of the setting sun. Sometimes a row of pearls can be seen, as though hanging before the after-image of a light, and more clearly seen than the luminous image itself.

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[1] Literature and Critical Review by ZIEHEN: "Uber das Gedächtnis," Berlin, 1908.

[2] 1876.

[3] PFLÜGER'S *Archiv*, cx.

OPTICAL MEMORY PICTURES.—The optical memory pictures are the after action of a visual impression which is stored in the cerebral cortex. The power of reflection and recollection reproduces them, though in a shadowy manner, and in the play of fancy they appear either in fragments or complete.

VISUALIZED MEMORY PICTURES.—Memory pictures[1] are said to be visualized when they are represented with such vividness that they approach the clearness of an actual sensation (a sense memory). According to URBANTISCH such visualized memories often occur in young and emotional persons. He relates how one occurred to himself; he saw a Gothic window appear with the distinctness of a photograph; and from its detail he recognized it as a window in the Votive Church in Vienna which he had seen a long time before, and whose peculiarities he first noticed in the hallucination. These memory pictures usually occur only on the first day, but in the case given they did so after a considerable lapse of time. Such a repetition of a retained sense impression may appear to be direct, as the associations which induce the representation are outside the consciousness.

FURTHER EXAMINATION OF THE SUBJECTIVE PERCEPTION IMAGES.—URBANTISCH carried out an exhaustive investigation of these phenomena, and brought forward many facts of psychical interest.

Visualized memory pictures, according to him, may fail in a remarkable manner in those very persons who have a keen memory of visual impressions. A painter was able to paint a picture from memory, and still could not visualize his memories. Further, URBANTISCH records the influence of auditory impressions on visual percepts, the relative opposition of optical and visualized memories, &c., details which we will only mention here.

OCCURRENCE OF SUBJECTIVE PERCEPTION IMAGES.—In his work on false perceptions, KRAEPELIN[2] records the case of an artist who painted portraits from these subjective images; he further reports that the painter was later affected mentally. According to URBANTISCH these phenomena appear to be common and to occur in healthy persons. Certainly their occurrence is not the rule, and in his excellent little book on fantastic visual phenomena (Coblentz, 1826) JOH. MÜLLER speaks of the difficulty of producing definite perception images by the strongest effort of the will. As an example of an extremely marked case of subjective memory pictures, I will here quote OTTO LUDWIG, the author from whose biography by ADOLF STERN I take the following passage: "He used to say that he had learnt the Dresden gallery by heart. The impression which he had of the paintings was so strong that he would see them for a long time with the distinctness of an hallucination in front of him. A friend had brought him a photograph of RUBENS's celebrated 'Descent from the Cross,' and he related that when he was reading, the picture would stand

[1] URBANTISCH: "Über subjektive optische Anschauungsbilder," Vienna, 1907.

[2] *Vierteljahrsschrift f. wiss. Philosophie*, 1881.

as though actually present between his eyes and the print and cover over the lines of the book."

These subjective perception images appear to be especially common when the person is exhausted, after a long and tiring railway journey; then in the evening the landscape, the sea, the trees, and the streets pass before the closed eyes with the clearness of an actual sensation. (KRAEPELIN.)

CO-PERCEPTIONS. —In contrast to these phenomena which essentially reproduce sense impressions, we must mention those pathological phenomena in the purely psychic side of vision, in which sportive, creative and productive fancy plays the chief part. I must now mention those phantoms which so many people see when hearing music (music phantoms). Corresponding to my definition of *audition colorée* as a co-sensation, I will call these phantoms co-perceptions, for whose appearance the exciting factor supplied by music is necessary.

MUSIC PHANTOMS. —For a description of a music phantom I will quote HEINE'S[1] "Florentine Nights," where such a transformation of auditory impressions into visual images is depicted. PAGANINI steps forward and plays the violin, and the listener had the sensation "as though it were twilight, and the red glow of the evening overspread the rolling sea. The sea became redder and redder, and the sky grew paler, till at last the surging water looked like bright scarlet blood, and the sky above became of a ghastly corpse-like pallor, and the stars came out large and threatening; and those stars were black, black as glooming coal. But the tones of the violin grew ever more stormy and defiant, and the eyes of the terrible player sparkled with such a scornful lust of destruction, and his thin lips moved with such a horrible haste, that it seemed as if he murmured some old accursed charms to conjure the storm and loose the evil spirits that lie imprisoned in the abysses of the sea. . . . He seemed like some sorcerer who commands the elements with his magic wand; and then there was a wild wailing from the depth of the sea, and the horrible waves of blood sprang up so fiercely that they almost besprinkled the pale sky and the black stars with their red foam. There was a wailing, and a shrieking, and a crashing, as if the world was falling in fragments."

RUTHS[2] made extensive investigations concerning music phantoms, and found that in a bewildering manner these phantoms, in persons who had not been informed as to the character of the music (*e.g.*, the different parts of BEETHOVEN'S "Pastoral Symphony"), agreed with the statements of musicians. A musical gentleman told me that to him a deep musical sense without these phantoms appeared impossible. But that intense musical sense does occur without these phantoms is certain, and co-sensations also are very frequent, even in perfectly healthy persons. If they are

[1] From the translation by Havelock Ellis (T.).

[2] "Induktive Untersuchungen über die Fundamentalgesetze der psychischen Phänomene," Darmstadt, 1898.

to be called hallucinations, then they must be classified as reflex hallucinations (KAHLBAUM).[1] Their fixed connection with the exciting cause, music, their steady flow along with the musical conception (RUTHS), are quite enough to justify their place as "co-perceptions" in opposition to illusions and hallucinations (false perceptions).

FALSE PERCEPTION. DREAM.—The characteristic of a false perception is the vivid sensory character of the phenomenon, although no peripheral stimulus corresponding to the sensation is present. Phenomena of this nature occur in healthy persons in dreams, when fancy draws, out of the storehouse of memory, broken fragments of pictures, and by some quaint trickery imposes them on the dreamer as actual events. According to RUTHS, the laws which govern dreams are, the same as those which control the music phantoms and hallucinations. The law of substitution and progression which forms the basis of the psychic phenomena, and rules our dreams, acts so that the "memory elements in the dream do not arrange themselves like the coloured stones in a kaleidoscope, but rather in such a way that the stronger replace those which are similar, but relatively weaker. There is an astonishing similarity between this law of synthesis and both the struggle for existence in the organic world and the chemical law of substitution."

HYPNAGOGIC HALLUCINATION.—Another series of false perceptions is recognized by the names of "hypnagogic hallucination," or "phenomena of dosing." HOPPE[2] and RUTHS record a number of these phenomena, which occur in healthy persons as they dose before sleeping. Such phantoms can be referred to definite and well-known exciting causes, and I will give some of them out of RUTHS' book.

"It is winter, and in the afternoon, walking in the street, I see two children's sleighs, the one attached to the other. On the sleighs are seated little boys and girls with rosy cheeks; two larger boys in front draw them. In the evening I saw a beautiful phantom; two large sleighs, the one attached to the other. The sleighs are decked with beautiful colours, red, green, &c. Young ladies and young men are seated in them, fantastically clad with masks. They hold up long shields against the wind, the shields are gaily embroidered. Four black horses draw them, two and two abreast, red plumes on their heads, red saddle cloths with golden tassels and embroidered corners. The saddle cloths have a scalloped edge. The phantom remained for about half a minute, and then disappeared."

Or: "I saw a velocipede, standing in an open place, in the afternoon. I looked at it and saw how the pedals turned. In the evening I saw, in a phantom, a child who was turning a grindstone. As a child I used to enjoy working with a grindstone."

RUTHS's attempt to derive the popular myths and sagas from these dream phantoms is interesting. Music phantoms also appear

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[1] *Allg. Zeitschr. f. Psychologie*, xxiii.

[2] "Die Erklärung der Sinnestäuschungen," Würzburg, 1888.

to take an important place in music and poetry (*cf.* NIETZSCHE: "Die Geburt der Tragödie aus dem Geiste der Musik").

ILLUSIONS AND HALLUCINATIONS.—The false perceptions which occur without a corresponding external stimulus and in the waking state, occur almost exclusively in the mentally affected, and are commonly divided into illusions and hallucinations. In an illusion there is a falsification of the optical impression in that the normal process of perception is interfered with by the admixture of subjective elements which have no relation to it. A classical example of such false visual impressions is furnished by the well-known ballad of GOETHE, "Der Erlkönig." A statement of a mentally affected person will furnish a further example of an illusion; looking at a portrait, he suddenly said that the painted head was putting out its tongue.[1] Such false perceptions as occur day by day in the amalgamation of our sensory impressions with the residuum of previous perceptions can be designated as physiological illusions, in contrast to the phantasmic illusions (WUNDT) where, as a result of an increased central excitability, that part of the psychic image which is derived from actual perception almost entirely disappears.

In the hallucinations, as opposed to the illusions, there is a false image corresponding to no external visual stimulus. The following is from KANDINSKY, who in the *Arch. f. Psychiatrie*, Bd. xi, records his own hallucinations in a state of psychosis. The hallucinations occurred both when his eyes were open and closed. In the first case they were projected on the floor of the room, the ceiling, or the walls; or they appeared to be in the room and obscured objects lying behind them. In other cases the true surroundings appeared to vanish entirely, and the shore of a bay appear. There is a distinction between memory pictures and hallucinations. The determining factor is not the vividness of the scene but the apparent objective reality which attaches itself to hallucinations.

During the time he suffered from these hallucinations KANDINSKY's dreams were exceptionally vivid, "they were hallucinations in sleep." The patient is awake (so to speak) during sleep; while in the same way the hallucinations are so wonderful and varied in the waking hours that the patient can be said to "dream while he is awake."

THE ORIGIN OF HALLUCINATIONS.—In many hallucinations we certainly have a stimulus in the eyes or in the visual tracts. According to ZIEHEN, *mouches volantes* will change in delirium tremens into swarms of mice and flies. LIEPMANN's[2] view that these delusions of the senses which occur in delirium tremens can be excited by pressure on the globe, was corrected by BONHOEFFER,[3] who held that a compression of the globe had little effect in producing hallucinations, for such could be inhibited by attracting the attention. KRAEPELIN recalls the observations of NAGELI, the

[1] ZIEHEN: "Leitfaden der physiol. Psychologie."

[2] *Arch. f. Psych.*, xxvii.

[3] *Habilitationsschrift*, Breslau, 1897.

botanist, on himself; after an erosion of the cornea he saw numbers of varying images with a puzzling similarity, which only disappeared when the inflammatory symptoms subsided. UHTHOFF,[1] too, observed the occurrence of hallucinations in disease of the eyes. On one occasion a branch with leaves appeared inside a scotoma (atrophic choroidal patch). The patient learnt to distinguish this image from leaves which really were seen, by a difference in distance of the plane on which it was projected. In another case UHTHOFF observed that false perceptions arose from entoptic sensations; the case was one of sympathetic ophthalmia with vitreous opacity, giving rise to clouds and spots. From these flying birds developed, and, finally, the patient thought that he saw angels and men. In unilateral hallucinations (which must not be confused with the hemianopic form, *see* Chapter XI) the origin of the phenomenon is invariably in a peripheral change. In one of UHTHOFF's patients there was a one-sided scotoma as the result of a patch of choroiditis, and the patient thought that he could see a policeman with this eye. HOPPE, by extensive investigations, attempted to trace the origin of hallucinations to peripheral stimuli of entoptical nature. It would appear from KANDINSKY's observations on his own case that we cannot admit this to the extent claimed at the time of his hallucinations. KANDINSKY noticed phosphenes of all kinds due to the hyperæmia of the retina; but these entoptical sensations continued on closing his eyes, which was not the case with regard to his hallucinations. These pathological entoptical appearances followed the movements of the eyes; whereas the hallucinations disappeared when the eyes were moved sideways, so that in the new direction, either nothing at all or a quite new image would be seen.

FORMS OF HALLUCINATION.—Although in other forms of hallucination the images are said to move with the eyes, a peripheral stimulus of one of the visual tracts or centre must be presumed. ZIEHEN's statement, that squinters (? paralytic) see their visions double, can be used in this sense. KRAEPELIN[2] combats the standpoint that a stimulation of the primary optic ganglion occurs in those cases of hallucination (perception hallucination) which are characterized by great sensory vividness but which appear to surprise the patient. Those more obscure hallucinations (psychic or apperception hallucinations) associated with the imaginative life of the patient, and therefore less startling, according to ZIEHEN originate in the actual perceptions which form the contents of consciousness, wrongly setting up collateral stimulation of the sensory cells in the cerebrum; while the same writer explains the first form, which we have just considered, as a stimulation of the sensory cells through latent psychic perceptions.

Along with the last named two forms of hallucinations, I would agree with KAHLBAUM in placing the following "stabile" hallucinations. Slight stimuli, from any source will induce in the over-excited

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[1] *Monatssch. f. Psych. u. Neurol.*, v.
[2] *Vierteljahrsschrift f. wiss. Philosophie*, 1881.

sensory centre visual sensations which will depend on the particular condition of the centre, also on the state of the individual and their reminiscences. The same appearance will always occur in the same way under the same circumstances.

The "erethism" hallucinations (abnormal excitement) form another group. These occur when the person is thrown into a specially violent excitement. The "reflex hallucinations" which result from the action of some other sense impression, according to KRAEPELIN, are not analogous to the ordinary reflexes, for they must indicate a passage through the cerebral cortex at least.

EXAMPLES OF HALLUCINATIONS, E. T. A. HOFFMANN.—Passing on to individual examples in the *belles lettres*, I call to mind an instance in E. T. A. HOFFMANN'S fantastic novel "Kreisleriana," which contains a reflex hallucination in the form of an auditory sensation, and in that part which also relates to visual sensation, a hypnagogic phenomenon. "Not so much in dreams themselves as in that stage of stupor which precedes sleep, and especially when I have heard much music, do I find a harmony of colour, music and odour. It appears to me as though they all were caused in the like mysterious way by the light beams, and then driven to unite in the most wonderful concert. The odour of a dark red carnation has a marvellous magical effect on me; involuntary I sink into a dreamy condition and hear as though from the distance the notes of the basset horn swelling and again sinking."

GOETHE'S HALLUCINATIONS.—Amongst the many celebrated intellectuals who have been subject to hallucinations, the best known along with LUTHER, is GOETHE. One hallucination (the rider in a light grey cloak) is considered as an illusion by ZIEHEN. The incident is in "Warheit und Dichtung," iii, 2, and runs: "I was riding along the footpath to Drusenheim, when the most remarkable vision befell me. With the eye not of the body but of the soul, I saw myself riding towards me on the same road, and clad in a cloak which I had never worn, of light grey and gold. As soon as I roused myself from this dream the image vanished. The remarkable thing is that eight years later, I found myself on the same road on another visit to Frederic; by mere chance, and not of my own choice, I was wearing the same cloak which I had formerly seen in my dream." Another phenomenon certainly appears to be an hallucination, and was the origin of GOETHE'S study of the morphology of plants. JOH. MÜLLER referred to this account which GOETHE himself gave; he perceived a plant in his skull; it developed and took on many diverse forms in succession.

GANGHOFER'S ACCOUNT OF HIS HALLUCINATIONS.—I conclude this chapter with the account which GANGHOFER gives of himself in "The Life of an Optimist, Book of Childhood": "During the week before Christmas, the Infant Christ appeared to me every evening in the twilight, a beautiful smiling child, lovelier than all the children of the earth, clad in a white robe reaching to his naked feet, with a bluish halo round his golden locks.

"When I moved in my bed and boldly gazed, the vision vanished. Lying still, and with motionless eyes glancing into the darkness of my chamber, it returned and remained till I must breathe. In the stillness and darkness of the night not only could I see the Infant Christ, but also other things which I desired and wished. I need only think of the chosen object, hold my breath and look into the darkness, and it appeared to me; I saw a violet hazy sun, which changed into coloured rings revolving round each other, and inside the circulating rings the object desired would appear; for a few seconds it would float about as though in the air; then a change would begin, the vision being obscured by the coloured rings and finally disappearing.

"Quarter of an hour later I could again see a vision, but never the same one twice in the same night. This wonderful gift remained to me till my 12th year and then was lost, to return again in my 18th year, when my heart first felt the deep passion of love; it disappeared with this—again to return when, in the riper years of life, in spite of a sound physique, severe mental work shattered my nerves and sleep failed me. This colour- and figure-seeing in the darkness for years has been an entertaining sport for my sleepless nights.

"The Infant Christ, whom I always saw before my school age, changed, as I grew up, into the Good Shepherd with a lamb's skin on his naked shoulders, with a white crook, accompanied by John, who resembled him as a twin brother.

"Then followed a time in which I always saw the boy Jesus, as he astounded the scribes in the temple; this boy then changed to a slight youth who meditated in the wilderness, or wandered, clad in blue, through the fields and stroked the ripe ears of corn with a gentle hand; I also saw the transfigured Saviour as he appeared to the doubting Thomas; never did I see the Son of Mary in his agony.

"Pictures and images of the Crucified in His agony were things which from childhood I did not like and could only look on with revulsion."

THE IMPORTANCE OF HALLUCINATIONS IN ART. — Just as in *audition colorée*, hallucinations play an important part in the realm of art; GOETHE records that "the metamorphosis of plants" owes its origin to a hallucination. The painter SPINELLO ARETINI is said to have painted his Madonna from hallucinations. As a general rule the artistic conception goes on quite unconsciously, and the image created lives in the imagination of the artist; it is seldom given to him in a manner perceptible to his senses.

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John Bale, Sons & Danielsson, Ltd., Printers, 83-91, Great Titchfield Street, London, W.