found, combined with angularity of drapery, and some awkwardness of attitude, in a full length portrait couple at the National Gallery (1434), in which a rare insight into the detail of animal nature is revealed in a study of a terrier dog. A Madonna with Saints, at Dresden, equally soft and minute, charms us by the mastery with which an architectural background is put in. The bold and energetic striving of earlier days, the strong bright tone, are not equalled by the soft blending and tender tints of the later ones. Sometimes a crude ruddiness in flesh strikes us as a growing defect, an instance of which is the picture in the museum of Bruges, in which Canon Van der Paelen is represented kneeling before the Virgin under the protection of St George (1434). From first to last Van Eyck retains his ability in portrait. Fine specimens are the two male likenesses in the gallery of Vienna (1436), and a female, the master's wife, in the gallery of Bruges (1439). His death in 1440–41 at Bruges is authentically recorded. He was buried in St Donat. Like many great artists he formed but few pupils. Hubert's disciple, Jodocus of Ghent, hardly does honour to his master's teaching, and only acquires importance after he has thrown off some of the peculiarities of Flemish teaching. Petrus Cristus, who was taught by John, remains immeasurably behind him in every thing that relates to art. But if the personal influence of the Van Eycks was small, that of their works was immense, and it is not too much to say that their example, taken in conjunction with that of Van der Weyden, determined the current and practice of painting throughout the whole of Europe north of the Alps for nearly a century. (J. A. C.)

EYE

THE sense of vision is excited by the influence of light on the retina, the special terminal organ connected with the optic nerve. By excitation of the retina, a change is induced in the optic nerve fibres, and is conveyed by these to the brain, the result being a luminous perception, or what we call a sensation of light or colour. If light were to act uniformly over the retina, there would be no image of the source of the light formed on that structure, and consequently there would be only a general consciousness of light, without reference to any particular object. One of the first conditions, therefore, of vision for useful purposes is the formation of an image on the retina. To effect this, just as in a photographic camera, refractive structures must be placed in front of the retina which will so bend luminous rays as to bring them to a focus on the retina, and thus produce an image. Throughout the animal kingdom, various arrangements are found for this purpose; but they may be all referred to three types, namely—(1) eye-specks or eye-dots, met with in Medusæ, Annelidæ, &c.; (2) the compound eye, as found in insects and crustaceans; and (3) the simple eye, common to all vertebrates. The *eye-specks* may be regarded simply as expansions of optic nerve filaments, covered by a transparent membrane, but having no refractive media, so that the creature would have the consciousness of light only, or a simple luminous impression, by which it might distinguish light from darkness. The *compound eye* (an account of which, as met with in the common lobster, will be found under CRUSTACEA, vol. vi. p. 637) consists essentially of a series of transparent cone-like bodies, arranged in a radiate manner against the inner surface of the cornea, with which their bases are united, while their apices are connected with the ends of the optic filaments. As each cone is separated from its neighbours, it admits only a ray of light parallel with its axis, and its apex represents only a portion of the image, which must be made up, like a mosaic-work, of as many parts as there are cones in the eye. When the cones are of considerable length, it is evident, from their form and direction, their apices being directed inwards, that the oblique rays emanating from a luminous surface will be cut off, and that only those rays proceeding along the axis of the cone will produce an effect. Thus distinctness or sharpness of definition will be secured. The size of the visual field will depend on the form of the eye, the outermost cones marking its limits. Consequently the size of the visual field will depend on the size of the segment of the sphere forming its surface. The eyes of many insects have a field of about half a sphere, so that the creature will see objects before and behind it as well as those at the side. On the other hand, in many the eyes have scarcely any convexity, so that they must have a narrow field of vision.

A description of the simple eye will be found in the article ANATOMY, vol. i. p. 885 *sq.* Optically, it consists of a series of refractive media placed in front of the retina by which rays emanating from an external object are brought to a focus on that structure. In this article, we shall consider (1) the physical causes of vision; (2) the optical arrangements of the eye; (3) the specific influence of light on the retina; (4) sensations of colour; (5) the movements of the eyes in vision; and (6) the psychical relations of luminous impressions.

1. PHYSICAL CAUSES OF VISION.

A luminous sensation may be excited by various modes of irritation of the retina or of the optic nerve. Pressure, cutting, or electrical shocks may act as stimuli, but the normal excitation is the influence of light on the retina. From a physical point of view, light is a mode of movement occurring in a medium, termed the ether, which pervades all space; but the physiologist studies the operation of these movements on the sentient organism as resulting in consciousness of the particular kind which we term a luminous impression. Outside of the body, such movements have been studied with great accuracy; but the physiological effects depend upon such complex conditions as to make it impossible to state them in the same precise way. Thus, when we look at the spectrum, we are conscious of the sensations of red and violet, referable to its two extremities: the physicist states that red is produced by 392 billions of impulses on the retina per second, and that violet corresponds to 757 billions per second; but he has arrived at this information by inductive reasoning from many facts which have not at present any physiological explanation. We cannot at present trace any connexion, as cause and effect, between 392 billions of impulses on the retina per second and a sensation of red. Below the red and above the violet ends of the spectrum there are vibrations which do not excite luminous sensations. In the first case, below the red, the effect as a sensation is heat; and above the violet the result is that of chemical activity. Thus the method of dispersion of light, as is followed in passing a ray through a prism, enables us to recognize these general facts:—(1) rays below the red excite thermal impressions; (2) from the lower red up to the middle of the violet, the thermal rays become gradually weaker until they have no effect; (3) from the lower red to the extreme violet, they cause luminous impressions, which reach their greatest intensity in the yellow; and (4) from about the end of the yellow to far beyond the extreme violet, the rays have gradually a less and less luminous effect, but they have the power of exciting such chemical changes as are produced in photography. In general terms, therefore, the lower end of the spectrum may be called thermal, the middle luminous, and the upper actinic or chemical; but the three merge into and overlap one another. It may be observed that the number of vibrations in the extreme violet is not double that of the low red, so that the sensibility of the eye to vibrations of light does not range through an octave. The ultra-violet rays may act on the retina in certain conditions, as when they are reflected by a solution of sulphate of quinine, constituting the phenomenon of fluorescence.

2. OPTICAL ARRANGEMENTS OF THE EYE.

(1.) *General.*—When light traverses any homogeneous transparent medium, such as the air, it passes on in a straight course with a certain velocity; but if it meet with any other transparent body of a different density, part of it is reflected or returned to the first medium, whilst the remainder is propagated through the second medium in a different direction and with a different velocity. Thus we may account for the phenomena of reflection and of refraction, for which see the article LIGHT. Let *a b*, in fig. 1, be a plane surface of some transparent substance, say a sheet of glass; a ray, *c d*, perpendicular to the surface, will pass through without refraction; but an oblique ray, *e f*, will be sent in the direction *e h*. If the ray *e h* had passed from a dense into a rarer medium, then the direction would have been *e g*. It might also be shown that the *sine* of the angle of incidence always bears a certain ratio to the *sine* of the angle of refraction; this ratio is termed the *index of refraction*. Thus, if a ray pass from air into water, the sine of the angle of incidence will have to the sine of the angle of the refraction the ratio of $4 : 3$, or $\frac{4}{3}$.

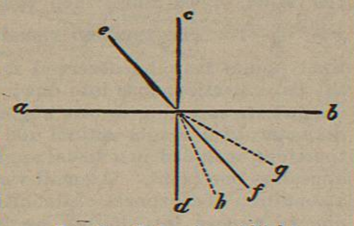

FIG. 1.—Refraction of Light.

Before a ray of light can reach the retina, it must pass through a number of transparent and refractive surfaces. The eye is a nearly spherical organ, formed of transparent parts situated behind each other, and surrounded by various membranous structures, the anterior part of which is also transparent. The transparent parts are—(1) the *cornea*; (2) the *aqueous humour*, found in the anterior chamber of the eye; (3) the *crystalline lens*, formed by a transparent convex body, the anterior surface of which is less convex than the posterior; and (4) the *vitreous humour*, filling the posterior chamber of the eye. The ray must therefore traverse the cornea, aqueous humour, lens, and vitreous humour. As the two surfaces of the cornea are parallel, the rays practically suffer no deviation in passing through that structure, but they are bent or refracted during their transmission through the other media.

From the optical point of view, the eye may be regarded as a *dioptric system* consisting of various refractive media. In such a system, as shown by Gauss, there are six cardinal points, which have a certain relation to each other. These are—

Two focal points: every ray passing through the *first* focal point becomes, after its refraction, parallel to the axis, and every ray which before refraction is parallel to the axis passes after its refraction to the *second* focal point; (2) *Two principal points:* every ray which passes through the first point before refraction passes after refraction through the second, and every ray which passes through any point of a plane elevated on a perpendicular axis from the first principal point (the *first principal plane*) passes through the corresponding point of an analogous plane raised upon the axis at the second principal point (the *second principal plane*); and (3) *Two nodal points*, which correspond to the optical centres of the two principal planes just alluded to. The distance of the first principal point from the first focal point is called the *anterior focal length*, and the term *posterior focal length* is applied to the distance of the posterior focal point from the second principal point. Listing has given the following measurements in millimetres from the centre of the cornea for the cardinal points in an ideal eye:—

Anterior focal point......	12·8326.	First nodal point..........	7·2420.
Posterior focal point......	22·6470.	Second nodal point.........	7·6398.
First principal point......	2·1746.	Anterior focal length.....	15·0072.
Second principal point...	2·5724.	Posterior focal length....	20·0746.

A view of such an ideal eye is shown in fig. 2.

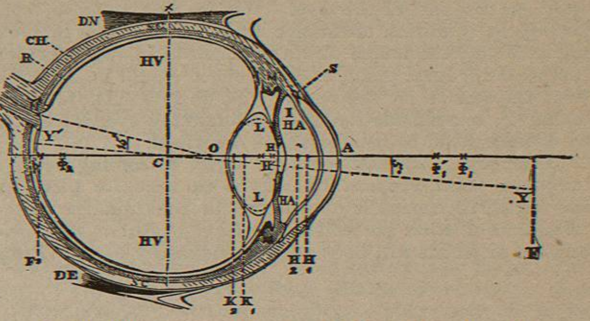

FIG. 2.—Transverse section of an Ideal or Schematique Eye.

A, Summit of cornea; SC, Sclerotic; S, Schlemm's canal; CH, Choroid; I, Iris; M, Ciliary muscle; R, Retina; N, Optic nerve; HA, Aqueous humour; L, Crystalline lens, the anterior of the double lines on its face showing its form during accommodation; HV, Vitreous humour; DN, Internal rectus muscle; DE, External rectus; YY', Principal optical axis; ΦΦ, Visual axis, making an angle of 5° with the optical axis; C, Centre of the ocular globe. *The cardinal points of Listing*:—H_1H_2, principal points; K_1K_2, nodal points; F_1F_2, principal focal points. *The dioptric constants according to Giraud-Teulon*:—H, Principal points united; $\phi_1\phi_2$, principal foci during the repose of accommodation; $\phi'_1\phi'_2$, principal foci during the maximum of accommodation; O, fused nodal points.

The remaining measurements of such an eye are as follows:—

Radii of curvature.

Of *anterior* face of cornea = 8 millimetres.
Of *anterior* face of lens = 10 ,,
Of *posterior* face of lens = 6 ,,

Indices of Refraction.

Aqueous humour .... $\frac{103}{77} = 1{\cdot}3379$
Crystalline lens .... $\frac{16}{11} = 1{\cdot}4545$
Vitreous humour .... $\frac{103}{77} = 1{\cdot}3379$

The optical constants of the human eye may be still further simplified by assuming that the two principal points and the two nodal points respectively are identical. Thus we may construct a *reduced eye*, in which the principal point is 2·3448 mm. behind the cornea, and the nodal point is 7·4969 mm., having an anterior focal length of 15 mm. and a posterior focal length of 20 mm. The refracting surface, or lens, has a radius of 5 mm., and is 3 mm. behind the cornea; and the index of refraction is that of the aqueous humour, or $\frac{103}{77}$.

(2.) *The Formation of an Image on the Retina.*—This may be well illustrated with the aid of an ordinary photographic camera. If properly focussed, an inverted image will be seen on the glass plate at the back of the camera. It may also be observed by bringing the eye-ball of a rabbit near a candle flame. The action of a lens in forming an inverted image is illustrated by fig. 3, where the pencil of rays proceeding from *a* is brought to a focus at *a'*, and those from *b* at *b'*, consequently the image of *a b* is inverted as at *b'a'*. The three characteristic features of the retinal image

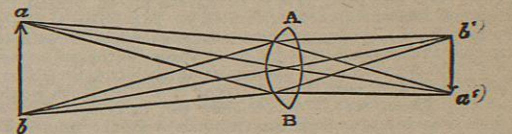

FIG. 3.—Inversion by action of a Lens.

are—(1) it is reversed; (2) it is sharp and well defined if it be accurately focussed on the retina; and (3) its size depends on the visual angle. If we look at a distant object, say a star, the rays reaching the eye are parallel, and in passing through the refractive media, they are focussed at the posterior focal point,—that is, on the retina. A line from the luminous point on the retina passing through the nodal point is called the *line of direction.* If the luminous object be not nearer than, say, 60 yards, the image is still brought to a focus on the retina without any effort on the part of the eye. Within this distance, supposing the condition of the eye to be the same as in looking at a star, the image would be formed somewhat behind the posterior focal point, and the effect would be an indistinct impression on the retina. To obviate this, for near distances, accommodation, so as to adapt the eye, is effected by a mechanism to be afterwards described.

When rays, reflected from an object or coming from a luminous point, are not brought to an accurate focus on the retina, the image is not distinct in consequence of the formation of what are called *circles of diffusion*, the production of which will be rendered evident by fig. 4. From the point A luminous rays enter the eye in the form of a cone, the kind of which will depend on the pupil. Thus it may be circular, or oval, or even triangular. If the pencil is focussed in front of the retina, as at *d*, or behind it as at *f*, or, in other words, if the retina, in place of being at F, be in the positions G or H, there will be a luminous circle or a luminous triangular space, and many elements of the retina will be affected. The size of these diffusion circles depends on the distance from the retina of the point where the rays are focussed: the greater the distance, the more extended will be the diffusion circle. Its size will also be affected by the greater or less diameter of the pupil. Circles of diffusion may be readily studied by the following experiment, usually called the experiment of Scheiner:—

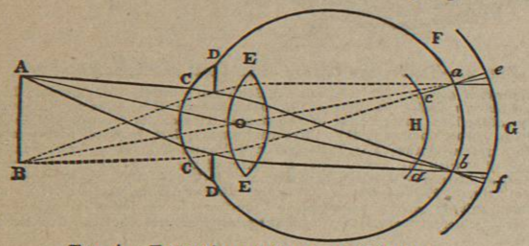

FIG. 4.—Formation of Circles of Diffusion.

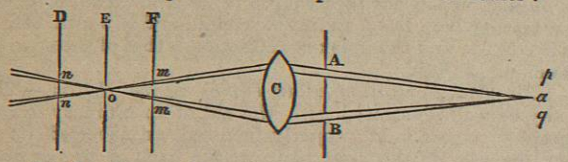

FIG. 5.—Diagram illustrating the experiment of Scheiner.

Let C be a lens, and D E F be screens placed behind it; hold in front of the lens a card perforated by two holes A and B, and allow rays from a luminous point *a* to pass through these holes; the point *o* on the screen E will be exact focus of the rays emanating from *a*; if *a* were removed farther from the lens, the focus would be on F, and if it were brought near to C, the focus would then be on D. The screens F and D show two images of the point *a*. If, then, we close the upper opening in A B, the *upper* image *m* on F, and the *lower* image *n* on D, disappear. Suppose now that the retina be substituted for the screens D and F, the contrary will take place, in consequence of the reversal of the retinal image. If the eye be placed at *o*, only one image will be seen; but if it be placed either in the plane of F or D, then two images will be seen, as at *m m*, or *n n*; consequently in either of these planes there will be circles of diffusion and indistinctness, and only in the plane E will there be sharp definition of the image.

To understand the formation of an image on the retina suppose a line drawn from each of its two extremities to the nodal point and continued onwards to the retina, as in fig. 6, where the visual angle is x. It is evident that its size will depend on the size of the object and the distance of the object from the eye. Thus, also, objects of different sizes, *c*, *d*, *e*, in fig. 6, may be included in the same visual angle, as they are at different distances from the eye. The size of the retinal image may obviously be calculated if we know the size of the object, its distance from the nodal point *o*, and the distance of the nodal point from the posterior focus. Let A be the size of the object, B its distance from the nodal point, and C the distance of *o* from the retina, or 15 mm.; then the size of the retinal image $x=\frac{A+15}{B}$. The smallest visual angle in which two distinct points may be observed is 60 seconds; below this, the two sensations fuse into one; and the size of the retinal image corresponding to this angle is ·004 mm., nearly the diameter of a single retinal rod or cone. Two objects, therefore, included in a visual angle of less than 60 seconds, appear as one point. A small visual angle is in most eyes a condition of sharpness of definition. With a large angle, objects appear less sharply marked. Acuteness is determined by a few retinal elements, or even only one, being affected. A very minute image, if thrown on a single retinal element, is apparently sufficient to excite it. Thus it is possible to see a brilliant point in an angle even so small as $\frac{1}{4}$ of a second, and a sharp eye can see a body the $\frac{1}{50}$th of a line in diameter, that is, about the $\frac{1}{600}$th part of an inch.

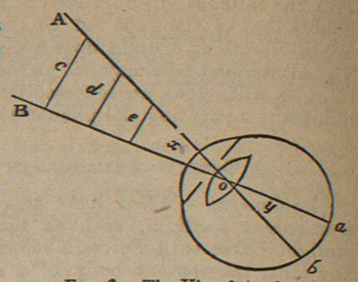

FIG. 6.—The Visual Angle.

(3.) *The Optical Defects of the Eye.*—As an optical instrument, the eye is defective; but from habit, and want of attention, its defects are not appreciated, and consequently they have little or no influence on our sensations. These defects are chiefly of two kinds—(1) those due to the curvature of the refractive surfaces, and (2) those due to the dispersion of light by the refractive media.

(*a*) *Aberration of Sphericity.*—Suppose, as in fig. 7, M A K to be a refractive surface on which parallel rays from L to S impinge, it will be seen that those rays passing near the circumference are brought to a focus at F^1, and those passing near the centre at F^2,—intermediate rays being focussed at N. Thus on the portion of the axis between F^1 and F^2 there will be a series of focal points, and the effect will be a blurred and bent image. In the eye this defect is to a large extent corrected by the following arrangements:—(1) the iris cuts off the outer and more strongly refracted rays; (2) the curvature of the cornea is more ellipsoidal than spherical, and consequently those farthest from the axis are least deviated; (3) the anterior and posterior curvatures of the lens are such that the one corrects, to a certain extent, the action of the other; and (4) the structure of the lens is such that its power of refraction diminishes from the centre to the circumference, and consequently the rays farthest from the axis are less refracted.

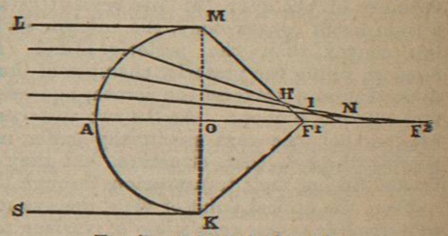

FIG. 7.—Spherical Aberration.

(*b*) *Astigmatism.*—Another defect of the eye is due to different meridians having different degrees of curvature. This defect is known as *astigmatism.* It may be thus detected. Draw on a sheet of white paper a vertical and a horizontal line with ink, crossing at a right angle; at the point of distinct vision, it will be found impossible to see the lines with equal distinctness at the same time: to see the horizontal line distinctly the paper must be brought near the eye, and removed from it to see the vertical. In the cornea the vertical meridian has a shorter radius of curvature, and is consequently more refractive than the horizontal. The meridians of the lens may also vary; but, as a rule, the asymmetry of the cornea is greater than that of the lens. The optical explanation of the defect will be understood with the aid of fig. 8.

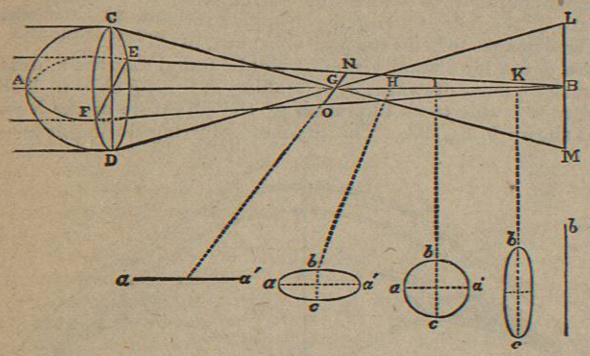

FIG. 8.—Diagram illustrating Astigmatism.

Thus, suppose the vertical meridian C A D to be more strongly curved than the horizontal F A E, the rays which fall on C A D will be brought to a focus G, and those falling on F A E at B. If we divide the pencil of rays at successive points, G, H, I, K, B, by a section perpendicular to A B, the various forms it would present at these points are seen in the figures underneath, so that if the eye were placed at G, it would see a horizontal line $a\,a'$; if at H, an ellipse with the long axis $a\,a'$ parallel to A B; if at I, a circle; if at K, an ellipse, with the long axis, $b\,c$, at right angles to A B; and if at B, a vertical line $b\,c$. The degree of astigmatism is ascertained by measuring the difference of refraction in the two chief meridians; and the defect is corrected by the use of cylindrical glasses, the curvature of which, added to that of the minimum meridian, makes its focal length equal to that of the maximum meridian.

(*c*) *Aberration of Refrangibility.*—When a ray of white light traverses on a lens, the different rays composing it, being unequally refrangible, are dispersed: the violet rays (see fig. 9), the most refrangible, are brought to a focus at *e*, and the red rays, less refrangible, at *d*. If a screen were placed at *e*, a series of concentric coloured circles would be formed, the central being of a violet, and the circumference of a red colour. The reverse effect would be produced if the screen were placed at *d*. Imagine the retina in place of the screen in the two positions, the sensational effects would be those just mentioned. Under ordinary circumstances, the error of refrangibility due to the optical construction of the eye is not observed, as for vision at near distances the interval between the focal point of the red and violet rays is very small. If, however, we look at a candle flame through a bit of cobalt blue glass, which transmits only the red and blue rays, the flame may appear violet surrounded by blue, or blue surrounded by violet, according as we have accommodated the eye for different distances. Red surfaces always appear nearer than violet surfaces situated in the same plane, because the eye has to be accommodated more for the red than for the violet, and consequently we imagine them to be nearer. Again, if we contemplate red letters or designs on a violet ground the eye soon becomes fatigued, and the designs may appear to move.

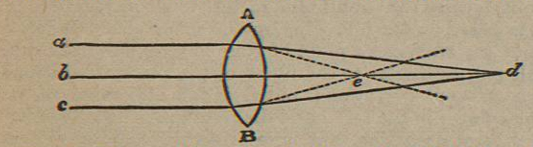

FIG. 9.—Diagram illustrating the Dispersion of Light by a Lens.

(*d*) *Defects due to Opacities, &c., in the Transparent Media.*—When small opaque particles exist in the transparent media, they may cast their shadow on the retina so as to give rise to images which are projected outwards by the mind into space, and thus appear to exist outside of the body. Such phenomena are termed entoptic. They may be of two kinds:—(1) *extra-retinal*, that is, due to opaque or semi-transparent bodies in any of the refractive structures anterior to the retina, and presenting the appearance of drops, striæ, lines, twisted bodies, forms of grotesque shape, or minute black dots dancing before the eye; and (2) *intra-retinal*, due to opacities, &c., in the layers of the retina, in front of Jacob's membrane. The intra-retinal may be produced in a normal eye in various ways. (1) Throw a strong beam of light on the edge of the sclerotic, and a curious branched figure will be seen, which is an image of the retinal vessels. The construction of these images, usually called *Purkinje's figures*, will be understood from fig. 10. Thus, in the figure to the left, the rays passing through the sclerotic at b'', in the direction $b''c$, will throw a shadow of a vessel at *c* on the retina at b', and this will appear as a dark line at B. If the light move from b'' to a'', the retinal shadow will move from b' to a', and the line in the field of vision will pass from B to A. It may be shown that the distance $c\,b'$ corresponds to the distance of the retinal vessels from the layer of rods and cones (see ANATOMY, vol. i. p. 888). If the light enter the cornea, as in the figure to the right, and if the light be moved, the image will be displaced in the same direction as the light, if the movement does not extend beyond the middle of the cornea, but in the opposite direction to the light when the latter is moved up and down. Thus, if *a* be moved to a', *d* will be moved to d', the shadow on the retina from *c* to c', and the image *b* to b'. If, on the other hand, *a* be

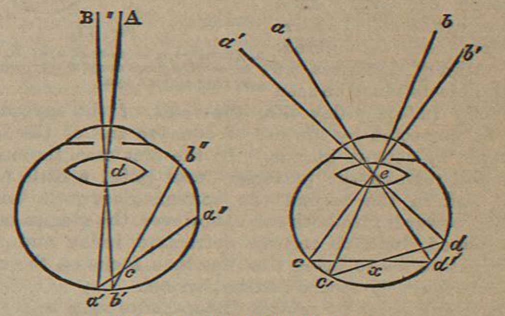

FIG. 10.—Purkinje's Figures.

In the eye to the right the illumination is through the sclerotic, and in the one to the left through the cornea.

moved above the plane of the paper, *d* will move below, consequently *c* will move above, and *b′* will appear to sink. (2) The retinal vessels may also be seen by looking at a strong light through a minute aperture, in front of which a rapid to and fro movement is made. Such experiments prove that the sensitive part of the retina is its deepest and most external layer (Jacob's membrane).

(4.) *Accommodation, or the Mechanism of Adjustment for Different Distances.*—When a camera is placed in front of an object, it is necessary to focus accurately in order to obtain a clear and distinct image on the sensitive plate. This may be done by moving either the lens or the sensitive plate backwards or forwards so as to have the posterior focal point of the lens corresponding with the sensitive plate. For similar reasons, a mechanism of adjustment, or accommodation for different distances, is necessary in the human eye. In the normal eye, any number of parallel rays, coming from a great distance, are focussed on the retina. Such an eye is termed *emmetropic* (fig. 11, A). Another form of eye (B) may be such that parallel rays are brought to a focus *in front of* the retina. This form of eye is *myopic* or short-sighted, inasmuch as, for distinct vision, the object must be brought near the eye, so as to catch the divergent rays, which are then focussed on the retina. A third form is seen in C, where the focal point, for ordinary distances, is *behind* the retina, and consequently the object must be held far off, so as to allow only the less divergent or parallel rays to reach the eye. This kind of eye is called *hypermetropic*, or far-sighted. For ordinary distances, at which objects must be seen distinctly in every-day life, the fault of the myopic eye may be corrected by the use of concave and of the hypermetropic by convex glasses. In the first case, the concave glass will remove the posterior focal point a little farther back, and in the second the convex glass will bring it farther forwards; in both cases, however, the glasses may be so adjusted, both as regards refractive index and radius of curvature, as to bring the rays to a focus on the retina, and consequently secure distinct vision.

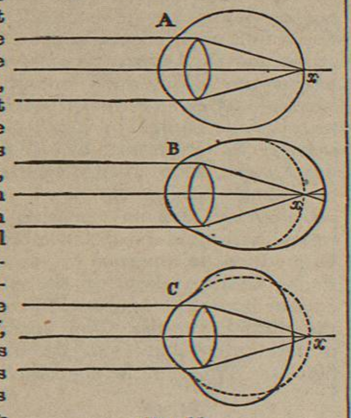

Fig. 11.

A, Emmetropic or normal eye; B, Myopic or short-sighted eye; C, Hypermetropic or long-sighted eye.

From any point 65 metres distant, rays may be regarded as almost parallel, and the point will be seen without any effort of accommodation. This point, either at this distance or in infinity, is called the *punctum remotum*, or the most distant point seen without accommodation. In the myopic eye it is much nearer, and for the hypermetropic there is really no such point, and accommodation is always necessary, If an object were brought too close to the eye for the refractive media to focus it on the retina, circles of diffusion would be formed, with the result of causing indistinctness of vision, unless the eye possessed some power of adapting itself to different distances. That the eye has some such power of accommodation is proved by the fact that, if we attempt to look through the meshes of a net at a distant object, we cannot see both the meshes and the object with equal distinctness at the same time. Again, if we look continuously at very near objects, the eye speedily becomes fatigued. Beyond a distance of 65 metres, no accommodation is necessary; but within it, the condition of the eye must be adapted to the diminished distance until we reach a point near the eye which may be regarded as the limit of visibility for near objects. This point, called the *punctum proximum*, is usually 12 centimetres (or about 4 inches) from the eye. The range of accommodation is thus from the *punctum remotum* to the *punctum proximum*.

The mechanism of accommodation has been much disputed, but there can be no doubt it is chiefly effected by a change in the curvature of the anterior surface of the crystalline lens. If we hold a lighted candle in front and a little to the side of an eye to be examined, three reflections may be seen in the eye, as represented in fig. 12. The first, *a*, is erect, large, and bright, from the anterior surface of the cornea; the second, *b*, also erect, but dim, from the anterior surface of the crystalline lens; and the third, *c*, inverted, and very dim, from the posterior surface of the lens, or perhaps the concave surface of the vitreous humour to which the convex surface of the lens is adapted. Suppose the three images to be in the position shown in the figure for distant vision, it will be found that the middle image *b* moves towards *a*, on looking at a *near* object. The change is due to an alteration of the curvature of the lens, as shown in fig. 13. The changes occurring during accommodation are:—(1) the curvature of the anterior surface of the crystalline lens increases, and may pass from 10 to 6 mm.; (2) the pupil contracts; and (3) the intraocular pressure increases in the posterior part of the eye. An explanation of the increased curvature of the anterior surface of the lens during accommodation has been thus given by Helmholtz. In the normal condition, that is, for the emmetropic eye, the crystalline lens is flattened anteriorly by the pressure of the anterior layer of the capsule; during accommodation, the radiating fibres of the ciliary muscle pull the ciliary processes forward, thus relieving the tension of the anterior layer of the capsule, and the lens at once bulges forward by its elasticity. The exact mechanism of the ciliary muscle is still not clearly understood.

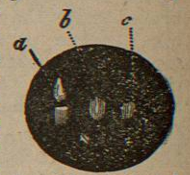

Fig. 12.—Reflected images in the Eye.

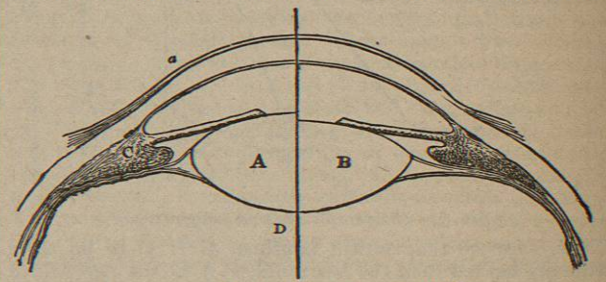

Fig. 13.—Mechanism of Accommodation.

A, The lens during accommodation, showing its anterior surface advanced; B. The lens as for distant vision; C, Position of the ciliary muscle.

Helmholtz has succeeded in measuring with great accuracy the sizes of these reflected images by means of an instrument termed an ophthalmometer, the construction of which is based on the following optical principles. When a luminous ray traverses a plate of glass having parallel sides, if it fall perpendicular to the plane of the plate, it will pass through without deviation; but if it fall obliquely on the plate (as shown in the left hand diagram in fig. 14) it undergoes a lateral deviation, but in a direction parallel to that of the incident ray, so that to an eye placed behind the glass plate, at the lower A, the luminous point, upper A, would be in the direction of the prolonged emergent ray, and thus there would be an apparent lateral displacement of the point, the amount of which would increase with the obliquity of the incident ray. If, instead of one plate, we take two plates of equal thickness, one placed above the other, two images will be seen, and by turning the one plate with reference to the other, each image may be displaced a little to one side. The instrument consists of a small telescope (fig. 14) T, the axis of which coincides with the plane separating the two glass plates C C and B B. When we look at an object X Y, and turn the plates till we see two objects *xy*, *xy* touching each other, the size of the image X Y will be equal to the distance the one object is displaced to the one side and the other object to the other side. Having thus measured the size of the reflection, it is not difficult, if we know the size of the object reflecting the light and its distance from the eye, to calculate the radius of the curved surface. (See Woinow's *Ophthalmometrie*, St Petersburg, 1871, and an account given in Appendix to M‘Kendrick's *Outlines of Physiology*, 1878.) The general result is that, in accommodation for near objects, the middle reflected image becomes smaller, and the radius of curvature of the anterior surface of the lens becomes shorter.

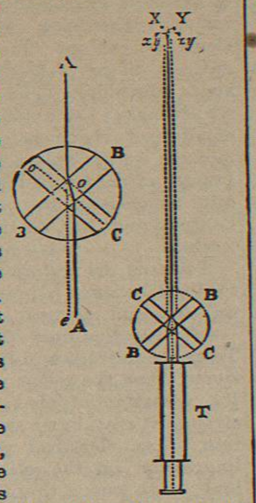

Fig. 14.—Diagrammatic view of the Ophthalmometer of Helmholtz.

(5.) *Absorption and Reflection of Luminous Rays from the Eye.*—When light enters the eye, it is partly absorbed by the black pigment of the choroid and partly reflected. The reflected rays are returned through the pupil, not only following the same direction as the rays entering the eye, but uniting to form an image at the same point in space as the luminous object. The pupil of an eye appears black to an observer, because the eye of the observer does not receive any of those reflected rays. If, however, we strongly illuminate the retina, and hold a lens in front of the eye, so as to bring the reflected rays to a focus nearer the eye, then a virtual and erect, or a real and reversed, image of the retina will be seen. Such is the principle of the ophthalmoscope, invented by Helmholtz in 1851. Eyes deficient in pigment, as in albinos, appear luminous, reflecting light of a red or pink colour; but if we place in front of such an eye a card perforated by a round hole of the diameter of the pupil, the hole will appear quite dark, like the pupil of an ordinary eye. In many animals a portion of the fundus of the eyeball has no pigment, and presents an iridescent appearance. This is called a *tapetum*. It probably renders the eye more sensitive to light of feeble intensity.

(6.) *Functions of the Iris.*—The iris constitutes a diaphragm which regulates the amount of light entering the eyeball. The aperture in the centre, the *pupil*, may be dilated by contraction of a system of radiating fibres of involuntary muscle, or contracted by the action of another system of fibres, forming a sphincter, at the margin of the pupil. The radiating fibres are controlled by the sympathetic, while those of the circular set are excited by the third cranial nerve. The variations in diameter of the pupil are determined by the greater or less intensity of the light acting on the retina. A strong light causes contraction of the pupil; with light of less intensity, the pupil will dilate. In the human being, a strong light acting on one eye will often cause contraction of the pupil, not only in the eye affected, but in the other eye. These facts indicate that the phenomenon is of the nature of a reflex action, in which the fibres of the optic nerve act as sensory conductors to a centre in the encephalon, whence influences emanate which affect the pupil. It has been ascertained that if the fibres of the optic nerve be affected in any way, contraction of the pupil follows. The centre is probably in the anterior pair of the corpora quadrigemina, as destruction of these bodies causes immobility of the pupil. On the other hand, the dilating fibres are derived from the sympathetic; and it has been shown that they come from the lower part of the cervical, and upper part of the dorsal, region of the cord. But the iris seems to be directly susceptible to the action of light. Thus, as was first pointed out by Brown-Séquard, the pupil of the eye of a dead animal will contract if exposed to light for several hours, whereas, if the eye on the opposite side be covered, its pupil will remain widely dilated, as at the moment of death.

The pupil *contracts* under the influence—(1) of an increased intensity of light; (2) of the effort of accommodation for near objects; (3) of a strong convergence of the two eyes; and (4) of such active substances as nicotine, morphia, and physostigmine; and it *dilates* under the influence—(1) of a diminished intensity of light; (2) of vision of distant objects; (3) of a strong excitation of any sensory nerve; (4) of dyspnœa; and (5) of such substances as atropine and hyoscyamine. The chief function of the iris is to so moderate the amount of light entering the eye as to secure sharpness of definition of the retinal image. This it accomplishes by (1) diminishing the amount of light reflected from near objects, by cutting off the more divergent rays and admitting only those approaching a parallel direction, which, in a normal eye, are focussed on the retina; and (2) preventing the error of spherical aberration by cutting off divergent rays which would otherwise impinge near the margins of the lens, and would thus be brought to a focus in front of the retina.

3. SPECIFIC INFLUENCE OF LIGHT ON THE RETINA.

The retina is the terminal organ of vision, and all the parts in front of it are merely optical arrangements for securing that an image will be accurately focussed upon it. The natural stimulus of the retina is light. It is often said that it may be excited by mechanical and electrical stimuli; but such an observation really applies to the stimulation of the fibres of the optic nerve. It is well known that such stimuli applied to the optic nerve behind the eye produce always a luminous impression; but there is no proof that the retina, strictly speaking, is similarly affected. Pressure or electrical currents may act on the eyeball, but in doing so they not only affect the retina, consisting of its various layers and of Jacob's membrane, but also the fibres of the optic nerve. It is probable that the retina, by which is meant all the layers except those on its surface formed by the fibres of the optic nerve, is affected only by its *specific* kind of stimulus, light. This stimulus so affects the terminal apparatus as to set up actions which in turn stimulate the optic fibres. The next question naturally is,—What is the specific action of light on the retina? Professors Holmgren of Upsala individually, and Dewar and M‘Kendrick conjointly, have shown that when light falls on the retina it excites a variation of the natural electrical current obtained from the eye by placing it on the cushions of a sensitive galvanometer. The general effect was that the *impact* of light caused an increase in the natural electrical current,—during the *continuance* of light, the current diminished slowly, and fell in amount even below what it was before the impact,—and that the *withdrawal* of light was followed by a rebound, or second increase, after which the current fell in strength, as if the eye suffered from fatigue.