the following changes during accommodation for near objects :—

1. The pupil diminishes in size. 2. The pupillary edge of the iris moves forwards. 3. The peripheral portion of iris moves backwards. 4. The anterior surface of the lens becomes more convex (arched), and its vertex moves forwards. 5. The posterior surface of the lens also becomes slightly more arched, but does not perceptibly change its position. The lens, therefore, becomes thicker in the centre.*

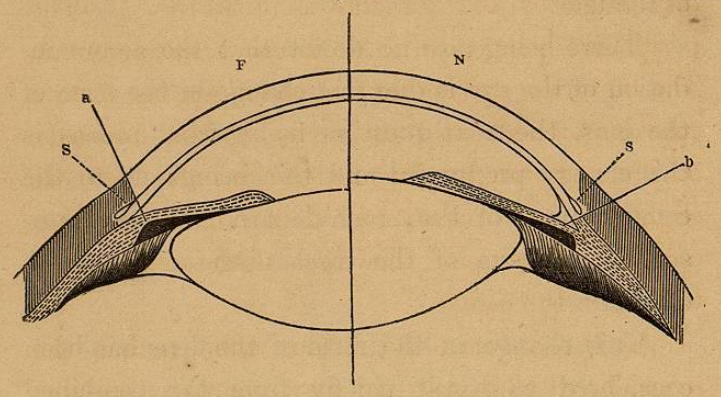
As the volume of the lens must remain the same, he thinks that we may, moreover, assume that the transverse diameter of the lens becomes diminished. He finds, from calculation, that these changes in the lens are quite sufficient for all accommodative purposes.†

* Otto Becker has found that in albinotic eyes the space between the ciliary processes and the edge of the lens becomes increased in size during accommodation for near objects. He thinks it probable that the volume of the ciliary processes varies in the different conditions of the accommodation, and supposes that this is due to the difference in the blood supply to the iris, which he thinks varies with the dilatation and contraction of the pupil.

† It was found, with the ophthalmometer, that the position of the reflection images of a candle, produced by the cornea and the anterior and posterior surfaces of the lens,

Fig. 13 illustrates the changes which the eye undergoes during accommodation. The anterior

Fig. 13.



portion of the eye is divided into two equal parts. The one half, F, shows the position of the parts when the eye is adjusted for distance, the other, N, when it is accommodated for near objects. When the eye is in a state of rest, the iris forms a curve (*a*) in the vicinity of Schlemm's canal (*s*); but when accommodated for near objects, the fibres of the iris undergo contraction, the periphery of the iris

undergoes a change during accommodation for near objects. Whilst the reflex image from the cornea remains unchanged, that from the anterior surface of the lens approaches the corneal image and diminishes in size; the image from the posterior surface of the lens also diminishes very slightly in size, but undergoes no appreciable change of position.

becomes straightened (*b*), and the anterior chamber lengthened, so that its diminution in depth is compensated for by the advance of the anterior surface of the lens.

There being now no doubt that the accommodation of the eye is due to a change in the form of the lens, the next question is, by what means is this change produced? and this brings us to the consideration of the much-debated, but yet unsettled question of the mechanism of accommodation.

This change in the form of the lens has been considered to result chiefly from the combined action of the iris and ciliary muscle, some physiologists giving the pre-eminence to the iris, others to the ciliary muscle. Before entering into this question, it will be well just to glance at the anatomical position of the parts involved, by referring to the accompanying plate (copied from Ecker's "Icones Physiologicæ").

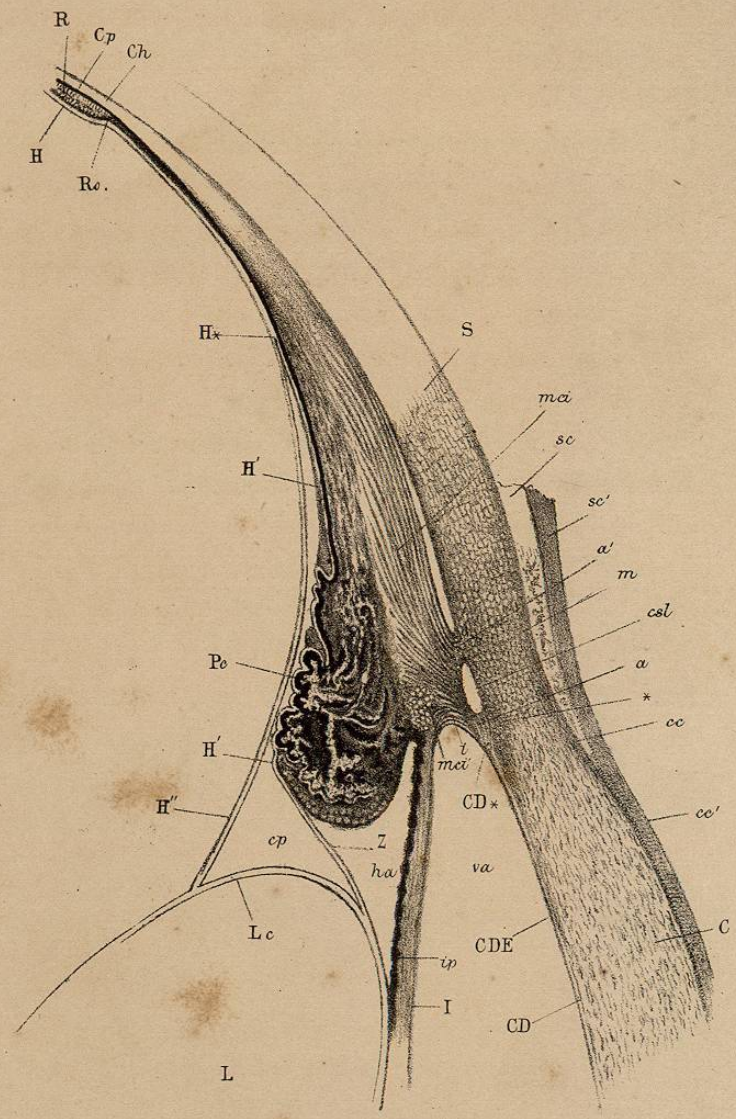
Fig. 14.

Section of the parts of the human eye concerned in accommodation × 15.

C. Cornea.

c c. Its anterior elastic lamina passing over

Fig. 14



from the layer of connective tissue (*s c*) of the sclerotic.

c c′. Epithelium of the anterior surface of the cornea.

C D. Membrane of Descemet; its homogeneous lamella.

C D E. Its epithelium.

S. Sclerotic.

S c. Vascular layer of connective tissue of the sclerotic conjunctiva.

s. c′. Its epithelium.

The tissue of the cornea passes over into that of the sclerotic without any well-defined boundary. The place of the caudated corneal corpuscles is gradually supplied by elastic meshes, and that of the homogeneous corneal plates between them, by layers of fibrous connective tissue. The elastic meshes are particularly close together in the vicinity of Schlemm's canal, running here also, by preference, in a circular direction.

c s l. Canal of Schlemm.

In the vicinity of this canal, (at *C D**) the homogeneous lamina of the membrane of Descemet splits up into a number of fibrous plates, which appear first at the outer side, so that the membrane of Descemet seems to terminate with its edge bevelled off towards the inner side. These

fibres, whose character appears to lie midway between the elastic and the fibrous connective tissue, are thus distributed: (1), the external (a) pass over into the elastic meshes of the sclerotic, and particularly, into the external wall of Schlemm's canal; (2), the middle fibres (m) serve as an origin for the ciliary muscle; (3), the most internal (i), forming the ligamentum pectinatum (pillars of the iris), are connected with the iris.

Ch. Choroid.

C p. Its pigment layer.

P c. Ciliary process (a longitudinal section).

On account of its uneven, nodulated surface, the section of the tissue is at one place edged with pigment, and at another, deeper portions of the surface appear not touched by the section.

m c i. Ciliary muscle; its fibres run in a wavy manner. The greater portion of them lie in the direction of the meridians, and can be easily peeled off. When these have been removed, other fibres are also seen to run in a transverse direction (*m ci*).* It is probable that the one set bend round and pass over into the other, thus forming arcades. This has not, however, yet been ascertained with certainty.†

* Circular fibres of Müller.

† The following is Kölliker's description of the ciliary muscle: "The ligamentum ciliare of anatomists, called also musculus ciliaris or tensor choroideæ, was recognised as being of a muscular nature, almost simultaneously, by Brücke and Bowman; it is a tolerably thick lamina of radiating, smooth, muscular fasciculi, which pass from the most anterior border of the sclerotic to the corpus ciliare, and are lost in the anterior half of that body, at the spot corresponding to the situation of the ciliary processes internally. More accurately described, the ciliary muscle arises at that part of the sclerotic where it is furrowed for the formation of the venous sinus of Schlemm (vide Fig. 4, *c s l*); indeed, it is from a special dense, smooth tract, which, whilst forming the inner wall of the above-mentioned canal, coalesces with the sclerotic, receiving at the same time a part of the fibrous network prolonged from the membrane of Desmours; the last-mentioned fibres coalesce perfectly with the similar elements of the special tract, which are, however, finer, anastomose more densely, and have a circular direction. The termination of the ciliary muscle is at the attached part of the ciliary processes, but not in these structures themselves. The muscular elements are somewhat shorter (0·02‴) and broader (0·003‴ to 0·004‴) than the ordinary fibre cells, and are finely granular and very delicate; they are, indeed, so perishable, that they cannot be easily isolated in the human subject. Very lately, H. Müller has discovered a circular muscular layer, quite anteriorly, beneath the radiating fibres of the ciliary muscle; and this I call the circular muscle of Müller. The latter forms the deepest and most anterior layer of the ciliary muscle close to the insertion of the iris."

I. Iris.

i p. Pigment layer.

In the substance of the iris radiating fasciculi of connective tissue are seen.

R. Retina.

R o. Ora serrata.

H, Hyaloid.
*H**. Place of its division.
H'. Zonula.
Z. Its free portion.
H''. Posterior lamina of the hyaloid.
c. p. Canal of Petit.
L. Lens.
L. c. Capsule of lens.
v. a. Anterior chamber.
h. a. Posterior chamber.

Cramer supposed that the arching forward of the lens is caused by the iris, its dilatator and sphincter being simultaneously contracted, the peripheral portion of the iris at the same time moving backwards. By this means a certain amount of pressure is exerted upon the peripheral portion of the lens which is covered by the iris, in consequence of which pressure, the anterior surface of the lens must become more arched. The simultaneous tension of the radial and circular fibres of the iris have the effect of decreasing the pressure in the anterior chamber, and increasing that in the vitreous. He thinks that the ciliary muscle acts in so far, that it prevents the lens being pushed backwards under the pressure of the iris, and that it defends the retina from deleterious pressure.

Donders agrees on the whole with these opinions, but thinks, also, that the ciliary muscle, by drawing the peripheral edge of the iris backwards against the wall of the canal of Schlemm, forms a fixed point for the action of the dilatator pupillæ. This would form the posterior fixed point, the anterior being formed by the contracted sphincter pupillæ. Donders, moreover, vindicates the importance of the ciliary muscle during accommodation, for he says, "I consider this muscle (ciliary muscle) just as important for the change in the form of the lens as the muscular fibres of the iris. Without it, the iris would not be able to exert a pressure of any importance upon the lens."

Helmholtz, however, shows that, although these theories of Cramer and Donders suffice to explain the arching forward of the anterior surface of the lens, they do not suffice for the explanation of the whole change in the form of the lens which occurs during accommodation for near objects. Heinrich Müller gives the following very clear *résumé* of Helmholtz's views :—"Finally, Helmholtz thinks with Donders that the iris, in conjunction with the ciliary muscle, is the chief organ of accommodation. He, however, believes that the recession of the peripheral portions of the iris may also be

explained by the tension of the dilatator, the latter levelling the iris, which was before slightly bent (vide Fig. 13), by the action of the elastic fibres of the ligamentum pectinatum (pillars of the iris), and laid along the whole breadth of the canal of Schlemm against the inner wall of the latter. Besides this, Helmholtz also assumes that the ciliary muscle not only draws the insertion of the iris backwards, but also draws the posterior ends of the ciliary processes forwards, thus causing a relaxation of the zonula, which in its turn again favours the increase in the thickness of the lens."

Heinrich Müller attaches far greater importance to the action of the ciliary muscle than to the iris. He, moreover, discovered that the ciliary muscle consists of two different sets of fibres—a radiating longitudinal and a circular. (Vide Fig. 14, *m c i*, and *m c i'*.)

He ascribes a different action to each set of fibres, and has come to the following conclusions as to the probable action of the different parts concerned in accommodation. He thinks that*—

1. "The circular fibres of the ciliary muscle exert a pressure upon the edge of the lens, by means of which the latter becomes thicker.

2. "The longitudinal fibres of the muscle cause

* Von Graefe's Archiv. iii, 1, 23.

an increase of tension in the vitreous humour, on account of which, the posterior surface of the lens is prevented from shifting, and the action of the peripheral pressure is chiefly confined to the anterior surface.

3. "The pressure of the tense iris on the peripheral portion of the anterior surface of the lens assists in increasing the convexity (arching forward) of the latter, and in preventing the arching of the posterior surface.

4. "The arching forward of the centre of the anterior surface of the lens is rendered possible and favoured by the recession of the peripheral portion of the iris, which is accompanied by a contraction of the deeper (circular) layer of the ciliary muscle and the iris.

5. "The contraction of the ciliary muscle causes finally a relaxation of the anterior portion of the zonula, by which means, again, the increase in the thickness of the lens is promoted."

We have shown how Cramer, Donders, Helmholtz, Müller, as well as many other observers, have considered the iris to play a more or less important part in the mechanism of accommodation. It was difficult, indeed impossible, to determine with accuracy the relative amount of importance of the iris or ciliary muscle, even after the most

careful dissections and most elaborate investigations. This question as to the importance of the iris in accommodation has, however, been definitely set at rest by a case which occurred in Von Graefe's clinique, in which, together with a total absence of the iris (the latter was removed after an accident) the power of accommodation remained perfect. Moreover, on the application of a strong solution of atropine it became completely paralysed.*

NEGATIVE ACCOMMODATION.

We have assumed that when the normal eye is in a state of absolute rest, parallel rays (emanating from objects at an infinite distance) are brought to a focus upon the retina, and that a positive change of the accommodative apparatus within the eye is only required for objects at a finite distance. But it is thought by some (particularly Weber and Von Graefe) that the eye, when in a state of rest, is adjusted neither for its far nor for its near point, but for a distance between the two, and that adjustment for either nearer or more distant objects necessitates an effort of accommodation. Now, if we call the adjustment for near objects the *positive* accommodation,

* Vide "Archiv. f. Ophthalmologie," vii, 2, 26.

that for distant objects may be designated the *negative*.

Von Graefe thinks that, by the help of certain accessory powers (chiefly the external muscles of the eyeball), which exert a slight pressure upon the eye, and flatten the cornea a little, the refraction of the eye is somewhat diminished, and the far point removed still further than when the eye is in a state of absolute rest.

Henke has, however, advanced the theory that the negative and positive accommodation are produced by the action of the ciliary muscle, which he would divide into two, according to the direction of the fibres, viz., the "musculus circularis" and the "musculus radialis." He considers their action to be different and antagonistic, and thinks that in accommodation for near objects the circular muscle is contracted, the radial extended, whereas in accommodation for distance the reverse occurs—the radial muscle being contracted, the circular extended.*

The discovery of the circular fibres in the ciliary muscle is undoubtedly of great importance, although some think that their action is almost completely neutralized by the longitudinal fibres.

* "Der Mechanismus der Accommodation für Nähe und Ferne." Henke. "Archiv. f. Ophthalmologie," vi, 2, 53.

The mechanism of the accommodation could be, indeed, more easily explained if we might assume that the radial and circular fibres are supplied by branches from different nerves, and that they stand in a similar antagonistic relation to each other as the dilatator and sphincter pupillæ.

The chief argument against the theory that the eye accommodates itself actively for distant objects is in the action of a strong solution of atropine, which paralyses the power of accommodation, but does not interfere with the distant vision of the emmetropic eye, and does not change the position of the far point.

CHAPTER II.

RANGE OF ACCOMMODATION.

Before we speak of the mode of examining the range of accommodation, it will be well to consider what test-types are the best for the purpose of determining the acuteness of vision, and the position of the near and far point. Formerly Jaeger's test-types were chiefly in use, but they did not afford us a perfect clue to the acuteness of vision; for a person might be able to read No. 1 of Jaeger, and yet not enjoy a normal acuteness of sight. Snellen has, however, devised a set of test-types which fulfil this desideratum. The letters are square, and their size increases at a definite ratio, so that each number is seen at an angle of 5 minutes. Thus, No. 1 is seen by a normal (emmetropic) eye up to a distance of 1 foot, at an angle of 5 minutes; No. 2 up to 2 feet, and so on. These numbers cannot, as a rule, be seen distinctly beyond these distances.*

* At Professor Longmore's suggestion, Dr. Snellen has given, in his later editions of the Test-types, some tables containing a series of figures and single numbers, for the examina-