Physiology. — *"Lens measurements and Emmetropisation"*. By Dr. W. P. C. ZEEMAN. (Communicated by Prof. T. PLACE).

(Communicated in the meeting of September 24, 1910).

Since DONDERS' pioneer writings on the refraction of the human eye, a great amount of research has been devoted to the study of the refractive anomalies, but conspicuously little attention has been given to emmetropia.

Nevertheless the question of the origin of emmetropia is of the greatest importance, not only to physiology but also for a right understanding of the refractive anomalies.

STRAUB has repeatedly pointed this out, and has endeavoured to give an explanation of the origin of emmetropia. From a point on the illuminated retina, a bundle of rays of light goes out with a certain divergence. The divergence of this bundle is modified by the optic system of the eye, which has a certain converging power. The peculiarity of emmetropia now lies in the fact that the converging power of the optic system is just equal to the divergence of the retina bundle. An explanation of how this equality comes about has been given by STRAUB in his theory of emmetropia.

According to this theory the tone of the ciliary muscle gives to the lens the exact form to attain this equality. The lens form, or tone of the ciliary muscle is, therefore, the factor whereby in every eye emmetropia can be reached and maintained.

The ophthalmometric measurements, which I made and the results of which I shall give here, do indeed show that the production and maintenance of emmetropia is the work of the lens. Measurements of the eyes of hypermetropes and myopes prove that in these eyes there is also a tendency towards emmetropia, that in them the lens has such a curvature as to lessen the degree of refractive anomaly.

My researches extended over 75 persons (25 emmetropes, 25 hypermetropes, 25 myopes) of about the same age.

The refraction was determined by means of the shadow test, spectacle glasses or by the direct method of ophthalmoscopy; the radius of the cornea was measured with JAVAL's ophthalmometer ("Kagenaar" model), the accuracy of which was tested by means of a quartz ball with a radius of 15.4 mm.; the angle α, the position and curvature of the anterior and posterior surfaces of the lens were determined by TSCHERNING's ophthalmophakometer, the method of using which instrument is described minutely in the Encyclopédie franc. d'Ophthalmologie.

We introduced only a few slight modifications in the method; a cross-shaped fixation mark, illuminated from behind, for which a lens was set up, forced the subject to relax his accommodation.

The depth of the anterior chamber was measured by means of TSCHERNING's ophthalmophakometer, but according to the method of VON HELMHOLTZ, by fixing the point of convergence by two lines intersecting each other in the centre of the pupil.

With the exception of finding the depth of the anterior chamber of the eye, the measurements were taken after the pupil had been dilated by a mydriatic.

From the results we calculated the position of the principal planes, principal foci and nodal points of the optic system, and finally the length of the axis of the bulb.

After fixing angle α, it appeared that a good centering is a great rarity. In accordance with EHRNROOTH the centre of the cornea appeared to lie at the temporal side of the axis of the lens.

Properly, therefore, we cannot speak of an principal axis. We shall therefore give the name of principal axis to the connecting line of the centres of cornea and anterior surface of the lens. Further we found that angle α was smaller in the case of the myope than in that of the emmetrope, and in the latter smaller than in that of the hypermetrope. Considering that the size of angle α is dependent on 3 factors, viz. the position of the nodal point, the position of the retina, and the distance of the fovea centralis retinae, from the principal axis, it was of importance to investigate the influence of these factors further. For this purpose I calculated the position of the nodal point in respect to cornea and retina, and the distance of the fovea from the principal axis.

From the curves formed with these results the following conclusions could be drawn.

1. The differences in angle α in refractive anomalies are dependent upon the differences in the length of the axis.

2. The differences in angle α in persons of one and the same refraction are exactly proportional to the distance of the fovea from the principal axis.

3. The distance of the fovea from the principal axis has no relation whatever to the refraction.

The radius of the cornea was found with JAVAL's ophthalmometer. The myopes proved to have a shorter, and the hypermetropes a longer cornea-radius than the emmetropes, which is in accordance with the results of earlier investigators (SCHIÖTZ, PLANTENGA etc.).

The peculiar fact that the investigators who took their measurements with JAVAL's apparatus as a rule obtained figures larger than those taken with HELMHOLTZ' ophthalmometer (no good reason for which could be found) was evident in my case also, as was seen in comparing my measurements with a series which I had formerly made with the ophthalmometer of HELMHOLTZ. I obtained then as averages in emmetropes, hypermetropes and myopes respectively: 7.8, 7.66 and 7.66 mm. against 8.07, 7.92 and 7.87 mm. in the present case.

By means of a quartz ball with a radius[1]) of 7.7 mm. both instruments were subjected to a new test, which revealed that our HELMHOLTZ ophthalmometer had indicated too low values. The averages of our first series were after correction, therefore, 8.1, 7.96 and 7,96 mm., and thus practically agree with the averages of our new cases examined with JAVAL's apparatus.

I therefore venture to express the supposition that the low values found by some early investigators for the cornea radius are to be attributed likewise to similar inaccuracies of the instruments employed.

The *depth of the anterior chamber* was originally determined by TSCHERNING's method. This method requires the greatest care if reliable results are to be arrived at. In my opinion it is of the utmost importance to repeat the examination after the interchange of lamp and glass, a point also mentioned by GULLSTRAND in the 3rd edition of HELMHOLTZ' "Physiologische Optik". The depth of the anterior chamber was generally determined by fixing the point of intersection of the two lines running through the centre of the pupil (after the example of the method indicated by HELMHOLTZ).

The depth of the anterior chamber proved, in accordance with the results of former investigators as well as with my own, to be smaller in the hypermetrope than in the emmetrope, and in the latter smaller than in the myope.

The differences in the depth of the anterior chamber are undoubtedly for a part the direct result of the differences in curvature of the anterior surface of the lens.

The radii of the *anterior and posterior surfaces*, and the *thickness of the lens* were determined by the method indicated by TSCHERNING with his ophthalmophakometer.

The examination of the curvature of the lens surfaces, especially that of the anterior surface of the lens, showed considerable differences in persons with dissimilar refraction, in the hypermetrope a

[1]) The diameter of the quartz ball was found with a pair of adjustable compasses to be 15.4 mm and the regular concavity at different points was controlled with the ophthalmometer. Finally, by very careful weighing, Prof. ZEEMAN fixed the diameter at 15.42—15.43 mm.

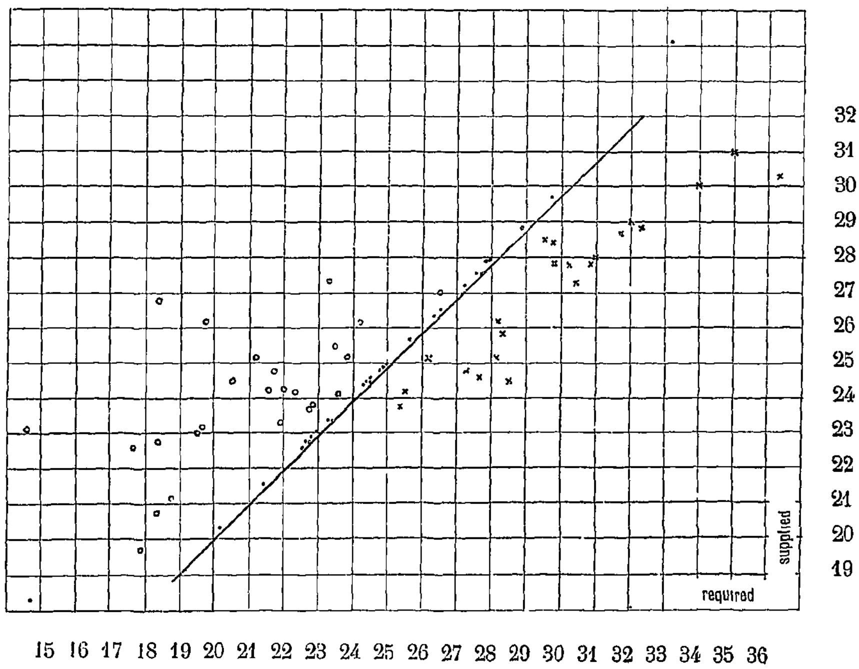
more decided, in the myope a less pronounced curvature of the lens surface.

The *thickness of the lens* did not vary in persons with different refraction. The errors, however, of measurement, are rather considerable.

The result of our measurements is, therefore:

Emmetropes, hypermetropes and myopes differ in respect to the curvature of the cornea, the size of angle α, the depth of the anterior chamber and the radii of the surfaces of the lens. The differences in the curvature of the cornea are such as to increase the refractive anomaly. The differences in the other measures are of such a nature as to lessen the refractive anomaly. In how far this is the case will be clear from the following computations.

From the data we possess at present we are able to estimate the strength of the lens as a whole. This proved to be greater in the hypertrope than in the emmetrope, and in the latter greater than in the myope. The importance of these figures is at once seen in



Refractive power of the lens in dioptres.

xxx Hypermetropes
.... Emmetropes
oo Myopes

Fig. 1.

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looking at fig. 1. We have computed the hypermetropia which each of the eyes examined should have from the curvature of their corneae and length of axis in the absence of the lens, and have arranged the eyes according to this hypertropia, after which we indicated, in dioptres, on the ordinates the refractive power of the lens.

Assuming that it is the work of the lens to correct the hypermetropia occasioned by the curvature of the cornea and the length of the axis, the eyes are classed according to the work required of the lens, while the ordinates indicate in how far the lens has answered to these requirements. Where these two figures are the same, there is emmetropia, where the lens has supplied more dioptres than are desirable there is myopia, where it had a relatively weaker refractive power there is hypermetropia.

Thus, in a hypermetropical eye x the refractive power of the lens amounted to 31 dioptres, the eye was 4 D. hypermetropic, so that the lens would have had to supply 35 D. in order to reach emmetropia.

Now in this figure we see a regular ascension from left to right, that is to say the more there is required of the lens the stronger is its refractive power. The lens has thus apparently the tendency to reduce the refractive anomaly. It goes without saying that the emmetropes lie on one line, as the refractive power here invariably answers to the demand put upon it.

The hypermetropical lens supplies more, and the myopical lens fewer dioptres. This clearly points to a tendency towards emmetropia.

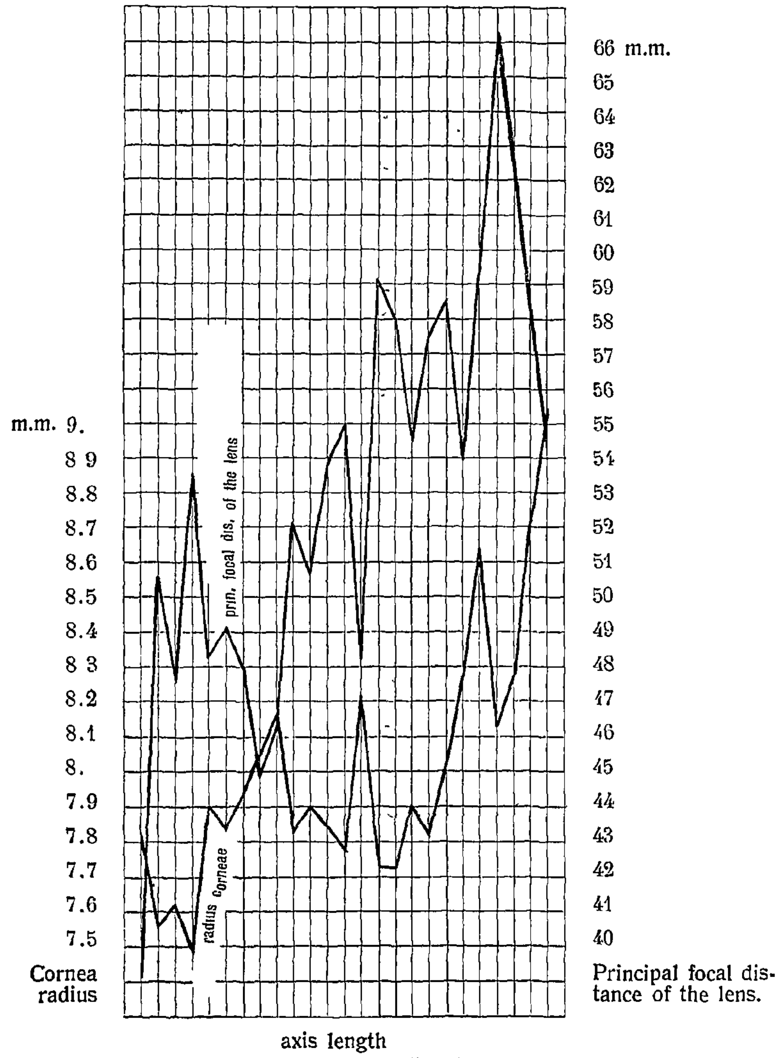
Without such a tendency, without an emmetropisation, we might expect to find in hypermetropes and myopes a lens of equal refractive power, and in our figure all these would have to be arranged on a horizontal level.

If we know the position and curvature of the refracting surfaces and the refraction of every eye, we are able to calculate the position of the retina.

In doing this it is assumed that the refractive indices of aqueous humour and lens are the same in the various eyes.

In the emmetrope the distance from the posterior principal focus to the cornea is equal to the length of the axis, in the ametrope we can determine the axial length approximately by placing the retina for each 3 dioptres 1 mm. before respectively behind the posterior principal focus.

In the emmetrope it has been seen that the length of the axis fluctuated between wide limits. If, nevertheless, emmetropia is present in these eyes the cornea or the lens must possess an accordingly diminished or increased refractive power, i. e. a greater or less curvature. This is seen most clearly in fig. 2. The cornea radii and principal focal distances of the lens increase regularly as the length of the axis increases. In the case of a greater length of axis we find, therefore, a greater focal distance of the lens. The greater fluctuations of these two lines are invariably in contrast. This contrast is a characteristic of emmetropisation. The eyes with



Emmetropes arranged according to *length of axis*.
Mutual relation of the cornea radius to the principal focal distance of the lens.
Fig. 2.

a relatively greater cornea radius have been kept emmetropic by a weaker lens refraction.

The length of the axis is closely related to the refraction. To demonstrate this unambiguously we must endeavour to exclude the influence of the differences in size. For this purpose the different measures of each eye must be reduced to one and the same cornea.

From the actual axis length of each of the eyes examined, I have determined the axis length which each should have if the cornea radius measured 8 mm. If now these axis lengths are brought together in curves, it will be found that the axis length of the emmetrope can vary very greatly, that at the most, however, it measures 23.5 mm. while in hypermetropes and myopes an axis length of 22 mm., and 24.5 mm. respectively are most frequently met with. It seems to me that we may consider the 9 emmetropes, in whom the reduced axis length amounts to 23.5 mm., the 10 myopes in whom it is 24.5 mm., and the 11 hypermetropes in whom it is 22 mm., as types of emmetropia, myopia, and hypermetropia.

We have, therefore, reduced the other measures also of these types to a cornea radius of 8 mm. and then found:

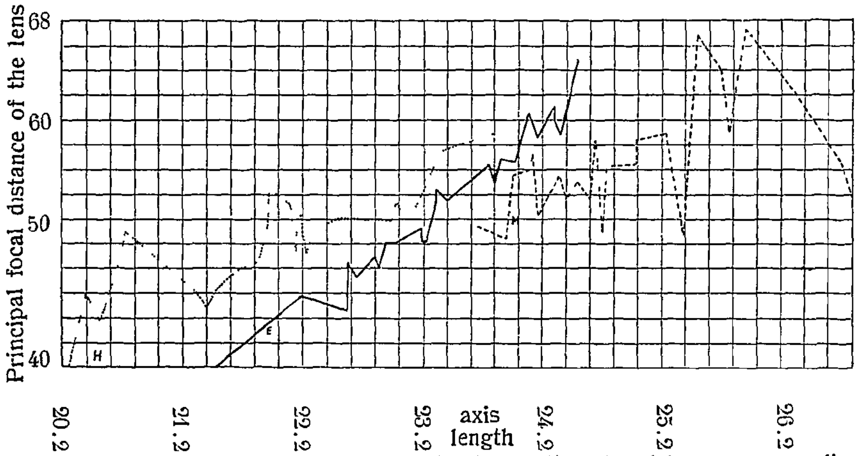
	Cornea radius	Length of axis	Depth of anterior chamber	Radius of anterior surface	Radius of posterior surface	Thickness of the lens	Focal distance of the lens	Dist. cornea and posterior focus	Refractive power of the lens	Refractive power of whole system
1st group (Emmetropes)	8 *mm.*	23.54	3.81	11.5	6.17	3.7	54.5	23.54	24 D.	62.3
2nd group (Myopes)	8 mm.	24.4	4.03	12.7	6.1	3.5	56.	23.7	23 85 D.	61.5
3rd group (Hypermetropes)	8 mm.	22.	3.65	10.03	5.95	3.67	50.8	22.95	26.3 D.	64.3

Finally we have tried to demonstrate the connection between length of axis and principal focal distance of the lens by arranging the eyes, after reducing all the measures to a cornea radius of 8 mm. according to axis length, and indicating the principal focal distance of the lens on the ordinates (fig. 3).

We have now to do with eyes of the same dimensions; we might make the corneae coincide, and then we could best study the relationship between axis length and principal focal distance.

As was to be expected the emmetropes lie again on one line; greater axis lengths are of course compensated by a greater principal focal distance; possible deviations from this line must be attributed to errors of measurement.

The end points of this line give us the limits between which in



Principal focal distance of the lens and axis length reduced to a cornea radius of 8 mm. with different refractions.

Fig 3.

emmetropes the axis length and the focal distance of the lens can oscillate. On the one side of this line the hypermetropes must lie and on the other the myopes, as the focal distance of the former is relatively greater, and of the latter relatively less, than with emmetropes.

Hypermetropes and myopes are thus separated by the slanting line of the emmetropes; this is simply a result of the definition.

It is interesting, however, to note that they can also be divided by a vertical and a horizontal line, which was not to be expected a priori.

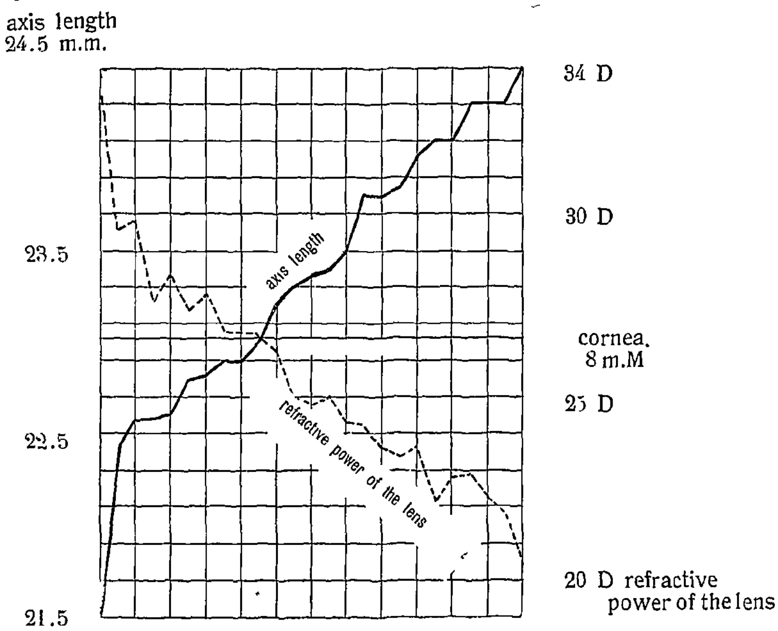
These dividing lines show that the hypermetropes and myopes can not only be divided by a difference in the ratio between axis length and focal distance, but moreover by differences in the absolute size of axis length and of focal distance of their lenses separately.

The vertical dividing line falls on 23.7, which bears out the well-known fact that the hypermetropes possess a shorter, and the myopes a longer axis length. Below 23.7 mm. there is no myopia, and above 23.7 mm. no hypermetropia.

The horizontal dividing line, which would have to be drawn at 53.5, shows that the focal distance of the lens in the hypermetrope (in 84 °/₀ of the cases) is less, and in the myope (in 80 °/₀ of the cases examined) is more than 53.5 mm.; hypermetropes and myopes are thus separated by their axis length and by the focal distance of their lens. The first factor causes the refractive anomaly, the second factor tends to diminish it.

This arrangement of our figures also shows in the clearest possible way that the lens tends to diminish the refractive anomaly, and that it is undoubtedly the lens which, by adapting itself to the axis length, reduces so many eyes to emmetropia, so that STRAUB's theory of Emmetropisation by the lens is confirmed by our measurements.

The nature of emmetropia is best seen in fig. 4, in the varying course of the lines representing the *axis length* and the *refractive power of the lens.*



Emmetropes, arranged according to the axis length reduced to a cornea radius of 8 m.m.
Fig. 4.

Physics. — "*On the solid state.*" V. By J. J. VAN LAAR. (Communicated by Prof. H. A. LORENTZ).

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17. More than a year ago I published the fourth part of my Treatise on the solid state. (These Proceedings June, 1909); the continuation announced there, had, however, to be postponed to the present day in consequence of all kinds of interruptions.

Before proceeding with the further examination of the coexistence-curve liquid-solid, the equation of which was derived by me in IV (formula (16) on p. 134), I will first reduce this equation to a some-