10

THE VELOCITY OF ACCOMMODATION. By JAMES W. BARRETT, M.B. (*Melbourne*), *Demonstrator of Physiology in King's College, London.*

Introduction.

THE experiments on which this communication is based, and their general mode of conduct, have been subjected to the supervision of Professor G. F. Yeo, by whose kind assistance many of the detailed parts of the apparatus with which the measurements have been made were arranged.

Mr W. Lang (of Moorfields) has also devised several additional appliances for facilitating the work, notably the method of estimating the accommodation velocity with binocular vision.

Further Mr Stanford Morton has materially assisted the writer, who feels that the effectiveness of the apparatus he has used depended in great measure on the kindness of his friends.

It would appear that but few workers in physiology have attempted to ascertain the time occupied by the act of accommodation.

The first, as far as the writer is aware, who examined the subject experimentally was Volkmann[1], who when discussing the motion of the eye, in his article "Sehen" in Wagner's Dictionary, states that by an application of Scheiner's method he found that in half a minute he could change his accommodation 20 times from 11 to 6 inches and back again. This gives an average of 1·5 seconds for each movement but makes no distinction between alteration from far to near and from near to far.

The first who devoted a special work to the subject was Vierordt[2], who by means of a chronoscope determined the duration of the acts of changing the accommodation of his practised left eye to and from a fixed object situated at 1819 cm. and another at a varying near point. The objects were diagonally placed threads. He found that the rate varied

[1] Wagner's *Handwörterb. d. Physiol.* Bd. III. p. 309.

[2] "Versuche über die Zeitverhältnisse des Accommodationsvorganges im Auge." *Arch. f. physiol. Heilkunde*, N. F. Bd. I. 1857.

(1) from day to day in the first week, shortening by practice, (2) according to the distance of the near object; (3) with the duration of the period of previous accommodation; that is to say, a number of observations rapidly following one another were effected more rapidly than an isolated one. The time taken by the change of accommodation from near to far bore the relation to that taken from far to near of 100 to 135, the general mean duration being ·7987 sec. and ·9430 sec. respectively.

The only other special paper which has come within the writer's reach is one by Aeby[1], who attempted to determine by direct observation the duration of the act of accommodation. He used needles as the points of fixation and estimated the time intervals by making and breaking the electric current through an electro-magnet which recorded on a glass cylinder.

He worked within comparatively narrow limits, 430 mm. being the maximum far limit and 115 mm. the minimum near limit. The relation of the mean time occupied in accommodating from the near to far and far to near was 100—150. Owing to the nearness of his maximum far point, his results can hardly be compared with those of Vierordt (which it appears he had not seen); but on the whole, the measurements seem longer, and more irregular.

No statement accompanies these observations as to the conditions of refraction of the eyes of these observers, or of their ages; nor do they seem to have compared the left with the right eye. Their results are moreover somewhat conflicting and their methods appear to be deficient in some respects. It therefore seemed advisable to investigate the matter in a modified way.

The difficulties of recording the exact time at which the near and far objects are seen most clearly, i.e. the exact time at which the act of accommodation begins or ends, are exceedingly great under any circumstances; because the time required for the mental decision is variable. This difficulty is especially so when the method of the former observers—viz. that of putting the accommodation apparatus in action by the will and recording the time by another volitional act—is adopted.

In this laboratory an endeavour has been made by the foregoing method to measure the velocity of accommodation of the laboratory assistant and of the writer, but in both cases it has not been possible to arrive at satisfactory results. One of the difficulties encountered is

[1] "Die Accommodations-Geschwindigkeit d. menschlichen Auges." *Zeitsch. f. rat. Med.* Dritte R. B. XI. 1861.

the wandering of the eye which occurs when changing from the near to the far object, and the writer has been as yet unable to satisfy himself that his observations taken in this way are trustworthy, for objects such as Vierordt used are very difficult to see clearly at a distance of 1800 cm., and the needle points employed by Aeby are only applicable to short distances and are open to the same objection.

To the former observer's method there is also another objection. Rays of light proceeding from a point distant 600 cm. are usually regarded as being practically parallel, and so Vierordt, who placed his far point at 1819 cm., three times this distance, was justified in regarding rays proceeding from an object situated at that distance as parallel; still his eye could not have been perfectly relaxed when looking at such an object and must have been accommodated to the extent of $\frac{100}{1819} = + \cdot 05$ D, a slight, but as will be afterwards shewn, an important amount. The last objection to these methods is their very great inconvenience and the difficulty experienced in rapidly changing the distances of the far and near points in order to vary the observations. On account of these objections the writer has endeavoured to construct an apparatus capable of effecting all these measurements in a moderate space and with considerable rapidity, but which at the same time should ensure optical accuracy.

Method of Experiment.

The apparatus by which the measurements now given have been taken is constructed so as to eliminate the objections mentioned. It consists of a skeleton compound microscope; the objective, being a lens of about 5 cm. diameter and about 7 cm. focal distance, is supported on a fixed stem, whilst the oculars, which can be changed from time to time as required, are of slightly less diameter and of varying focal distance. They are supported on a lever which can be quickly depressed and by this action the circuit of a magnet is made and the time recorded on a rapidly rotating drum.

The apparatus is placed horizontally. Under ordinary circumstances an observer looking through the ocular would see the inverted image of an object placed beyond the focal distance of the objective. If an ocular, say of 25 cm., be introduced, and the distance of the real image from the objective be accurately measured, and then the ocular (which can be moved towards or from the objective) be placed exactly 25 cm. from the image, it follows that the rays issuing from the ocular will be parallel.

An emmetropic observer, placed with his eye say 10 cm. from this ocular, will see a clear inverted image of the object if his accommodation be perfectly relaxed, but not otherwise.

If the ocular be nearer to the image than 25 cm. he will be compelled to accommodate to see it clearly, and if it be further away he will be quite unable to see it, since the normal eye cannot focus convergent rays upon the retina under any circumstances.

The writer is aware that theoretically no image will be seen if the rays are exactly parallel, but as scarcely any eye is emmetropic within ·25 D this fact is of no import.

If the observer's eye be 10 cm. from the ocular, and the ocular 25 cm. from the image, he sees the image distinctly with perfectly relaxed accommodation. Now either he or someone else suddenly draws the ocular right away from the line of vision, and by so doing makes the circuit of an electro-magnetic time-writer, and a graphic record of the event which throws the image out of focus is made on a rotating drum.

But as the ocular is drawn away a blurred image is seen, and then an efferent impulse is sent to the ciliary muscle which contracts and the eye is accommodated for the image distant 35 cm.

As soon as the image becomes clear the galvanic circuit is broken by a movement of the observer's hand, and the end of the change thus marked. The interval between the two records is the time taken for the ciliary muscle to contract, together with that taken for the impulses to pass through the necessary nervous mechanism. The time is measured by a tuning-fork writing under the magnetic recorder.

This preliminary explanation of the method and its mode of application must now be followed by a more practical one.

The object to be viewed should be as small as convenient, in order to eliminate as far as possible errors arising from the imperfections of the ordinary opticians' lenses which have been used.

There have been used as objects the (1) red wick of an ignited candle, (2) letters and slits cut in a large black screen with a light behind them (the glare being prevented by sheets of tissue paper), and (3) black letters of small size printed on white tissue paper placed over an opening in a large black illuminated screen. This last form of object was found to be most useful and convenient, since it is much more easy to decide quickly when such an image becomes clear than in the case of the candle wick or the slits. It should be mentioned here that the determination at the end of the observation of the exact moment at which the object becomes clear is one of the difficulties of the method, but the error arising from it is soon minimized by practice, since each observer forms for himself a standard of clearness.

The objective used has been an ordinary ophthalmologist's lens, and the oculars were spectacle trial glasses of known focal distance.

The oculars are placed in a grooved brass frame on the end of the lever which can be depressed or raised at will.

By the act of depression the contact is made in an adjustable cup of mercury, and the circuit, in which the time-writer is situated, is completed without loss of time, and vice versâ on raising.

Great care must be exercised to see that the glasses are centred accurately, since otherwise the prismatic action of the ocular is brought into play, and on depressing the lever and removing the ocular from the line of vision the image has to be sought in a new direction, and so much time is lost, not by the contraction of the ciliary muscle but by the contraction of the recti muscles, which are moving the eye in search of the object.

The head must be firmly fixed at a given distance from the ocular, and has been secured in these experiments with a photographic head-rest.

The time thus taken for accommodation in one and both eyes together has been measured, the latter observation being effected by the use of a large reading-glass as an ocular. The reading-glass was a double cylinder of about 19 cm. focal distance; and although this method was therefore quite inapplicable to observations on confirmed astigmatic eyes, still it was readily applicable in cases where the eyes of young emmetropic persons were being tested. In this case the large glass was fixed into the lever 19 cm. from the image, and thus replaced the ocular ordinarily employed.

On looking through this glass one image of binocular production was visible, and then on depressing the lever and so removing the glass from the line of vision two blurred images were seen, which rushed into one another and became one clear image: thus indicating the action both of the ciliary muscle and of the internal recti.

Measurements of distances were made with a common centimetre rule, and as it was clear that total errors of at least ·5 cm. might readily arise with the most careful measurements, in all cases where possible the apparatus was kept unchanged for a large number of experiments, so that no external conditions whatever were consciously altered; the present as well as the former observations made on the rate of accommodation are of relative rather than absolute value, and it is to relative values that I would especially direct attention, since the errors for nearly all observations are alike.

In order to measure the time taken to relax the accommodation the reverse experiment is performed. The ocular is first depressed and the observer accommodates for the image which is distant 35 cm.; he then suddenly elevates the ocular into the line of vision, and, as soon as the image becomes clear, again depresses it. The recorded interval between the raising and depression of the lever represents the duration of the relaxation period together with the time taken for the nervous changes.

In all cases where one eye was used alone, a large blinker was placed over the other eye, which was allowed to remain open; for the ordinary practice of shutting the eyelids of one eye and keeping the other open was found to alter the result very materially, since there is a great tendency to accompany the closing of the lids by contraction of the ciliary muscle. It was found that if the eyelids be closed and then opened, the accommodation is nearly always completely relaxed. In fact, when the writer was estimating his own accommodation velocity, he at times found difficulty (especially if fatigued) in relaxing fully in any other way. In all cases a definite period was allowed to elapse during which the object was looked at prior to the observation being commenced; this varied from 5 to 10 secs.

The following is the method by which the measurements have been made.

Determination of the rate of accommodation from far to near.

To measure the time required to change from infinity to 33·3 cm. an ocular (+ 4D) whose focal distance is 25 cm. is fixed at 25 cm. from the image formed by the objective. The eye of the observer is fixed at 8 cm. from the ocular. Then the ocular is depressed and the image thrown out of focus. The time at which the image again becomes clear, is then recorded by the lever being raised. In this case the ciliary muscle contracts through + 3D, i.e. adds on to the crystalline lens + 3D.

To measure from near to far, the person accommodates for the image, while the ocular is depressed: he then raises the lens into the axis of vision, and, as soon as the image is clear, again depresses it to record the time when the act is completed.

To measure accommodation velocity from infinity to 11 cm. The ocular is a lens (+ 20D) the focal distance of which is 5 cm. and the eye is at 6 cm. from ocular. The experiments were conducted as before.

By modifications of oculars and of the distance of the head from the ocular it is possible to measure the accommodation or relaxation velocity from infinity to any point required and vice versâ.

To measure intermediate distances, for example, from 50 cm. to 16 cm. and back, the following plan has been adopted.

If a negative lens be placed in front of the eye in a spectacle frame, and care be taken that the lens is distant from the cornea not more than 13 mm., then it amounts practically to putting that lens within the eye, so that if a − 2D lens were so placed in front of an eye, that eye would be rendered hypermetropic to the extent of 2D.

Now in order to get distinct vision for objects at an infinite distance the ciliary muscle would contract to the extent of 2D, which in the emmetropic eye corresponds to a far vision point of 50 cm. Hence if an eye, with such a lens in front of it be applied to this instrument, all observations begin not with a relaxed eye, but with an eye whose far vision point is (practically) 50 cm.

Suppose then that the ocular is a lens (+ 10D) whose focal distance is 10 cm., that it be placed at a distance from the real image of 10 cm., and that the eye be fixed at a distance of 16·6 cm. with this − 2D lens in front of it:—It then follows that the eye already accommodated for 50 cm. will have to accommodate, when the ocular is depressed, not for 16·6 cm. (+ 6D), as it would if no additional negative glass were interposed, but for (6D + 2D) 8D, i.e. 12·5 cm.

By similar calculations, any other intermediate distance can be measured either from far to near, or from near to far.

For example. The accommodation velocity from 33·3 to 11 cm. can be measured, by putting a (− 3D) lens the focal distance of which is 33·3 cm. in front of the eye, then adjusting an ocular of 10 cm. f. dist. (+ 10D), and fixing the head at 6·6 cm. distance and experimenting as before.

The accommodation velocity of both eyes of four individuals has been measured separately; and of these eight eyes, two pairs have been tried separately and together.

The measurements which follow are given without any deductions for the time occupied by the passage of nerve impulses. The observations extend over a considerable period of time; to each is attached the date at which it was taken, so that any comparisons of varying rates in the same individual may be made with measurements taken on the same day, and as far as possible under the same circumstances.

The writer desires to remark, apropos of these measurements, that the wearying nature of the repeated efforts to focus soon makes itself evident; and further that a number of accommodations from far to a very near point was followed in two cases by nausea and a most unpleasant nervous disturbance.

Gross measurements of the accommodation and relaxation of Case (A), æt. 22, Physiologist.

Right eye V = $\frac{6}{6}$ manifest hypermetropia ·25D.
Left eye V = $\frac{6}{6}$ " " "

Punctum proximum about 9 cm.

I. Accommodation Velocity. (From Far to Near.)

Distance From	Distance to	Right Eye	Left Eye	Date
		sec.	sec.	
Infinity	33 cm.	1·66	1·76	Jan. 9th.
		{1·34	1·76}	Jan. 10th.
		{1·34	2·09}	
		1·36	1·97	Jan. 12th.
		1·19	1·33	Jan. 15th.
		·98	1·07	Jan. 20th.
		·906		Jan. 23rd.
		·67	·72	Jan. 24th.
		·75	·77	Feb. 4th.
		·72	·82	Feb. 7th.
Infinity	11 cm.	2·26	2·39	Jan. 10th.
		1·73	1·66	Jan. 20th.
		1·62		Jan. 23rd.
			1·1	Jan. 24th.
		1·58	1·5	Feb. 4th.
		1·66	1·5	Feb. 7th.
33 cm.	11 cm.	1·14	1·04	Jan. 23rd.
		1·02	1·06	Feb. 4th.
		1·45	1·29	Feb. 7th.
50 cm.	16 cm.	·98		Jan. 23rd.
		·9	·88	Jan. 21st.
			·93	Jan. 24th.
		·96	·82	Feb. 7th.

II. Relaxation Velocity. (From Near to Far.)

33 cm.	Infinity	About ·7 sec. Varying and difficult to measure, since some days the accommodation could not be completely relaxed. Relaxation velocities for all other distances too rapid for measurement.

Measurements of the accommodation velocity of the two eyes, tested separately and together.

From	to	Right Eye	Left Eye	Mean	Both together	Date.
Infinity	25 cm. (Reading distance)	1·29 1·12	1·43 1·07	1·36 1·095	1·3 1·06	Feb. 6th. Feb. 7th.

All measurements given in January are the mean of from 15—22, in February from 5—15 observations.

In this case also at least 4 days' observations prior to the earliest mentioned here have been rejected; being made simply for the purpose of practising the eyes.

From these observations a certain number of points are obvious.

(1) That a considerable diminution in the time occupied in accommodating occurred as the result of practice. Thus the accommodation velocity from infinity to 33 cm. was 1·66 secs (Right Eye) on Jan. 9 and steadily diminished to ·67 sec., Jan. 24. Since this date it has slightly increased.

(2) That the time occupied by either eye in accommodating appears almost exactly the same as that occupied by the two together.

(3) That the results varied somewhat from day to day, and that they were usually fairly constant on any one day.

(4) That the accommodation velocity of the practised right eye and the unpractised left were at first different, but ultimately became fairly equal.

(5) That all relaxation periods except that from 33 cm. (approx.) to infinity were unmeasureably short though the method employed recorded with accuracy periods of time as small as ·1 sec.

Gross measurements of the accommodation and relaxation of Case (B), Laboratory Assistant.

Right eye $V = \frac{6}{6}$ manifest hypermetropia 1D.

Left „ $V = \frac{6}{6}$ „ „ 1D.

Punct. prox. about 8 cm.

I. Accommodation Velocity. (Far to Near).

From	to	Right Eye	Left Eye	Date
Infinity	33 cm.	·44	·5	Jan. 27th.
		·5	·54	Feb. 7th.
Infinity	11 cm.	·6		Jan. 27th.
		·72	·53	Feb. 4th.
		·78	·79	Feb. 7th.
33 cm.	11 cm.	·56	·53	Jan. 28th.
		·56	·5	Feb. 7th.
50 cm.	16 cm.	Too rapid for measurement.		

II. Relaxation Velocity. Too rapid for measurement.

Measurements of Accommodation Velocity of the eyes of (B) examined separately and together.

From	to	Right Eye	Left Eye	Mean	Both Eyes together	Date
Infinity	25 cm.	·6	·68	·64	·67	Feb. 6th.

The facts to be gathered from these observations are:

(1) That the accommodation velocity of this young hypermetrope was exceedingly rapid.

(2) That he accommodated from 50—16 cm. at a rate that defied measurement.

(3) That the result varied from day to day.

(4) That his right and left equally practised eyes varied little from one another.

(5) That the time taken for either eye to accommodate separately was the same as that taken by both acting together.

(6) That it was impossible to measure *any* of his relaxation periods by reason of their rapidity.

Gross measurements of the accommodation and relaxation Case of (C), æt. 35. Ophthalmologist.

Right eye $V = \frac{6}{6}$ Emmetropia

Left „ $V = \frac{6}{6}$ „

Punct. prox. about 17 cm.

From	to	Right Eye	Left Eye	Date
		sec.	sec.	
Infinity	33 cm.	·79		Feb. 3rd.
Infinity	17 cm.	1·57	1·58	
Infinity	18 cm.	1·48	1·48	
50 cm.	20 cm.	·986	·85	
33 cm.	Infinity	·68		

All near to far accommodations, except that noted 33 to infinity, too rapid for measurement.

It seems then:

(1) That the rate of contraction and relaxation of C's eyes does not differ materially from those of A.

(2) That, like A, he can estimate the time taken to relax only from moderately near to the very far off.

All other near to far observations were too rapid for accurate measurement.

Gross measurements of the accommodation velocities of the eyes of (D), æt. 32. Ophthalmologist.

Right eye $V = \frac{6}{6}$ with − 3D glasses.

Left " $V = \frac{6}{6}$ " " "

Myopia is − 3D with − ·75D astigmatism left uncorrected. Punct. prox. with glasses about 14 cm. Glasses used during observations.

From	to	Right Eye	Left Eye	Date
		sec.	sec.	
Infinity	33 cm.	1·2		Jan. 31st.
		1·5	2·03	Feb. 4th.
		1·3	1·58	Feb. 4th.
Infinity	15 cm.	1·77		Jan. 31st.
		1·84	2·42	Feb. 4th.
Infinity	14 cm.	1·8	2·6	"
33 cm.	15 cm.	1·61		Jan. 31st.
50 cm.	20 cm.	1·5		"
33 cm.	Infinity	1·08		Jan. 31st.

All near to far accommodations other than that noted were too rapid for measurement.

From these measurements it follows that

(1) The velocity of this myopic accommodation was very slow compared with that of the other eyes.

(2) The unpractised left eye accommodated much more slowly than the right.

(3) As in the case of C and of A all near to far measurements except the moderately near to very far, of which 33 cm. to infinity is the type, are too rapid for measurement.

General Considerations.

The exact details of the method by which accommodation is effected are hardly yet clear; thus the respective parts played by the radial fibres of the ciliary muscle and by the so called circular muscle of Müller do not seem to have been determined. And since the mere mechanical part of accommodation is so very complex, quite apart from the complexities of innervation, it is obvious that conclusions as to the rate of any of the acts included in accommodation can only be tentative. It is not the purpose of the writer to enter into any discussion on this point, or yet on the mode of relaxation.

The first point of interest in relation to these measurements is the reduction in accommodation velocity effected by practice. It will be observed that the gross measurements of both the right and left eyes of A shew a progressive increase in rate from Jan. 9th, when the velocity of the right eye from infinity to 33 cm. was 1·66 secs. and that of the left 1·76 secs., to Jan. 24th when it was ·67 sec. right and ·72 sec. left; since this date the rate has altered but slightly.

Similarly the velocity from infinity to 11 cm. on Jan. 10th was 2·26 secs. for the right and 2·39 secs. for the left. After the steady practice in January it was reduced to an average of about 1·5 secs. for each eye, which is the present rate.

It should be stated here that during the few days prior to Jan. 10th the observations were very long and very variable.

To what, then, is this reduction to be ascribed? Is it a diminution of the latent period, an increased rate of contraction of the muscle, or increased mobility of the apparatus? Or, is it that the nerve mechanism used for setting the accommodation apparatus in motion became better educated so as to allow more rapid transit of the impulses? It is probable that with short practice the exact period at which the image becomes clear was more quickly determined.

As to the latent period and rate of contraction of the muscle varying, if they altered from day to day there must be a departure from the behaviour commonly attributed to other kinds of muscle tissue; and as it is only known from analogy that the ciliary muscle has a latent period, there is no warrant for assuming that it differs from that of other muscles in this important respect.

If the increased mobility of the apparatus has any influence, it is probably inappreciable, since if it were great it would be reasonable to assume that the relaxation velocity would alter also. Now as the relaxation velocity from extreme tension to complete relaxation is from the first so short that it cannot be measured, it is evident that the increased mobility of the apparatus plays a very slight, if any, part in the reduction of the period of accommodation which results from practice.

It would seem then that the increased facility with which nerve impulses are transmitted can alone explain the gradual alteration of the measurements effected by practice.

The variable and lengthy character of the measurements, antecedent to those here recorded, soon rapidly disappears; this is probably due to the fact that the brain becomes educated, and the gradual improvement in rate which sets in afterwards is probably due to the slower education of the subordinate nervous mechanism.

The last hypothesis is that the diminution depends on the more rapid recognition of the time at which the image becomes clear. As mentioned at an earlier part of this communication, this source of fallacy is speedily removed by practice, each observer forming for himself as it were a standard of clearness. Hence it may be regarded as having influence only in the first few observations.

Binocular Measurements.

It has been mentioned that in all these experiments where one eye alone was being tested, a blinker was placed over the other eye which was then kept open, since the effort of closing the one eye voluntarily seemed to alter materially the observations made. The reason for this possibly is that some such muscular movements habitually act in association with accommodation and one movement is sufficient to excite the other; so that when closing one eye and measuring the accommodation velocity, time is lost in controlling and preventing the associated movement excited by closing the eye. Now since both eyes were open, it is probable that both are accommodated together by reason of their educational association, although the velocity of the movement in one only was measured.

This being so, it ought not to have been a matter of surprise that the accommodation velocity of the two eyes used together was about equal to the mean of the results found by testing them separately, for on *a priori* grounds, such a conclusion would seem probable. Yet the thought suggested itself that the increased definition of the image consequent on the production of Binocular Vision would have certainly diminished the period of the observation. But experiment enabled one to conclude that this increased "Acuity of Vision" has but slight influence on the time taken to form a clear image. A reference to the tables given will shew how nearly the mean of the accommodation velocity of the two eyes tested separately coincides with that of the two taken together.

The difference between the accommodation velocities of the two eyes is another interesting point. If one eye were very astigmatic one might expect that its rate of accommodation would be slower than that of the other. However in the instances (A and B) both eyes were of the same character, except in so far as one was practised more than the other and was so functionally superior.

It is noteworthy that the accommodation velocity of the eyes of B (who had never practised his accommodation for special purposes with either eye) was nearly the same in both eyes.

But in the case of A, who had used his right eye very much more than his left, the accommodation velocity was at first very much faster in the right than in the left eye, but with practice it became very much the same in both eyes.

Thus an accommodation velocity from infinity to 33 cm. of

1·66 secs. right, and 1·76 secs. left on Jan 9th,

and of 1·34 secs. „ and 1·76 secs. / 2·09 secs. left on Jan. 10th,

became

·75 sec. right, and ·77 sec. left on Feb. 4th.

·72 sec. „ and ·82 sec. „ on Feb. 7th.

And in some of the other measurements in February the right eye accommodation velocity was even slower than that of the left.

Now in the case of C the velocities in each eye were nearly the same, but in D's case the velocity of accommodation in the right eye was very much greater than that in the left.

Thus on Feb. 4th his accommodation velocity from infinity to 33 cm. for the right eye was 1·5 secs. and for the left 2·03 secs., whilst from infinity to 11, in the right 1·84 secs., in the left 2·42 secs. was required.

Whether this difference would as in the case of A disappear by practice could not be determined.

It will be observed that in all cases where comparisons have been instituted, they have been made between measurements obtained on the same day, for comparisons made between measurements obtained on different days would (except for special purposes) be liable to error.

Observations taken for purposes of comparison on any one day have always been taken, so far as possible, under the same circumstances (i.e. with as little alteration of lenses etc. as possible) and very often at one sitting.

Effect of Fatigue.

The effect of fatigue is well shewn by the observations taken on Jan. 10th. After taking some 60 consecutive records, measurements of the accommodation velocity of the left eye of A from infinity to 33 cm. were commenced. The right had given very uniform results 1·34 secs. for two sets of 22 observations each.

The first 22 with the left gave 1·76 secs. and A then felt very fatigued, but the next 22 averaged 2·09 secs., and then the observations had to be discontinued.

The exact cause of this fatigue would seem to be the unusual and new strain thrown on the subordinate nerve mechanism, which governs the ciliary muscle, for it is probable that 100 contractions conducted even in rapid succession would not fatigue the muscle itself, which, ordinarily in A's case was daily occupied in doing much more severe work.

Age Difference.

The general difference in the accommodation velocity in the cases of A, B, C, and D is remarkable.

Thus in accommodating from infinity to 33 cm.,

B æt. 19 years took ·5 sec.
A „ 22 „ „ ·75 sec.
C „ 35 „ „ ·8 sec.
D „ 32 „ (myope) took 1·3 secs.

from infinity to 11 cm.,

B took ·7 sec.
A „ 1·5 secs.

from infinity to 18 cm.,

C took 1·5 secs.

from infinity to 14 cm.,

D took 1·8 secs.

These measurements though only approximate, are instructive.

The young hypermetrope was most rapid. Then came the slightly older emmetrope, and then with but slight difference, the older emmetrope; whilst far the slowest of all, was the middle-aged myope.

These differences might have been expected, but have been neglected by previous observers, and require a more comprehensive examination, which will be made by the same method.

So far as the measurements of the change from far to near are concerned the results here arrived at correspond with Vierordt's careful observations on his own left eye. But the next set of measurement, is apparently in direct opposition to those he made.

Relaxation Velocity.

The exact mode in which moderate degrees of relaxation is effected is not quite clear. It may be assumed that in changing from the near to the very far, the apparatus is allowed to run down. But what happens in changing from a near to a moderately far object, for example from 8 to 33 cm.? Does the apparatus run down altogether, and then re-accommodate up to the required point, or does the muscle relax down to 33 cm. where it is then suddenly checked?

Now, if the first view were correct, it ought to take longer to relax from 11 cm. to 33 cm. than from 11 cm. to infinity. The writer tried to see if this were so, but found in every one of the persons examined, that any of these periods were too rapid for measurement. That is they were less than ·1 sec. Possibly something like this complete running down may occur in childhood but probably by education the second method becomes generally used. By what nervous mechanism the muscle is checked at the necessary point is very difficult to understand, for owing to the rapidity of the process it cannot well be a central coordination.

The only relaxation velocity that could be measured in A, C and D, is from a moderately near point, say 33 cm. to infinity. In B's eyes all relaxation and some accommodation periods defied measurement by reason of their rapidity.

The important practical bearing of this relaxation rapidity is the lesson it teaches relative to presbyopia.

If presbyopia were in great measure due to rigidity of the apparatus and not to failure of the ciliary muscle, it would be expected, that the relaxation periods of C would be fairly long; but, although that from 33 to infinity was somewhat long, all others were too rapid for measurement. Yet his near point has receded to 18 cm. Now this seems to negative the view, that rigidity of the passive part of the accommodation apparatus plays a large part in the defective accommodation of old emmetropic people.

It is interesting to compare the relaxation velocities of the eyes of C, D and A from 33 cm. to infinity, the only measurement that could be recorded.

	Right Eye.	Left Eye.
D Myope	1·08 secs. 1·3 secs.	1·58 secs.
C Emmetrope	·68 sec.	
A "	·7 sec.	

That there is some difference in the arrangement of the relaxation apparatus in the myopic eye and the emmetropic eye is rendered probable by these figures, and it appears also that this relaxation apparatus differs in the two eyes of the same individual.

But it is difficult to explain the fact that the relaxation velocity from 33 to infinity was easily measurable, whilst that from 11 to infinity and from 11 cm. to 33 cm. was too rapid for measurement—particularly in eyes like those of D, which took 1·08 secs. R. 1·58 secs. L., to relax through the former distance. One may suppose that the great tension of the elastic tissue in near accommodation, causes rapid relaxation.

It is well known that spasm of the accommodation apparatus, (ciliary muscle ?) in hypermetropes of low grade, often simulates a slight degree of myopia, and that a negative glass improves their vision. The question arises, when these curious relaxation results are considered, as to whether the accommodation apparatus under ordinary circumstances in emmetropes and hypermetropes is ever completely relaxed. If so, why is the result of Retinoscopy so variable, in an eye not paralysed with atropine, even if the patient is directed to look at a point 10 metres off?

Further if the accommodation apparatus were contracted to the extent, say of + ·2D, that is the vision point were 500 cm. yet the most distant objects would be clear to the observer, for such an error would not interfere with the definition of the image. Now, when it is remembered how relatively rarely in urban life people look at the more distant objects, such as require complete relaxation, it may be conceded that this hypothesis of a prevalent "functional myopia" of very low grade is a plausible one; and if so these curious relaxation velocities are more easily explainable.

But of course, even if it took a little time to overcome this spasm of the accommodation (and in A it on some days takes several seconds), why is it, that relaxation from 11 cm. or other very near point to infinity is effected with such great rapidity? The most probable explanation is that the great tension causes a more complete as well as a more rapid relaxation, than that effected in relaxing from 33 cm. to infinity. This explanation is further borne out, by the fact that relaxation velocity from 11 cm. to 33 cm., or from 16 cm. to 50 cm., or from 11 cm. to 50 cm., has proved in the cases of A, C and D, too rapid to be measured.

It appears then that whereas Vierordt found the relative duration of the accommodation and relaxation periods was about 130 : 100 and Aeby gave them as 150 : 100, the present measurements, except in some special cases, give a much greater difference.

Now as Aeby measured such short distances, his observations are of limited value from this point of view; and the discrepancy between Vierordt's observations and the writer's may be explained.

Vierordt's far point was not an infinite distance, but 1819 cm., hence his practised left eye was not completely relaxed when looking at the far point, but remained contracted to the extent of ·05 D at least.

There is, moreover, no information as to the refractive condition of his eye, nor of his age—points which might make a great difference; so that the contradiction of the near to far observations of Vierordt and those on emmetropes recorded here seems to be far more apparent than real; and when it is remembered that the far to near observations in the main agree, this explanation seems the more probable. But under any circumstances the view put forward as to the existence of this functional myopia, long recognised by ophthalmologists, is, it seems to the writer, entitled to consideration.

Rates of contraction of the Ciliary Muscle.

Up to the present, the gross measurements have been given merely with a view of comparing the rate of accommodation under varying circumstances; and the absolute duration of the local acts of accommodation has not been discussed. An endeavour will be now made to arrive at a more definite conclusion concerning this point.

The measurements herein recorded represent the (1) latent period and time of contraction of the ciliary muscle, and (2) the time occupied by the activity of the nerve mechanism which controlled it.

At the end of any observation, the observer makes a record on the drum as soon as the image becomes clear, by breaking the galvanic circuit with a key. Therefore the time between the end of his accommodation and the making of the signal is occupied by:

1. The latent period of the retina.
2. Passage of an impulse from the retina to the brain.
3. Cerebral changes.
4. Passage of impulses to the muscles of the forearm, through subordinate nerve mechanism.
5. Latent period of the muscles.

The time occupied by the movement of the apparatus may be neglected.

The total time occupied by similar processes, called the "Reaction period for light," has been frequently measured under different conditions, and whilst varying from time to time, usually averages ·2 sec.

The writer has measured it in the case of B and of A for the right forearm.

In B's case it averaged ·17 sec.
In A's „ „ ·2 sec.

This is not a very great difference when it is remembered that A's accommodation velocity was very much more rapid than B's. This time ·2 sec. has therefore been assumed to be fairly correct for A, C, D, and should therefore be deducted from the observations given. For it is evident that if there be any error at all in the case of C and D it will be in making the reaction period too small.

At the beginning of the observation a corresponding correction should be made.

After the ocular is depressed, the ciliary muscle contracts, but there is an interval before this contraction begins, which is occupied by (1) the latent period of the retina; (2) the passage of an impulse to the brain; (3) Cerebral changes; (4) the action of the subordinate nerve mechanism; and (5) the latent period of the ciliary muscle. Now the latent period of the ciliary muscle can be judged of only by analogy, it must be assumed to be about equal to that of other non-striated muscle.

What is then the time occupied by this "reaction period" required for impulses leaving the retina to return to the ciliary muscle? This question, the writer fears, cannot be answered at all satisfactorily. But he thinks that he will be well within the mark if he assume that it will be at least equal to the reaction period calculated for striated muscle, viz. ·2 sec.

It is, however, probable that with special practice it diminishes very much, just as that of striated muscles is said to do also, and that was the explanation given at another part of this paper, of the great reduction in the duration of accommodation with practice. The relative uniformity of the results obtainable after the first few days' practice being probably due to psychical training, the steady daily decrease after this is due to the education of the subordinate nerve mechanism.

Hence, at least ·4 sec. must be deducted from the measurements given for A, C and D and ·34 sec. for B, in order to arrive at an approximate measurement of the duration of contraction of the ciliary muscle; and such a result will only be trustworthy when obtained from observations effected after some practice.

The writer only feels justified in assuming that this reduction corrects for the reaction period at the end of the observation, and diminishes the difference caused by that at the commencement. It might be thought that the whole difficulty could be got over by adopting Vierordt's plan of trying to send two impulses from the brain at the same moment, one to the recording hand and one to the ciliary muscle, but this method has been found in practice to give unreliable results.

The corrected measurements for the eyes of A, B, C and D follow, and represent the duration of the contraction of the ciliary muscle, as nearly as it can be arrived at by this method of calculation. The amount of the reduction, however, is necessarily provisional, and only in the case of A and B was it determined by direct examination of their reaction periods.

Corrected Measurements in the case of A.

I. Accommodation Velocity.

Distance From	to	Right Eye	Left Eye	Date
		secs.	secs.	
Infinity	33 cm.	1·26	1·36	Jan. 9th.
		{ ·94	1·36 }	Jan. 10th.
		·94	1·69	
		·96	1·57	Jan. 12th.
		·79	·93	Jan. 15th.
		·58	·67	Jan. 20th.
		·506		Jan. 23rd.
		·27	·32	Jan. 24th.
		·35	·37	Feb. 4th.
		·32	·42	Feb. 7th.
Infinity	11 cm.	1·86	1·99	Jan. 10th.
		1·33	1·22	Jan. 20th.
		1·42		Jan. 23rd.
			·71	Jan. 24th.
		1·18	1·1	Feb. 4th.
		1·22	1·1	Feb. 7th.
33 cm.	11 cm.	·74	·64	Jan. 23rd.
		·62	·66	Feb. 4th.
		1·05	·89	Feb. 7th.
50 cm.	16 cm.	·58		Jan. 23rd.
		·5	·44	Jan. 21st.
			·53	Jan. 24th.
		·56	·42	Feb. 7th.

Corrected Measurements in the case of B.

From	to	Right Eye	Left Eye	Date
		secs.	secs.	
Infinity	33 cm.	·1	·16	Jan. 27th.
		·16	·2	Feb. 7th.
Infinity	11 cm.	·26		Jan. 27th.
		·38	·19	Feb. 4th.
		·44	·45	Feb. 7th.
33 cm.	11 cm.	·2	·19	Jan. 28th.
		·2	·16	Feb. 7th.

Corrected Measurements in the case of C.

From	to	Right Eye	Left Eye	Date
		secs.	secs.	
Infinity	33 cm.	·39		Feb. 3rd.
"	17–18 cm.	1·17	1·18	
"	18–19 cm.	1·08	1·08	
50 cm.	20 cm.	·586	·45	
33 cm.	Infinity	·28		

All other Relaxation Velocities too rapid for measurement.

Corrected Measurements in the case of D.

From	to	Right Eye	Left Eye	Date
		secs.	secs.	
Infinity	33 cm.	·82		Jan. 31st.
		1·1	1·63	Feb. 4th.
		·93	1·18	Feb. 4th.
Infinity	14 cm.	1·4	2·2	Feb. 4th.
Infinity	15 cm.	1·37		Jan. 31st.
		1·44	2·02	Feb. 4th.
33 cm.	15 cm.	1·21		Feb. 4th.
50 cm.	20 cm.	1·1		Jan. 31st.
33 cm.	Infinity	·68		Jan. 31st.

Mean Results.

In the case of A.

From	to	Right Eye	Left Eye
Infinity	33 cm.	·691 secs.	·96 secs.
"	11 cm.	1·4 "	1·22 "
33 cm.	11 cm.	·80 "	·73 "
50 cm.	16 cm.	·546 "	·53 "

In the case of B.

Infinity	33 cm.	·135 "	·18 "
"	11 cm.	·36 "	·32 "
33 cm.	11 cm.	·2 "	·17 "

Rates at Different parts of the Range.

The velocity of active accommodation seems to be the same for equal distances at any part of the range.

Thus on Feb. 4 in case of A, the time occupied in accommodating from infinity to 33 cm. (·35 sec. R. and ·37 sec. L.), together with that occupied from 33 cm. to 11 cm. (·62 sec. R. and ·66 sec. L.) amounts to ·97 sec. R. and 1·03 secs. L., and nearly equals the time taken to accommodate through the whole distance infinity to 11 cm., viz. 1·18 secs. R. and 1·1 secs. L.

Again on Feb. 7,

The accommodation period from infinity to 33 cm. was ·32 sec. R. and ·42 sec. L. This with the duration of accommodation from 33 cm. to 11 cm., viz. 1·05 secs. R. and ·89 sec. L., together amount to 1·37 secs. R. and 1·31 secs. L., whilst the period occupied in accommodating for the whole distance from infinity to 11 cm. was 1·22 secs. R. and 1·1 secs. L.

Again on Jan. 23rd,

Infinity to 33 cm. required ·506 sec. R., which together with ·74 sec. R., time required for the change from 33 cm. to 11 cm., = 1·246 secs., whilst that of whole distance was 1·42 secs. R.

Hence it will be seen that the difference in any case is less than ·2 sec. and being variable in both directions may reasonably be ascribed to defective measurement.

In the case of B,

On Feb. 7th the period of accommodation from infinity to 33 cm. was ·16 sec. R. and ·2 sec. L., which together with that from 33 cm. to 11 cm. viz. ·2 sec. R. and ·16 sec. L., is ·36 sec. R. and ·36 sec. L., whilst the whole distance took ·44 sec. R. and ·45 sec. L.

The observation of the same character on the eye of D gives a discordant result, but its isolated character and the peculiarities of D's eye render the observation untrustworthy.

The results of these measurements shew that the duration of accommodation from infinity to 33 cm. and from 33 cm. to 11 cm. together very nearly equal that from infinity to 11 cm. But it will be seen that any comparison of this sort depends for its value on the accurate determination of the reaction periods.

Since, if the reaction periods be x for the ciliary muscle, and y for the hand muscle, and the contraction period say ·5 sec. for accommodation from infinity to 33 cm. and ·7 sec. from 33 cm. to 11 cm.

Then these together are

$$1{\cdot}2 \text{ secs.} + 2x + 2y.$$

Now assuming the duration of the contraction from infinity to 11 cm. to be 1·2 secs. the accommodation would take 1·2 secs. $+ x + y$. In other words in the first case the reaction delay appears twice in the calculation.

This objection applies equally to the observations made by anyone, and the writer is very loth to place much value on conclusions based on the corrected measurements.

It was suggested that possibly the accommodation velocity from a moderately far to a moderately near distance might be relatively rapid, and measurements have been made accordingly from 50 cm. to 16 cm. in the case of A and B, and from 50 cm. to 20 cm. in the case of C and D.

The range to be travelled over in accommodating

from infinity to 33·3 cm. is 3 D,
from 50 cm. to 20 cm. is 3 D,
and from 50 cm. to 16 cm. is 4 D.

Although the distance to be traversed from 50 cm. to 16 cm. is greater than that from infinity to 33·3 cm., still the two sets of measurements will bear comparison.

In A, 50 cm. to 16 cm. acc. vel. was

on Feb. 7th, ·56 sec. R. and ·42 sec. L.,
on Jan. 23rd, ·58 sec. R.

From infinity to 33·3 cm.

on Feb. 7th, ·32 sec. R., ·42 sec. L.,
on Jan. 23rd, ·506 sec. R.

In the case B duration of accommodation from 50 cm. to 16 cm. was too rapid to be measured, i.e. less than ·1 sec. reduced, and less than ·5 sec. gross measurement. But that from infinity to 33 cm. varied from ·1 sec. to ·2 sec., so that though a difference does occur in this case it is not marked enough to establish any conclusion.

In the case of C accommodation from

infinity to 33 cm. took ·39 sec.,
and from 50 cm. to 20 cm. „ ·5 and ·6 secs.

In the case of D accommodation from

infinity to 33 cm. took ·82 sec.
and from 50 cm. to 20 cm. „ 1·1 secs.

The sum then of these observations tends to the rejection of the supposition that accommodation from moderately far to moderately near is more rapid than accommodation in the more extreme part of the range; and it is the writer's opinion that the ciliary muscle contracts at very much the same rate through equal distances in any part of its range, e.g. the accommodation velocity from 16·6 cm. to 11 cm. (3 D) is much the same as that from infinity to 33·3 cm. (3 D).

General Conclusions.

The conclusions which are to be deduced from these observations seem to be that

(1) The *accommodation apparatus* acts with varying degrees of rapidity according to different circumstances, the principal of which are

(*a*) Age.

(*b*) Lesions of refraction.

(*c*) Practice (?)

(*d*) Individual characteristics.

(*e*) Time of day.

(*f*) Fatigue.

(2) Relaxation occurs with very much greater rapidity than active accommodation.

(3) That, with two eyes of much the same refractive character, the accommodation velocity of either measured separately is about the same as that of the two acting in concert.

(4) That in the present state of knowledge no absolute data can be given as to the time occupied by the action of the local mechanism for any given distance.

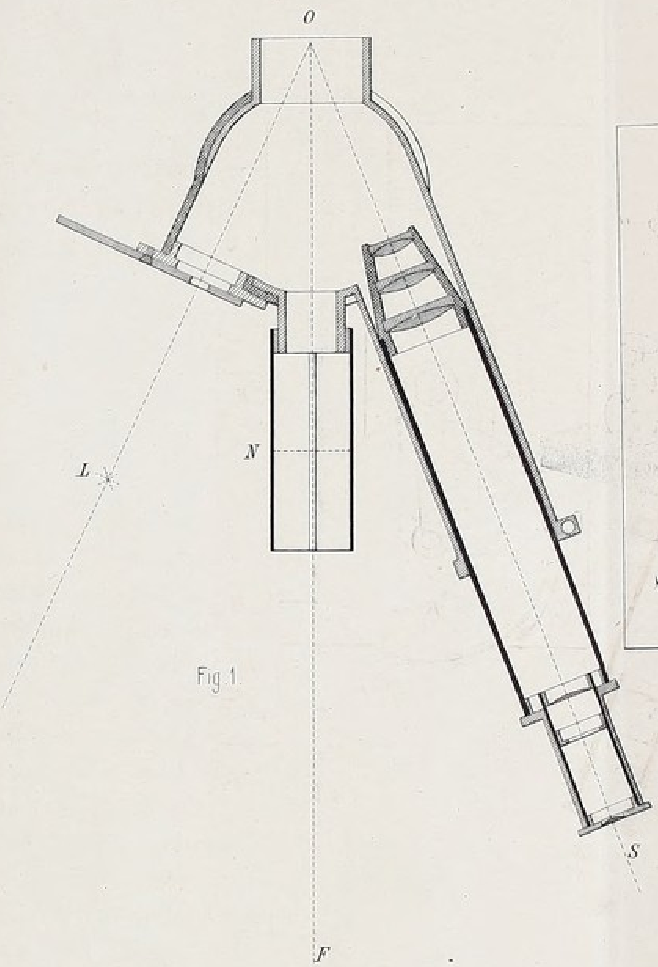

Fig. 1.

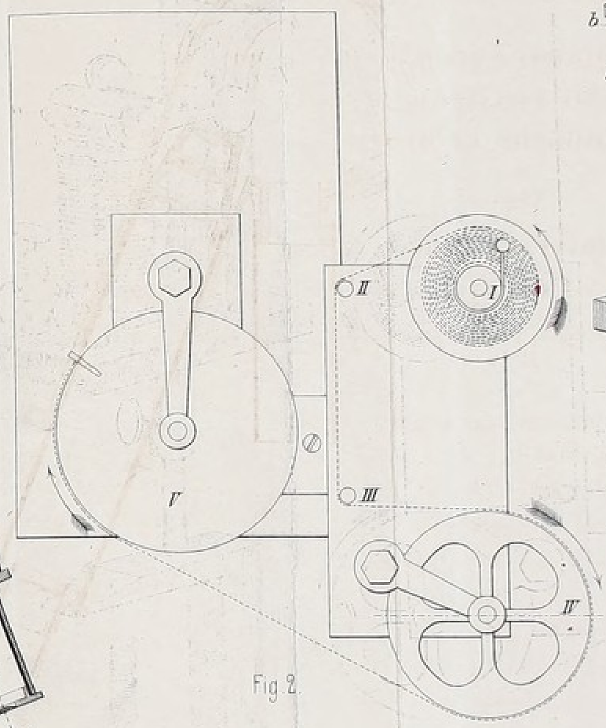

Fig. 2.

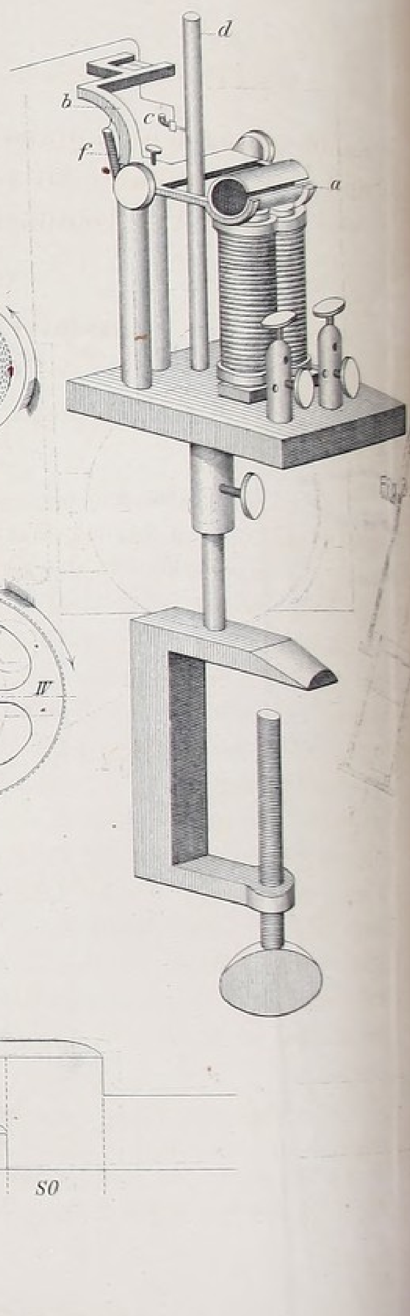

Fig. 3.

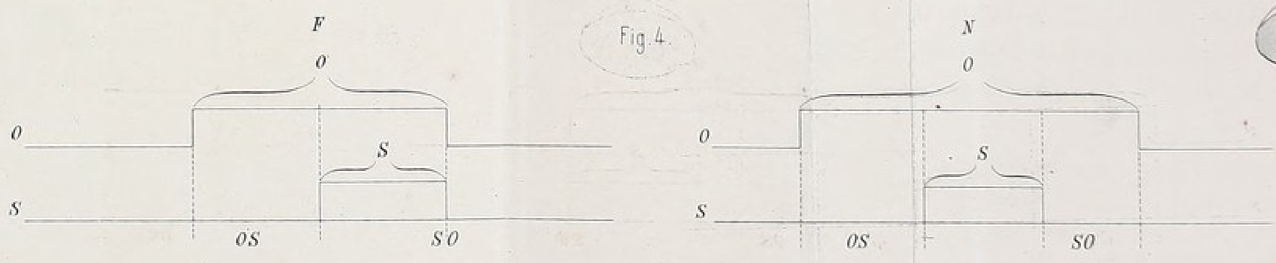

Fig. 4.

Lith. Anstalt v. F. Wirtz, Darmstadt.