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COMMUNICATIONS

FURTHER EXPERIMENTAL STUDIES IN
INTRAOCULAR PRESSURE AND TONOMETRY*

BY

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MANY and varied are the lines of investigation and experiment which may be carried out in relation to intraocular pressure, but inasmuch as I have come over here from the States on the invitation of the Master and Council of this Congress, to speak on the subject of tonometry and the McLean tonometer, I will confine my remarks to investigations made along those lines.

My first records of intraocular pressure were made from the finger palpation methods, and I have had no experience with the earlier tonometers such as the Fick, Maklakof, Priestley Smith, Donders, and the others. My first experience with tonometers was with the Schiötz and the Gradle-Schiötz instruments, and in using these instruments I discovered certain annoyances, which it seemed to me could be abolished in a tonometer constructed along different lines.

1. The distance between the cornea of the eye under examination and the reading scale of the Schiötz or Gradle instruments

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renders it difficult for one person to see that the tonometer is placed correctly on the cornea, and make a reading of the scale simultaneously.

2. A translation of the obtained readings into millimeters on the chart according to the weight used is necessary and consumes time.

3. The delineation of the fine lines on the chart is very trying to the eyes.

4. There are times when the estimated pressure is so far divergent from the indication by the instrument that a delay occurs in changing weights, after the reading has been started. (Some nervous patients while in the recumbent position become annoyed by the delay caused in changing weights, when it has been ascertained that the estimated weight was inadequate for the pressure of the eye under examination.) In this respect the Gradle instrument is an improvement on the Schiötz, as with the Gradle the changing of weights is simplified.

5. I have observed in both these instruments that the plunger fits the footplate barrel so closely that fluid remaining on the cornea at the time of making a reading may be drawn up into the instrument by capillary attraction, and the accuracy of the reading impaired. (Paul Knapp of Switzerland observed the same possibility of error due to capillary attraction).

In my tonometer the calibrations on the scale are in millimeters of Hg. as determined by actual manometer readings; a detailed description of this testing apparatus was given in a former paper.

The scale is placed just above the finger piece and as close to the examined eye as possible, so that it can be more readily observed by the operator.

The plunger, instead of fitting accurately, has a space of one millimeter between it and the base, and is held in position by the rounded ends of three hardened steel bearings placed 120° from each other. This reduces friction to a minimum, and also prevents capillary attraction of any fluid which might remain on the cornea.

All the readings on the scale from 10 to 130 mm. Hg. are made without change of weights.

Before the days of the Schiötz tonometer, I had been estimating the intraocular pressure of patients by the prevailing method of finger palpation. Estimations of pressure, if we translated them into mm. of Hg., were based on the experiment of Wahlfors. His determination of normal intraocular pressure was 26 mm. Hg., which was in harmony with the experiments on the lower animals, made by many other experimenters. This is the only experiment on record in which an eye of normal tension has been connected directly to a manometer.

When the Schiötz tonometer was adopted a new conception of the normal intraocular pressure was introduced. The Gradle

tonometer is a copy of the Schiötz and Dr. Gradle wrote me that he used a Schiötz tonometer to determine the scale for his tonometer.

My experiments tend to revert to the standard as established by Wahlfors and the early experimenters, rather than the newer scale put forth by the Schiötz tonometer.

The first reference I found in literature to increased intraocular pressure was that of Mackenzie who in 1830 observed that a hardness of the eyeball occurred in glaucoma. The importance of the correct conception of the intraocular pressure has been admitted since the full force of Mackenzie's discovery became manifest, and we find in looking over the history of ophthalmology that investigators early appreciated the inaccuracy of the estimation of intraocular pressure by the digital method.

The manometer in actual connection with the interior of the eye and with a perfect technique is the only method known to-day of obtaining absolutely accurate conceptions of the intraocular pressure.

The first records of experiments in ophthalmo-manometry that I could find are those of C. Weber in 1850, but he fails to draw any conclusions as to the normal intraocular pressure. Later, Wahlfors made some experiments with the human eye *in situ* in connection with the manometer, and in some correspondence I had with Professor Fuchs, he advised me that my experiments were in harmony with those of Wahlfors.

The usual method of determining the intraocular pressure experimentally has been to introduce a canula into the interior of the eye, and attach a manometer by means of tubing to the canula. Both the water and mercury manometers have been employed, depending on the construction of the apparatus.

Many experimenters have made investigations into intraocular pressure, and generally dogs, rabbits, and cats have been used. The conclusions reached are that the normal intraocular pressure of these animals ranges from 18 to 35mm. Hg.

In constructing an apparatus for my experimental work on eyes *in situ*, I tried to incorporate the good features of the apparatus used by previous investigators with improvements of my own design. I made a canula having a tempered steel needle, the opening in the needle being on the side. The taper conformed to an angle of two degrees and had two flat sides. I made two needles, the lumen of the one used for work in connection with the anterior chamber was 0.8 mm. in diameter, while for use in the vitreous, a needle of 2 mm. bore was used.

To overcome any possibility of altering the original pressure of the eye by the volume of metal thrust into the eye, a needle valve was interposed in the lumen just far enough back from the opening to compensate for the volume of the metal in the eye. A half turn of the valve was sufficient to open the needle completely.

Investigators have repeatedly found that the canulas of small bore will become clogged when used in connection with the vitreous chamber. I discovered while working on the living eye that my needle of 0.8 mm. bore could not be depended on when it was in connection with the vitreous chamber, but it worked very nicely in the aqueous chamber. With the 2 mm. needle I had no trouble.

One experimenter has published his results of work done along the line of intraocular pressure with the Schiötz tonometer when he used a canula of 0.8 mm. bore on eyes of the dead human being. During life the pulsations imparted to the fluid of the testing apparatus which comes in contact with the contents of the interior of the eye is an indication that the canula has not become clogged. With dead eyes there is no pulsation to aid the experimenter, so it is impossible to know that the apparatus is working properly. I made these experiments before the paper referred to above was published. After reading the article, to satisfy myself as to the value of experiments with an 0.8 mm. needle in the vitreous, I repeated the experiments and found they verified my first conclusions.

In my work the canula was connected to a thirty-inch-long glass capillary tubing by short lengths of rubber pressure tubing. The total volume of fluid contained in the capillary tubing was about ten minims. The other end of the glass tubing was connected through a T piece to a manometer and a reservoir. The object of the capillary tubing was to enable me, by means of a small air bubble sucked halfway up the tubing, to compare and equalise the manometer and the intraocular pressures.

A water manometer was used, but it was graduated to its equivalent in millimeters of mercury. The reservoir was suspended and was capable of adjustment as to height, in order to alter the manometer pressure at will. Figure 1 shows a cut of the apparatus. Figure 2 shows an enlargement of the canula needle.

In using the apparatus the needle was introduced with its valve closed and the connected manometer registering the estimated intraocular pressure. The position of the air bubble was marked, and when all was in readiness, the valve was given a half turn and the movement of the air bubble noted. If the bubble moved toward the manometer it indicated a greater intraocular than manometer pressure and vice versa. A manometer pressure was obtained which caused the bubble to remain at, or, in case of movement, to return to, its original position. A reading of the manometer was then made. Great care had to be exercised to prevent any traction or pressure of the needle on the eyeball.

To the present time, of living animals I have employed rabbits, dogs, and cats and four living human eyes.

I have been particularly fortunate in being allowed to make experiments on four living human eyes *in situ*.

In a paper which I read before the Section of Ophthalmology of the Academy of Medicine, New York City, I presented the results of experiments performed on the eyes of rabbits and dogs and the experiments on three living human eyes *in situ*. Since then I have been further favoured in being allowed to make similar tests on another living human eye *in situ*.

FIG. 1.

FIG. 2.

In my experiments an observation was made, one which I had never read or heard of: that the tonometer registered a difference in intraocular pressure under local, and immediately after under deep general anaesthesia. The animal was first cocainized and the intraocular pressure determined by tonometer, then after administering the general anaesthetic the tonometer was again used before any other instrumentation was done. With the human cases holocain was used for local anaesthesia instead of cocain, but approximately the same proportion of difference prevailed.

Since that paper was published I have received letters from oculists stating that since reading my article they have looked for and found a difference in intraocular pressure in local and deep general anaesthesia.

I made one set of animal experiments for the purpose of determining the relation of intraocular pressure to the depth of ether anaesthesia. In those experiments the canula here described was inserted into the eye. As the anaesthesia progressed, the intraocular pressure became lessened until a point was reached where for a period no drop in the intraocular pressure prevailed. The ether cone was removed and the animal allowed to recover. As the animal was about to regain consciousness, it was noted that the manometer registered approximately the same intraocular pressure as at the start of the anaesthesia. This also demonstrated that we had a perfect connection and no leakage around the canula at its insertion into the eye.

The purpose of the experiments in this paper is to determine the relative accuracy of the Schiötz and McLean tonometers, using a living eye *in situ* and connecting it directly to a manometer.

I might add that all the tonometer readings were made by others than myself.

Animal Experimentation

The general plan followed in this series on cats was first to determine the intraocular pressure under cocaine using both the Schiötz and McLean tonometers. The cat was then etherized and readings again taken, after which the canula was inserted and readings taken to determine any alteration in pressure caused by the introduction of the needle into the eye. (In all of my experiments it has been observed that on account of the position of the valve in the canula, the alteration of pressure by the introduction of the canula into the eye was a negligible quantity.)

With this system we were able to alter the intraocular pressure at will and make comparative readings with both tonometers.

CAT 1.—The eye was cocaineized and a Schiötz tonometer reading of 17.5 mm. Hg. was made. At the same time the McLean tonometer recorded a pressure of 32 mm. Hg. The animal was then etherized and the Schiötz recorded 10 mm. Hg. while the McLean registered 22.

The canula with its valve closed was inserted into the vitreous chamber and the Schiötz recorded 10; McLean, 22.

The valve of the canula was then opened and a manometer pressure of 25 mm. Hg. was necessary to keep the air bubble at its original position. This showed us that the actual intraocular pressure at that moment was 25 mm. Hg.

Subsequently manometer pressures of 20, 40, 50, 70, 90, 110 were produced and readings with both the Schiötz and McLean instruments were made.

After the experiment the eye was enucleated and connected to the manometer when comparative readings were again made.

Chart 1 shows graphically the results of this test.

CHART 1

McLean.			Schiötz.
Cocain	32		17.5
Ether	22	Before inserting canula.	10
Ether	22	After inserting canula.	10

Manometer with air bubble 25 mm. Hg.

Manometer mm. Hg.	McLean.		Schiötz.	
	In Situ.	Enucleated.	In Situ.	Enucleated.
20	19	23	7	10
30	—	34	—	20
40	40	43	21	24
50	50	52	38	35
60	—	60	—	37
70	70	72	52	53
80	—	82	—	65
90	90	93	72	76
100	—	102	—	70
110	110	110	78	72

CAT 2.—With the eye under the influence of cocain the Schiötz reading was 17.5 and the McLean 32. Under ether Schiötz was 10 and McLean 23. After the needle was inserted the Schiötz recorded 11, and the McLean 22, then the valve was opened and the intraocular pressure was found to be 22 mm. Hg.

Manometer pressures were produced the same as in the previous test and corresponding readings taken which are shown in Chart 2.

CHART 2

McLean.			Schiötz.
Cocain	32		17.5
Ether	23	Before inserting canula.	10
Ether	22	After inserting canula.	11

Manometer with air bubble 22mm. Hg.

McLean.			Schiötz.	
Manometer mm. Hg.	In Situ.	Enucleated.	In Situ.	Enucleated.
20	20	23	10	5
30	—	32	—	18
40	39	44	26	31
50	46	54	31	37
60	—	64	—	42
70	68	72	47	48
80	—	82	—	55
90	90	90	60	65
100	—	100	—	68
110	110	108	68	70

CAT 3.—With the eye under the influence of cocain the Schiötz reading was 24, and McLean 33. When the animal was thoroughly under ether the Schiötz reading 13 and McLean 23 was recorded. With the needle inserted the Schiötz again registered 13 and McLean 24. When the valve was opened the manometer pressure which sustained the bubble was 22mm. Hg. Chart 3 shows the results of readings made, altering the manometer pressures as in the previous tests.

CHART 3

McLean.			Schiötz.
Cocain	33		24
Ether	23	Before inserting canula	13
Ether	24	After inserting canula	13

Manometer with air bubble 22 mm. Hg.				
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McLean.			Schiötz.	
Manometer mm. Hg.	In Situ.	Enuc.	In Situ.	Enuc.
20	19	22	11	10
30	—	30	—	18
40	40	40	24	24
50	48	49	28	32
60	—	62	—	44
70	70	71	51	51
80	—	82	—	54
90	90	90	58	60
100	—	104	—	75
110	108	112	71	84

The tonometer readings on the animal eyes were made by Dr. Holzapfel. Dr. Hallett used the tonometer on the human cases. The human eyes tested were all glaucomatous, and were being removed on account of an uncontrollable pain. The experiments of the first two were performed before I had my tonometer perfected; on the third and fourth both the Schiötz and McLean tonometers were used.

The fact that I have had the privilege of experimenting on four living human eyes *in situ* is of sufficient importance to warrant a review of the three cases recorded in a former article.

The fourth case has not been previously recorded, and was demonstrated at the Clinical session of the June, 1919, meeting of American Homeopathic O. O. and L. Society in New York City.

In the first human case tonometer readings were made on both

eyes under holocain anaesthesia. The tension of the affected eye was 75, while the healthy eye registered 19 Schiötz. Under ether the affected eye registered 45, and the healthy eye 10 Schiötz.

A canula, as described before with a bore of 0.2 mm., was thrust into the vitreous chamber well back of the ciliary processes. After the position of the air bubble was marked, the valve was opened. It was found that a manometer pressure of about 65 mm. held the bubble at its mark. With the needle in the vitreous chamber we were able to make tonometer readings and compare them with the manometer, which readings were as follows :

Manometer pressure.		Schiötz's tonometer.
65	...	50
65	...	50
64	...	43
66	...	50

Tests made on this same eye after it had been enucleated gave the same ratio of variance between the manometer and Schiötz tonometer in all pressures of 10 mm. to 120 mm. Hg. as may be noted by Chart 4.

CHART 4.

Human eye *in situ* used at the hospital for tests with water manometer and Schiötz tonometer. (Diag. Glaucoma Absolutum, O. D.). Manometer needle, 2mm. bore, with valve, and glass capillary tubing, 30 in. long and 1mm. bore. Needle was connected with vitreous chamber.

	O.D. Schiötz.		O.S. Schiötz.
Before anaesthesia	75		19
During anaesthesia	45	Manometer	10
" "	50	65	
" "	50	65	
" "	43	64	
" "	50	66	
Same human eye (enucleated) :			

Manometer mm. Hg.	Schiötz Tonometer			
	15 Gm.	10 Gm.	7.5 Gm.	5.5 Gm.
120	105			
110	96	86		
100	86	71		
90	58	65		
80	53	60		
70	42	56	62	
60	33	51	43	43
50	23	32	31	
				35
40	14	23	20	22.5
30	6	14.5	19	16
20	x	6.	11.5	7.5

On the second human case tested, readings were made of the affected eye only. Before general anaesthesia a Schiötz tonometer reading of 88 mm. was made, and at the first reading under general anaesthesia the Schiötz recorded 72 mm. Hg. The canula was immediately inserted and the Schiötz again recorded 72, which shows that the insertion of the needle made no change in pressure. The valve was opened connecting the interior of the eye with the manometer and a manometer pressure of 88 mm. was required to keep the air bubble in its original position.

As the anaesthesia was increased tonometer and manometer readings were made, which were:

Manometer	Schiötz Tonometer
86	72
81	54
72	47

As the anaesthetic was continued there was no decrease of intraocular pressure below 72. (manometer), so the experiment was concluded and the eye enucleated.

On the third human case both the Schiötz and McLean tonometers were used. On account of the condition of the patient we were allowed time to make only one reading with each instrument. In my haste I perhaps chose a faulty location for my canula as it was with difficulty that we could keep a connection of the interior of the eye open to the manometer as evidenced by the diminished oscillations of the air bubble, while in the other cases the bubble oscillations were readily discernable all the time the valve was open.

The readings of this case were, Schiötz 40, McLean 58, and the manometer recorded 60 mm.¹

On the fourth human case, under holocain, a reading was made of 46 Schiötz, and 70 McLean. After the patient was etherised a reading was made of 43 Schiötz, and 62 McLean.

The needle was inserted with valve closed as in the other cases and a reading was made of 43 Schiötz and 63 McLean.

The manometer was adjusted to a pressure of 43mm., the pressure as recorded by the Schiötz tonometer, and the valve of the canula was then opened. As soon as the valve was open, the air bubble started toward the manometer. This showed us that the intraocular pressure was greater than the pressure of the manometer. There was also a slight oscillation of the air bubble which was synchronous with the heart and by that oscillation we were assured that a good connection between manometer and eye existed. The

¹ The demonstrations of the human cases above cited were all made at the New York Ophthalmic Hospital in the presence of eye specialists. At the demonstration of the third case about thirty oculists were present and of the fourth case about forty.

manometer pressure was raised until the air bubble was driven back to its original position, and it was found that a manometer pressure of 65 mm. Hg. sustained the air bubble at that point. The indication then was that the true intraocular pressure was 65 mm. Hg.

It may be noted in all the experiments on the living eye, both human and animal, that the intraocular pressure was highest under local anaesthesia, and as soon as the patient was thoroughly under the influence of the ether the pressure was lowered; the deeper the anaesthesia the lower the pressure until a limit was reached.

Chart 4 shows the readings made on the human eye *in situ*, and the corresponding readings after the eye was enucleated. It has been suggested that inasmuch as the large number of tests I made on living eyes *in situ* agreed with the tests of those same eyes after enucleation it is pretty good evidence that my testing apparatus for enucleated eyes is fairly correct.

When I began my work on the tonometer I had not the slightest idea I would run counter to the good work of Prof. Schiötz. My only thought was that it was possible with a new instrument* to render a refinement in tonometry.

I trust you will not consider this paper as an attack on the Schiötz tonometer.

The values of the Schiötz and McLean tonometers are not the same, and I have shown the differences in the readings of the two instruments in association with the manometer merely to substantiate my claims for the scale I have adopted on my tonometer.

In seeking, first, a method of testing out my tonometer, I used the Schiötz as a basis of measurement, and I discovered that I could not make the Schiötz and manometer agree, yet could not find anything wrong with my testing apparatus. I called on several oculists for assistance, and they were unable to suggest a fault in technique or apparatus. I then consulted a professor of physics of Columbia University, and he assured me my apparatus was correct, and if a discrepancy existed the fault must lie in the tonometer. At this same time I was working out the new features for my tonometer, and the first McLean tonometer I constructed entirely myself, as I did also all the canulas used in my experimental work.

At another time I invited a professor of physics of the boys' high school to inspect my testing apparatus from the standpoint of physics, and he reported to the Section of Ophthalmology, Academy of Medicine, that he had examined the apparatus, and saw tests made, and found everything in perfect keeping with the laws of physics.

I showed my tonometer to Mr. E. B. Meyrowitz when it was all

finished except the scale, and he asked the privilege of manufacturing and placing the instrument in the hands of the oculists.

The late Dr. Marple was one of the oculists who saw some of my early experiments, and I mentioned to him that I intended writing Prof. Schiötz regarding the discrepancy I found. Dr. Marple asked if I would allow him to communicate to Prof. Schiötz what he had seen of my experiments, and send him a description and drawings both of my testing apparatus and the results of my tests, as Dr. Marple and Prof. Schiötz were close friends. I allowed him the courtesy he asked, and furnished him with a drawing and description of the testing apparatus, also a tonometer to send to Prof. Schiötz. The McLean tonometer was in Prof. Schiötz's possession over six months, and in his reply he failed to criticize the testing apparatus or the results.

My testing apparatus for enucleated eyes consists of a water manometer, with its necessary connections of glass and rubber tubing; a canula connected to a stop-cock by short length metal tubing, to which is attached the apparatus which I have termed a pulsator.

I have used both the mercury and water manometers, and found the water manometer more convenient for use. The results were the same, as of course they should be.

The canula I made with a 2 mm. bore and made a trocar to fit, so that it could be inserted through a sufficiently long stump of optic nerve into the vitreous chamber.

The connection between the eye and stopcock is made entirely of metal to avoid the possibility of expansion by a more elastic substance.

The pulsator is an apparatus which I have constructed to simulate the pulsations of the arteries of the living eye. You have all noted in using the tonometer that there are oscillations of the needle which are synchronous with the heart beat. My apparatus causes these same slight oscillations of the indicating needle. The apparatus is run by clockwork.

The Testing of McLean Tonometers

For testing tonometers, the enucleated eyes *must not* be kept in any hardening or preserving fluid and should be used as quickly as possible after enucleation. A few hours is sufficient to alter the resiliency of the tunics of the eyeball for testing purposes. They must be absolutely fresh.

While the eye is being used in the testing apparatus, it is ensheathed in a rubber cap which acts similarly to Tenon's capsule. This cap is of extremely thin high-grade rubber tissue and is sufficiently large so as not to be put at all on the stretch when the

eye is placed in it. It encases the eye almost to the margin of the cornea, and acts as a reservoir to hold the normal salt solution which keeps the eyeball from becoming less resilient.

Before using the eye it is cleared of all extraneous material down to the sclera. The imitation Tenon's capsule is adjusted and the canula with its trocar is passed in through the centre of the stump of the optic nerve until the opening is in the vitreous chamber, when the trocar is withdrawn. A perfectly tight joint must be obtained, and the canula adjusted to the short metal tubing connected to the stopcock.

Outside the rubber tunic an adjustable ring support around the optic nerve acts as a base to support the eye without inducing any pressure or traction.

As soon as the eye is placed in position, I fill the rubber tunic with normal salt solution. This keeps the eyeball from becoming less pliable, as the eye under pressure changes quite rapidly by contact with the air.

When all is in readiness the stopcock is opened. The pressure of the liquid should be raised in the manometer until the correct height is reached. (Do not proceed from a greater to a lesser pressure). After the desired pressure is obtained an interval should elapse to allow the tunics of the eye to become adjusted to that pressure before a reading is made.

I have a normal salt solution at hand, also a pipette with which I am constantly dropping the normal salt on the cornea before each application of the tonometer. The stopcock remains open, except when it is closed to make a tonometer reading. It is opened immediately after the reading and remains open until the next reading.

With this apparatus I am able to obtain any pressure from 0 to 135mm. of mercury.

It was by actual tests with this manometer, using several tonometers on repeated readings, that the present scale on the McLean tonometer was adopted.

With this tonometer the lower limit of normal intraocular pressure is to be considered as 22, while I have not found a normal eye registering above 40. I have placed the upper limit at that figure because I have found eyes registering 40 in which there were no symptoms, subjectively or objectively, of glaucoma. It is difficult to give an absolute limit of normal pressure. I have found a few eyes that registered as low as 36 with the McLean tonometer and 22 with the Schiötz, in which symptoms of glaucoma were present.

Altogether, in my experimental work, I have tested over two hundred enucleated eyes, and a considerable number of eyes *in situ* of the lower animals.

Aside from the work of Weber and Wahlfors, I think I am the only man who has done any experimental work on living human eyes *in situ*, by connecting the interior of the eye to a manometer.

THE VISUAL PERCEPTION OF SOLID FORM.*

BY

E. M. EATON.

(Concluded from p. 340)

In the circumstances which lead to the perception of double images a small amount of non-identity of direction can be overcome by the tendency to achieve single vision. This is accomplished by error of projection, and the limits within which it is possible are those which have been described as the limits of fusion. As the underlying cause is in effect illusion of form, they are probably closely associated with the limits of illusion.

The mechanism of binocular vision, as I conceive it, may be summarized as follows:

1. The vision of each eye remains physiologically independent except as regards fixation; apart from this the unification of the two images has reference to the object perceived not to the means of perception.
2. The physiological axes of vision are interpreted as occupying their actual positions, the lines passing through the point of fixation and the nodal points of each eye.
3. The perceptive axis of vision lies between the fixation point and the middle of the interocular space. Its use involves a psychic modification of all visual angles similar to that which enables us to interpret foreshortened images in accordance with their true values.
4. The perception of position in three dimensions is a function of the sense of directional projection of the two eyes. The perception of relative position in three dimensions is a function of the sense of relative directional projection of the two eyes.
5. Double images result from a certain degree of perception of the subjective element in the sense of sight, with consequent alteration of the foregoing relationships.

If binocular impressions are but a phase of projection sense impressions, or more inclusively of form sense impressions, there can be no subjective reason, no reason on the ground of a specific feeling quality, why the vision to which they give rise should differ

* A paper read before the Ophthalmological Section, Royal Society of Medicine, on June 4, 1919.