

term to classify congenital tumors, even taining no dermal tissue, hairs or sweat those of simple histologic structure con- glands.

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## DETERMINATION OF MINIMUM LIGHT SENSE AND RETINAL DARK ADAPTATION WITH PRESENTATION OF A NEW TYPE OF PHOTOMETER.

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This paper reviews the principal hypotheses with reference to light and dark adaptation, and suggests a practical photometer, using a radioactive substance as a standard of comparison. With three illustrations, and experimental findings with this instrument.

The retina is the physiologic point of contact between the external stimulus, light, which the eyes require to convert the world without into a place of form and dimension, luminosity and color; and the final perception of these as "definite qualitative entities in consciousness." The conversion of the physical into a psychologic stimulus is brought about by demonstrable structural, chemic and electric changes engendered by the action of the light waves upon the retinal neuro-epithelial layer of rods and cones.

Reference to one monograph (J. Herbert Parsons, *An Introduction to the Study of Color Vision*, Cambridge, 1915) is sufficient to show the vast literature dealing with the complex elements, singly and combined, that go to make up this one phase of the visual act. The whole question may be roughly reduced to the one statement that all visual sensations are dependent upon the power that the retina possesses of adapting itself to, and converting into nerve stimuli, light vibrations of varying degrees of intensity.

The simplest example of light and dark adaptation of the retina is the experience of common knowledge, that if we pass from the bright sunlight into a dimly lighted room we cannot plainly

distinguish objects until our eyes have become accustomed to this feeble illumination. If, again, we go out into the sunlight we are dazzled by its brightness, until the eyes have once more become adjusted to this degree of light. From the physical standpoint this is entirely a question of the intensity of the external stimulus. From the psycho-physiologic viewpoint, these phenomena are dependent upon certain material alterations which take place in the nerve cells of the retina, in turn exciting neuro-visual consciousness.

It is with this latter aspect that we are concerned, for we may assume that the external stimulus as such exists whether or not we have eyes to see; therefore, we may dismiss from consideration all the qualities of light as vibratory energy in ether, except its quantitative variability, on which depends the two great classes of sensation into which our consciousness of light may be divided, viz.: color sensation and colorless sensation.

Light vibrations are converted into nerve stimuli by the neuro-epithelial rods and cones which make up the outer layer of the retina. It is necessary to remember that there are no rods at the fovea centralis, but passing outward from the

central spot rods begin to make their appearance in increasing numbers, until at the periphery they far outnumber the cones. Parsons distinguishes three areas, as follows: The fovea centralis measuring 0.24 mm. to 0.3 mm. and subtending a visual angle of from 55' to 70'. A rod free area measuring 0.8 mm. and subtending 3° 3'. The macula measuring from 1 to 3 mm. and subtending 4° to 12°.

Beneath the layer of rods and cones is the layer of pigment epithelium which, tho counted as part of the retina, is in reality outside. The cells of this layer are hexagonal in section and have processes passing up between the rods and cones. The cells contain minute needle shaped crystals of pigment. In the rods alone there is found the substance known as rhodopsin or visual purple, which may only be demonstrated after the eye has been in the dark, as it is completely bleached out by the action of light and is supposed to be reformed only in contact with the pigment cells. In the dark the pigment crystals are found in the cells close to the nucleus, but when the eyes are exposed to light they wander up into the cilia-like processes between the rods and cones. With these anatomic facts in mind let us consider the relationship that can be made out to exist between the varying intensities of the external stimulus light and the resulting sensations elicited.

Let us assume, for example, that we are seated in a room brightly and uniformly illuminated from a source capable of gradual reduction in power until the room is in complete darkness. Under the bright illumination the eyes may be said to be light adapted, or *photopic* (nomenclature of Parsons), we see all objects distinctly and recognize colors. As the illumination decreases in intensity the yellows, normally the brightest colors, are exceeded in brightness by the greens, the blues become lighter and the reds darker. These changes in the relative brightness of colors constitute the well known Purkinje phenomenon. Finally, we can no longer perceive colors at all and objects take on various shades of grey. Later, we can only perceive the form of objects, and then comes com-

plete darkness with no visual sensations. The eyes have been gradually becoming dark adapted or *scotopic*.

Under the conditions described we know that the following changes have been taking place in the perceptive end-organs of vision. In the photopic eye the rods are free of all demonstrable visual purple, and the pigment crystals are found in the cilia between the rods and cones. As dark adaptation proceeds the crystals of pigment migrate back into the cell body, and visual purple becomes evident in the base of each rod. On these anatomic facts there have been built up many theories, two of which must be briefly quoted, (1) The visual-purple theory of Edridge-Green and (2) the duplicity theory of v. Kries.

F. W. Edridge-Green (The Hunterian Lecture on Colour Vision and Colour Blindness, 1912), states his theory as follows: "A ray of light impinging on the retina liberates the visual purple from the rods and a photograph is formed. The rods are concerned only with the formation and distribution of the visual purple, not with the conveyance of the light impulses to the brain. The ends of the cones are stimulated thru the photo-chemical decomposition of the visual purple by light (very probably thru the electricity which is produced); and a visual impulse is set up which is conveyed through the optic nerve fibers to the brain. The character of the stimulus varies according to the wave length of the light causing it. In the impulse itself we have the physiologic basis of the sensation of light, and in the quality of the impulse the physiologic basis of the sensation of color."

Edridge-Green feels that he has proved his theory on evidence which he gives in his book. It is not necessary to go into this except to further quote: "that the visual purple is the essential factor in the retina which enables it to transform light into visual impulses. I find four depressions or canals which lead into the larger depression of the external fovea. These canals appear to have smaller branches and serve to conduct the visual purple into the part of most acute vision. The cones which are present in the fovea

have very long outer segments which would present a greater surface for photo-chemic stimulation. I have examined under the microscope the retinas of two monkeys which had been previously kept in a dark room for forty-eight hours. The yellow spot was the reddish part of the whole retina and the visual purple was seen to be between and not in the cones."

The duplicity theory of v. Kries (Parsons) states that achromatic scotopic vision is carried out thru the medium of the rods alone, the cones being the organs of photopic vision. In dark adaptation with low intensities of light, vision is performed by the rods stimulated by the visual purple, as the intensity of the light increases the liminal stimulation values for the cones is exceeded, and vision is carried out both by the rods and cones (chromatic scotopia). At still higher light intensities vision is carried out chiefly or wholly by the cones (photopia), but whether the rod effects are added to the cone effects, or are abolished, is as yet uncertain.

It will be seen that the formation of the visual purple is, at least, the basis of dark adaptation. In everyday life there is always a moderate amount of scotopia present which is constantly varying to meet the requirements of the moment. We cannot perceive colors unless the light stimulus is above a certain intensity whose liminal value Parsons calls the specific or color threshold. Below this is the colorless interval of light perception, which increases with the amount of dark adaptation present. It is with this interval that my studies are chiefly concerned.

In every physiologic process there is a stimulus which excites, and a resulting reaction, or sensation. There is, of course, a more or less constant relationship between the stimulus and the reaction; and in any investigation it is usual to reduce the external stimulus to its simplest form and then study the resulting sensations, or to observe the simplest reaction that can be elicited by a variety of stimuli. The simplest visual sensation that we can have is the recognition of light, and the sim-

plest stimulus is one that will just produce this reaction under approximately known conditions of retinal adaptation.

It occurred to me that the radioactive preparations so extensively used in the manufacture of luminous watch-dials and other instruments, would furnish an ideal light stimulus of constant value and low intensity, and with the coöperation of the "Cold Light Mfg. Co." of Denver and New York I obtained a series of discs of the radioactive substance which they put out under the trade name of "Marvelite." This substance is sulphid of zinc impregnated by radium: the latter constituent I have proved to my own sat-

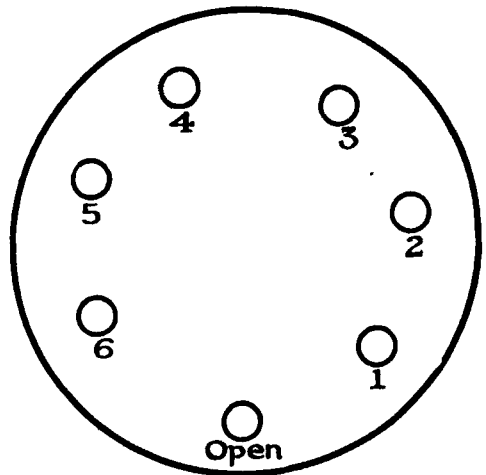


Fig. 1. Disc with openings carrying "Marvelite" exposed or covered with varying thicknesses of celluloid.

isfaction by numerous photographic experiments.

The Cold Light Mfg. Co. has instituted photometric measurements concerning the compound, and so far they have been able to determine that there is a rapid initial increase in the luminosity of the radium luminous compounds, followed by a decrease over a period of about six months, the rate of decrease then becomes slower and slower, until at the end of one year the luminosity attains a value which is sensibly constant. The "Marvelite" discs which I am employing in my ex-

periments have been in my possession for a year.

As my experiments were to be along clinical lines I have calibrated these discs in the following manner. One was chosen as a standard which would just give the sensation of light as soon

with layers of No. 5 opaque white celluloid I determined, by experiments carried out at night after two hours in an absolutely dark room, that my minimum lightsense in full dark adaptation was represented by the standard disc covered by five layers of the celluloid.

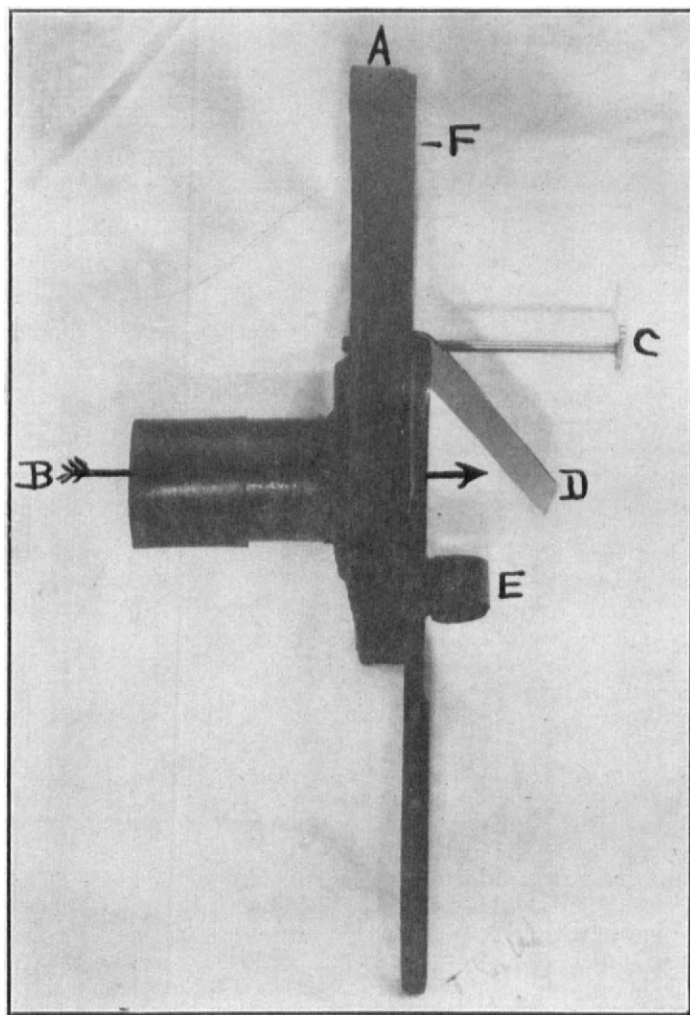


Fig. 2. The photometer described in the text. At F there is an opening through which may be read off the number of the "Marvelite" disc which is before the eye.

as I had passed from a well lighted room at midday into a photographic dark room. This disc is considered the minimum light stimulus to the light adapted eye. By photographic exposures I obtained a series of discs of similar intensity and by covering them

Six of these discs were then mounted on a circular plate (Figure 1), Disc No. 1, being the uncovered "Marvelite Button" accepted as the minimum effectual stimulus for the photopic eye. Disc No. 6 covered with five layers of celluloid being the minimum light stimu-

lus under full dark adaptation or scotopia. Discs Nos. 2, 3, 4, 5 and 6 being covered with 1, 2, 3, 4 and 5 layers of the celluloid. I have, therefore, six light stimuli of different degrees of intensity. The following apparatus was then constructed and certain experiments undertaken:

Figure 2 is a photograph of the photometer. The large wheel (Fig. 1) is mounted in the Box A and can be revolved before the eyepiece B by the handle C. When the opening in the wheel is before the eyepiece the observer is, of course, looking straight

moved and the photometer brought into position and kept light proof by a leather cuff.

Let us for the moment anticipate the many problems involved and assume that the instrument is of accepted usefulness. The "blinders" are adjusted with the shutters out of the eyepieces. One shutter is replaced and the instrument is adjusted over the other eye-tube. The test object wheel is set at "open" and the observer is told to watch the round spot of light. The "Marvelite" disc No. 1 is now quickly turned into place and the individual



Fig. 3. The "blinders" which are fastened over the eyes.

thru the instrument against the reflector D, which is covered with greenish blue paper to correspond with the faint greenish glow exhibited by the "Marvelite" discs of the higher intensities. The object E on the handle of the instrument is to hold a small electric light for experimental purposes to be later described. The "Marvelite" test discs are 7 mm. in diameter. The instrument is generally used at 10.5 cm. from the eye. The retinal image is therefore 1 mm. and subtends a visual angle of  $4^\circ$ . Figure 3 represents the "blinders" which are used in the application of the test. The slides are easily re-

should immediately see it. The actual test of the dark adaptation is made as follows. The "blinders" are closed and the patient is asked to keep the eyes shut. At the end of ten minutes the photometer is adjusted over one eye and the individual is asked to say when the light spot first becomes visible. The test-wheel is now slowly revolved so that the "Marvelite" discs of the weak intensities first appear before the eye. The moment the patient says, "now I see light," the number of the disc is noted and the result written in the form of a fraction the numerator of which denotes the patient's mini-

imum light sense, the denominator the minimum light sense which numerous observations have indicated as the normal. After ten minutes in complete darkness, disc No. 5 should be seen. If the dark adaptation of the retina is normal the test is completed in ten minutes; this statement, I think, can be substantiated by the experimental work now to be described.

EXPERIMENT 1.—Is the Marvelite Disc No. 1 the minimum light stimulus for the light adapted or photopic eye? Under ordinary conditions of everyday room illumination, yes. Under full light adaptation or what may be termed light excess induced by looking at the clear sky on a bright day, no. But even under the latter conditions disc No. 1 becomes evident within thirty seconds after the eye is brought from light into darkness, which proves that the range of light adaptability even in the photopic eye is exceedingly wide. This has been proved by experiments on many individuals. If we accept Edridge-Green's theory, then we must assume, that in the light exhausted eye the visual purple is very rapidly reformed, or that it still preserves photochemic activity even in the bleached out state.

Just how greatly the sensitiveness of the retina to light is increased by dark adaptation is proven by the comparative luminosity of the "Marvelite" disc No. 1 under photopic conditions and in scotopia. In the latter state of the retina the disc is sufficiently intense to illuminate the tube of the eye piece and to slightly raise the minimum light sense. For example, if Disc No. 1 is viewed under full scotopia and the test wheel is then quickly turned to disc No. 6, the latter cannot be distinguished for a few seconds, altho it represented the minimum light sense just a few moments before. Under photopia disc No. 1 can just be discerned as an extremely faint light.

EXPERIMENT 2.—Dark adaptation is very rapid at the beginning of the process and exceedingly slow toward the completion. When the light adapted eye is brought from light into darkness disc No. 2 will become visible in about

thirty seconds. Disc No. 3 requires at least ninety seconds of dark adaptation. Disc No. 4 is seen in from three to four minutes and after ten minutes disc No. 5 is just discernable. After ten minutes of dark adaptation the process becomes very slow. In observations made at midday disc No. 5 represented the minimum light stimulus after ten minutes; this was not lowered during an hour's experimentation, altho the luminosity of disc No. 5 became appreciably greater. After two hours observation in a dark room disc No. 6 could just be seen.

As Parsons has said, experiments in dark adaptation are much influenced by the condition of retinal adaptation at the beginning of the observations. I have found that if the individual to be tested has been sitting in a dimly lighted room his photopic minimum light sense may be represented by disc No. 2. With this in view I experimented with a small electric light mounted on the back of the photometer with the idea of bringing all eyes to the same degree of light adaptation before beginning any tests. This has been found unnecessary for the reason that dark adaptation, according to my observations, progresses with definite constancy within all periods under an hour. Disc No. 2 as the minimum photopic light sense only indicates that there is already that amount of dark adaptation present; disc No. 5 may become the minimum light stimulus in less than ten minutes, but beyond that time there will be no appreciable lowering of the light sense, certainly not within the time that one has to devote to a clinical test.

To obtain uniform results it is well to allow the patient to sit in a moderately lighted room for a while before the test is to be made. The photopic minimum light sense is then tested by bringing the instrument before the eye, the patient should immediately see disc No. 1. If there is some slowness in this, beyond sixty seconds, it is indicative of slow dark adaptation. The blinders are then put on and the patient allowed to wait for ten minutes. At the end of this time each eye is tested and

disc No. 5 should be seen. If disc No. 5 is seen the test may be discontinued and the dark adaptation noted as normal. If disc No. 4 represents the minimum light sense after ten minutes the test should be continued for ten minutes longer, when, if disc No. 4 still represents the minimum light sense, the result may be noted 4/5 and dark adaptation considered as "slow." A minimum light sense below disc No. 4 is considered "abnormal."

For the time being I have adopted the following chart to preserve a record of examinations.

	Dark
	Min. Light Stim. Adaptation
Immediate	{ R. Disc. No.
	{ L. Disc No.
After 10'	{ R. Disc No. /5
	{ L. Disc No. /5
After 20'	{ R. Disc No. /5
	{ L. Disc No. /5
Remarks:	

EXPERIMENT 3.—Dark adaptation occurs in each eye independent of its fellow and is not influenced by light adaptation of the other eye. One eye was kept in darkness for one hour, the other was left open, the experiments being made in a brightly lighted room at midday. Dark adaptation proceeded as heretofore described, disc No. 5 becoming visible in ten minutes and remaining the minimum light stimulus during an hour of further experimentation. Ordinary light stimulus of the other eye had no influence on the dark adaptation of the other eye. Excessive light stimulation of the open eye, e. g., looking directly toward the sun, had no appreciable effect on the dark adapted eye, except that for a moment the dazzling occurring in the light adapted eye seemed to confuse the dark adapted eye. This seemed more the result of the vast difference in the cerebral impressions than any effect on the retina, as the disc could be seen surrounded by a halo of after-dazzling.

EXPERIMENT 4.—Dark adaptation of one eye does not hasten dark adaptation in the other. After one eye had been kept in the dark for one hour, the other eye was closed and frequent observations made. It was found that dark adaptation proceeded in exactly the order before noted, that is to say it took ten minutes to bring the sensibility of the retina down to disc No. 5.

EXPERIMENT 5.—Dark adaptation proceeds equally in both eyes. If both eyes are tested simultaneously it will be found that dark adaptation is the same in each eye after the same period of time. This has been confirmed by numerous tests and, therefore, I feel that it may be stated that dark adaptation, altho an independent process of each eye, is an extremely constant and uniform chemico-physiologic process. If, in clinical determinations, one eye is found to be different from the other, after the same period of time, it is more than suggestive that there is some abnormality in the retinal adaptation.

EXPERIMENT 6.—Is there a summation of effect in the dark adapted eyes? Some observers have found that the minimum light stimulus required is less with binocular vision than with monocular vision. Working with these light stimuli of exceedingly low intensity I have not been able to confirm these findings.

EXPERIMENT 7.—Full dark adaptation is very quickly overcome by exposure of the eye to light. If, after full dark adaptation, the eyes are completely exposed to light, dark adaptation will be overcome in thirty seconds at the most; that is to say, that the minimum light stimulus will be raised from disc No. 5 to disc No. 1, and it will again require the minimum ten minutes to bring the minimum light sense down to disc No. 5. In other words, the bleaching out of the visual purple is very rapidly accomplished if the whole retina is exposed. If, however, only a restricted portion of the retina is exposed to light, the minimum light sense of that portion of the retina is raised, but very quickly regains its minimum light sense. This, to my mind, rather confirms the theory

of Edridge-Green that there is a flow of the visual purple.

Experiments in regard to this were conducted in the following way: Both eyes were kept in the dark for twenty minutes so that the minimum light sense was represented by disc No. 5. Then the blinders were entirely removed and the eyes exposed to bright daylight for thirty seconds; the blinders were then replaced and it was found that the minimum light sense had been raised to disc No. 1. Furthermore, it required the usual ten minutes to again lower the light sense to disc No. 5. After full dark adaptation was again obtained the eye was exposed to a bright light thru a small aperture (5 mm.). This raised the minimum light sense to disc No. 1, but within sixty seconds the minimum light sense was again disc No. 5. In my opinion dark adaptation proceeds regularly over the whole retina. It may be locally bleached but this portion is again quickly sensitized by a flow of the visual purple to the spot, rather than by immediate reformation, otherwise it would require a much longer time to lower the light sense of the restricted area. From these experiments I am inclined to believe that a test of a restricted portion of the retina, such as is made by my photometer, is sufficient to judge the adaptability of the whole retina.

EXPERIMENT 8.—Is there any dark adaptation at the central part of the retina? It has already been noted that Parsons distinguishes three areas in this part of the retina, the fovea, a rod-free area and the macula containing a few rods. Used at 10.5 cm. from the eye the 7 mm. test object subtends a visual angle of  $4^\circ$ . This would overlap the rod-free area slightly as this portion is estimated by Parsons to subtend  $3^\circ 3'$ . On the other hand it covers the minimum area allotted to the macula proper of from  $4^\circ$  to  $12^\circ$ . In the discs of low intensity the area of the disc is less than 7 mm. As these discs do not emit any divergent radiations

and can only be perceived as light "spots" of very low intensity, irregular in outline and not luminous in the periphery, I calculate their diameter to be about 5 mm. *Undoubtedly there is marked dark adaptation at the macula and if the size of the discs is reduced to 5 mm, dark adaptation can be shown to be present to the same degree in the rod-free area.*

If, however, the discs are viewed thru a pinpoint opening, thus reducing the visual angle practically to zero and making visibility entirely a question of luminosity, disc No. 2, even under complete dark adaptation, becomes the minimum light stimulus. I do not find, however, that the light sense is lower than disc No. 2 even in the extramacular region when tested with the pinpoint disc. I have reached the conclusion, therefore, that there is marked dark adaptation at the macula and in the rod-free area thereof, if the test-object is sufficiently large to subtend a definite angle. At the exact fovea, or in the periphery for that matter, when probably a few cones are stimulated by the point of light, there is very slight dark adaptation below the minimum light sense of the photopic eye. Conclusions in this regard are as yet uncertain. This particular phase of the question is open to much further investigation.

Finally, the work which I present at this time, is to a large degree confirmation of the findings of others; the instrument and the experiments are admittedly elementary.

The manufacturers of "Marvelite," with the coöperation of the United States Bureau of Standards, are making a scientific effort to standardize the luminosity of their product. It is probable that they will be able to produce a radiant substance of uniform value, which can be accurately calibrated. Clinically I have used the test for a year and have found the results extremely interesting and worthy of further study. These reports with further experiments I reserve for a future communication.