of a certain intensity will produce a positive after-image if it is of interest to the observer, negative if it is not. McDouball has pointed out that borders graded from the brightness of the figure to the darkness of the ground constitute a condition favorable for the production of positive after-images; also that the duration of both the positive and the negative phase is about the same under mean conditions; that is, the longer the positive lasts, the longer will be the duration of the negative. He has also demonstrated the production of a positive after-image of unusually long duration from fairly intense stimulations of the dark-adapted eye with durations of stimulation subliminal for the production of a negative after-image. This same phenomenon has also been studied by Swindle, and by Dimmick who found that no after-image of a red parofoveal stimulus nor of a white central stimulus of less than foveal size was obtained. Swindle maintains that a positive after-image stage merely preceded the negative if careful fixation has been maintained both during the impression and following impression, thus a loud sound occurring at the termination of the stimulus makes it impossible to see this primary positive stage because according to Swindle, it induces reflex movement of the eyes.

The phenomenon known as the "flight of colors" has been a favorite point on the fabigue assumption. Following stimulation by white light a varied series of color after-image is produced whereas theoretically, these should be achromatic. McDougall has shown that a similar "flight of color" follows when the stimulus is a colored light of any hue. Here the negative after-image should be comolementary. Hartman has pointed out that the negative after-image of an ambiguous field with different colored halves changes from one blended color to two separate complementary colors as the perception of the spatial pattern shifts from a single to a double meaning.

The instances are mentioned merely to indicate from the large literature the fact that the concept of the after-image as a "retinal fatigue" or adaptation phenomenon seems to account for many of the observed facts and therefore leaves the proper understanding of mechanism unaccounted for. Later in this paper some after-image phenomena will be shown which do not lend themselves either to the fabigue-adaptation assumption or to the concept that after-images are solely the result of local photochemical processes in the retinal elements. This simply means that there are grounds for reasonable doubt as to whether the simplest and most primary of the after-image phenomena is retinal or cortical or both.

Whenever we stimulate the retina with light and the stimulus is withdrawn after a short period the visual field will have a different appearance in consequence of the preceding stimulation from what it would have had if the latter had been of different intensity or color. This phenomenon is customarily referred to as visual adaptation and adaptation may be regarded as a temporally induced effect in contrast to spatial induction. If the primary stimulation is limited to a definite part of the retina the persisting after effects are called after images.

The nature and course and properties of after-images have been studied largely in relation to the size, hue, intensity, etc., of the stimulating ray and to some extent they have been viewed as dependent upon the brightness, form, etc., of the projection ground. In 1899 Franz studied the relation of size of the stimulus patch and the duration and intensity of the exposure to the induced after-image and its duration. He found that something analogous to the reciprocity law holds in that a reduction in stimulus duration or intensity or size was accompanied by a reduction in the process and duration of the after-image. A much more extended study of these relations was made by Barry and

Imus in 1935 in which they showed that the duration of the after-image increases with increased intensities of stimulation and with increased duration of the stimulus up to as long as 60 seconds.

Many observers have shown that if brightness is equated, the wave length of a stimulus has no effect on the duration of the after-image. In peripheral image the duration is shorter. After-image duration also was found to be greatest in the morning when the eyes were fresh and least when the eyes were fatigued from prolonged work at the near point.

Ebbecke in 1929 reported perhaps one of the most carefully made studies on the conditions for producing the after-image. He proposes, as a result of his work, a theory which assumes in the retina not two opposed after effects, but one effect only. This he called after-excitation.

After a brief flash of light, measured by the reaction time method, Creed and Granit and later Finebloom have shown that the latency of the after-image is generally from two to three seconds. This is longer for intense than for weak stimuli. The latent period is not empty as the observer is partially dark adapted. He can note the primary momentary flash, a second flash and a third weak positive effect followed by a negative after-image, all of which happens within a couple of seconds, as Judd has shown.

Under favorable conditions of stimulation a series of after images may be seen. As many as 9 fifferent after effects have been described by G. E. Mueller but all of these would be seen only in the ideal case. Of these the 3rd (Hering), 5th (Purkinje), 7th, 8th and 9th are after-images. If the stimulus is relatively intense and its background in good contrast the following effects can readily be described; (1) immediately after the stimulus there is a brief formless flash of fairly high intensity usually described as reddish or yellowish regardless of the hue of the stimulus; (2) an image of like chiaroscuro relations and like hue to the stimulus object. This is the positive after-image; (3) an interval of darkness or absence of after-effect lasting a second or two; (4) an image or reverse chiaroscuro relation and hue complimentary to the stimulus object; (6) an irregular fading, disappearance and modification of form comprising an unpredictable series. If the duration of this last series is gradual, shifts in hue take place. Most authorities tend to agree quite closely on the order of these effects. From the 4th stage on, there is usually considerable movement or drifting of the after-images.

In working with after-images it will be discovered that a certain amount of practice or training is necessary in order to acquire the best observation of these effects. At first it is best to work only in the early morning shortly after arising. Stimulate after partial or complete dark adaptation. Use a series of 8 inch by 8 inch squares of light, medium and dark gray, and red, green blue and yellow as background and prepare 2 inch by 2 inch squares of the same material. These can be laid flat on a table and illuminated from a shaded lamp of about 100 to 500 watts. The viewing distance should be about 2 feet. If black and white papers are available include them in the series. Place a small square of white in the center of the 8 inch square of black, fixate the center of the white patch continuously and without eye movement for 20 seconds. Maintain the same eye posture, extinguish the light and simultaneously cover up the test patch with medium gray. Wait patiently for the after-image to appear and do not be too hasty in assuming that it has run its full course. Following this same procedure use a medium gray ground. Place upon this successive 2 inch by 2 inch patches of yellow, green, blue and red.

Carefully describe the after images. If this is done several times and you carefully write out your description attempting to specify hue, saturation and brightness, you will note a marked improvement in your observational skill. Try all combinations of test patch and ground.

After dark adaptation in a darkened room look at a 25 or 40 watt frosted mazda lamp for 5 to 20 seconds. Extinguish the light and again without moving the head or eyes, observe carefully the succession of colored after-images and describe these carefully. Write down or dictate the order and duration of each phase and repeat these several times; sometimes when fresh and sometimes after a long hard day. Compare your protocols with respect to points of difference as to duration, intensity, hue, order, etc.

With the aid of an assistant develop an after-image of a bright yellow 2 inch by 2 inch square on the 8 inch by 8 inch black background, for example. Carefully measure the distance from the test patch to your eyes. After 20 seconds of such stimulation project the after-image upon a large square of gray cardboard about 24 inch by 30 inch. You work best if you work in a room where the illumination level is ve y low, enabling you just to distinguish the form of the gray square. Place the gray cardboard square first at 2 feet, then at 4 feet, then at 8 feet from the eyes. Have the assistant measure the total area of the projected after-image. It will be noted that the size of the after-image follows Emmert's Law. This law states that the projection area will be 4 times as great when the distance is doubled, 9 times as great if the distance is tripled, etc. Repeat the observation this time projecting the after-image to the corner of the room where the wall meets the ceiling. Note that the image tends to tale the shape of the projection ground. Set the gray cardboard square about 8 feet from the eyes and between the eyes and this square interpose a similar sized white square in the center of which has been cut a diamond shaped apperture whose dimensions are about 6 inch by 6 inch. Try to project the after-image through the hole in the first square onto the rear gray square. Also try changing the distance, shape and size of the apperture in the intermediate screen.

For work with transmitted light a light tight box should be constructed with a hinged front. Place a strong light inside this box. Arrange a suitable window in the front of the box so that pieces of colored glass, papers, etc., can be trans-illuminated. Cut from a square of black cardboard 4 slots as indicated in Figure I.

Fig. 1

The upper and lower members should be covered with red paper, the left and right members should be covered with green paper. The small central area should be covered with a piece of light gray. Develop an after-image from the light transmitted through this figure. Report the observation several times describing carefully what you see. Now reverse the test object so that the left right members are now in the top bottom position and report the observation. This is done in order to convince you that the effect noted must be ascribed to the retinal cortical mechanism and not to the hues of the members in the stimulus patch.

Prepare a transparency similar to Figure II below.

G

R

Fig. 2

The larger green square should be about 34 mm on a side, and the smaller red square 5mm by 5 mm. The small square is separated from the larger square 20 seconds and describe the after-image; after extinguishing the light and projecting upon a gray screen at the same distance. Now fixate the center of the smaller red square and repeat the observation. Repeat this with the small square in the R. L. above and below positions.

Make another transparency of the same materials like Figure III.

G R

Fig. 3

In making transparent figure, colored papers, gelatins or glass can be placed over suitable appertures cut in stiff black cardboard or thin metal.

Take two 8 inch squares of saturated green paper and place them side by side on a neutral gray ground so that a vertical gray strip about 1/2 inch wide is visible between them. Fixate on the middle of the gray strip with the eyes about 15 inches from the paper for 20 seconds in ordinary daylight Now look about the room and note that on whatever ground you look such as the walls, floor, chairs, etc., you will see a narrow green strip. Note that a reddish hue is induced in the gray strip during fixation and that the green strip after-image can be accounted for as the complementary after effect of the induced red. Regions eccentric to the maculae, however, which have been stimulated by the large green squares do not develop red after-images. Try to develop a certain explanation of the total suppression of the green field in this experiment.

Finally, I should like to suggest a most interesting field for study: after-image phenomena produced by stereograms in color. Recently I have shown that by the control of figure-ground relations in the stimulus-perceptual field third dimensional effects can be completely suppressed. By other arrangements they may be brought out clearly. Start with line-drawn geometric figures which make relatively simple shapes. At first try placing these in one hue upon an undifferentiated background of the complementary hue. Make another series in which black, white or gray stands between the figure and its ground. Surround the figure with a moderately heavy black circle slightly larger than the figure. You will observe some very thought-porvoking things.

ERRATA

In the April paper on Color Phenomena, Part II, the definitions of the terms protanopia and deuteranopia were reversed. Protanopia means a limitation of visibility for the red portion of the spectrum. Deuteranopia means a limitation of visibility for the green portion of the spectrum. This correction is made in the interests of accuracy of statement. It should be emphazized, however, that such classifications of anomalous color vision do not satisfactorily fit the facts.

The relative question is the determination of the amound of variation from the normal visibility for the spectral hues and not the arrangement of persons into a typological classification which is rarely seen in actual cases.