coast of Europe and Asia was perfectly practicable to that river. Some of the scientific results of these expeditions were published in NATURE at the time, and it is well known that so far as the immediate object was concerned the expeditions were completely successful. Full details will be found in Mr. Leslie's volume. From what we have said it will be seen that comparatively young as Prof. Nordenskjöld is, he has done an amount of work rarely accomplished even in a long lifetime. Appended to Mr. Leslie's volume is a long bibliography of the published results of these expeditions of Nordenskjöld, and from this it is evident that they have borne rich fruit in nearly every department of science.

HERING'S THEORY OF THE VISION OF LIGHT AND COLOURS[1]

II.

BEFORE propounding his theory, the author thinks it necessary to devote one memoir—the fourth—to an essay, the object of which is to define clearly the nature of the sensations of black and white and their mixture gray. He remarks that it is a habit to treat visual sensations rather according to their physical origin than by their own nature; and this peculiarly influences the ideas entertained about the sensations of black and white. We know that physically, white light is a combination of rays of all wave-lengths, and we have no physical notion of black except a negative one, namely, as an absence of light of any kind. Hence, transferring our physics to our physiology, we consider that our sensation of white is a positive one, but that our idea of black arises simply from the absence of all sensation; or, to use a metaphor drawn from painting, black is our canvas, or background, on which all our sensation-pictures are drawn in white or colours; as a result of this, all our reasoning is confined to the pictures, while the background receives no attention.

The author, as one of the main points of his theory, strongly objects to this view. He denies that the natural unimpressed state of the visual sensation corresponds with black, appealing to every-day experience in support of the opinion. Any one who carefully examines his impressions after being for some time in a perfectly dark room, will observe a dark field, it is true; but if he tries, in imagination, to compare this with his sensation of a piece of the blackest velvet, he will be obliged to admit that the field is nothing approaching the latter in darkness; it is, in fact, only dark gray. Or as an easier and simpler test, let him compare the black after-image of a white disk with the general field given by his closed and darkened eyes, and he will observe a similar contrast.

The author's view is that the impression of black, like that of white, can only be derived from external sources; and that consequently black is a perfectly independent visual sensation, which should be studied physiologically like those of white, or red, or blue. On physiological grounds it is no more reasonable to consider black as the absence of white, than white as the absence of black, or blue as the absence of yellow, or to consider a sphere as the absence of solids of every other form.

On this principle he proceeds to discuss the sensation of gray. He objects to the usual mode of defining different shades of gray as merely different *intensities of light*. He considers any sensation of gray as a combination of the two independent sensations, black and white, in certain proportions; he calls this accordingly a *black-white* sensation, and he proposes to express it in a mathematical form. The full and perfect extreme sensations are practically unknown, and therefore no positive quantitative expressions can be used for them. But it is quite permissible to give an algebraical idea of the difference between intermediate gradations, and this may be done in the form of a ratio, or fraction, of which the two components express the assumed amounts of white and black respectively that are combined in the sensation. For example, there must be a practical gray (though we cannot identify its exact shade) which is intermediate between white and black, resulting from an equal force of each sensation. Here therefore if W = the force of the white sensation, and B = that of the black one, $\frac{W}{B} = \frac{1}{1}$ or $= 1$. For a lighter gray in which there is twice as much white as black, $\frac{W}{B} = \frac{2}{1} = 2$. And for a darker gray, in which there is twice as much black as white, $\frac{W}{B} = \frac{1}{2}$. On this principle the pure white sensation would be expressed by $\frac{W}{0} = \infty$, and the pure black sensation by $\frac{0}{B} = 0$.

It is possible, still retaining the principle, to give a more convenient expression for the brightness or lightness (*Helligkeit*) of any black-white sensation; thus, the degree of brightness may be expressed by the ratio which the *white element* bears to the *whole sensation*, or $= \frac{W}{W + B}$. Thus the brightness of the medium gray will be $= \frac{1}{1 + 1} = \frac{1}{2} = 0{\cdot}5$; and that of the mixture of two white to one black will be $= \frac{2}{2 + 1} = \frac{2}{3} = 0{\cdot}66$; and that of the mixture of two black to one white $= \frac{1}{1 + 2} = \frac{1}{3} = 0{\cdot}33$. The brightness of pure white will be $= \frac{1}{1 + 0} = 1$, and that of pure black $= \frac{0}{0 + 1} = 0$. This mode of definition corresponds to the usual practical idea of the *intensity* of white in gray, but it differs from it by acknowledging the independent black element in the composition.

In the fifth memoir we at length get a statement of the fundamental features of the author's theory, so far as the black-white sensation is concerned.

He begins by objecting to the treatment of white as a mixture of complementary colours, as blue and yellow, or red and green, or of all colours together, an idea which has arisen solely from physical considerations. No one, he says, can pretend that the least trace of any other colour can be distinguished in a pure white sensation; all that can be said is that the sensation of white is produced by a mixture of light of different wave-lengths. But the sensation is a perfectly independent one, like black, or red, and must be so considered in an investigation into the *rationale* of the visual perceptions.

Since the physiologist considers all sensations as called into existence by physical processes of the nervous system (for otherwise every physiological investigation would be objectless), he must assume so-called psycho-physical processes or movements which correspond to the sensations of black, of white, and of all shades between them. In what part of the nervous system these psycho-physical processes are situated it is impossible to say; suffice it that, somewhere in the nervous apparatus of the eye and the parts of the brain standing in functional relation therewith, a substance must be sought, with the changes or motion of which the sensation is bound up; this substance may be called the "visual substance" (*Sehsubstanz*).

The action of this substance may be studied in two ways: either *à priori*, by considering the physical influences brought to bear upon it, or, *à posteriori*, by considering the sensations resulting from its changes. The former mode has hitherto been of little profit, for

[1] Continued from p. 613.

although we can follow the ether vibrations to the retina, it has not been possible to trace what happens beyond. We can, indeed, compare the physical influences with the sensations produced, but we are obliged, in doing so, to skip over the intervening physiological steps where the chief interest lies. Hence the backward study of the processes, as inferred from their results, affords the best chance of success.

As to the general nature of the action of the visual substance, we have a choice between the idea of mechanical vibrations and that of chemical changes. Modern physiology points to the latter, for the general physiology of the nerves has sufficiently shown that all movement and all activity of the nervous substance produces chemical changes in it, and all our representations of changes of sensitiveness, fatigue, and restoration after activity, are founded on the assumption of such chemical changes. And however varied may be the views as to the details of this action, so far is certain that the continual presence of chemical processes in every vital and sensitive substance is a fact, and that material change is the most universal known property of every living thing.

It is therefore taken for granted that light produces chemical changes in the nervous apparatus of the visual organs; and what we term fatigue and change of sensitiveness depend, by general consent, on chemical changes of the sensitive substance. Hitherto, however, it has been customary only to consider this (so far as black and white are concerned) as an effect of *white* light; the element of black being neglected altogether, as already explained. The author proposes to correct this error, and he formulates his extended theory as follows:—

The two kinds of sensation which we call white (or light) and black (or aark) correspond to two distinct kinds of chemical action in the visual substance; and the various proportions in which these appear in the mixed sensation of gray, correspond to the same proportions of intensity of these two psycho-physical processes.

This is the simplest explanation conceivable, and it fulfils every condition demanded by general nervous physiology. We must assume a sensitive substance in the visual apparatus, which suffers a change by the action of light, and this change is generally believed to be a chemical one; and when the stimulating action is removed there must be a corresponding change in the other direction, giving a return to the normal condition. If the former change is assumed to be a partial consumption of matter, then the opposite change must be a restitution; if the former change is an analytical or disintegrating one, the latter must be a synthetical or reintegrating one, and so on.

Now the latter process, by which the living organic substance replaces the quantity lost by stimulation or activity, is usually called *assimilation*, and the author retains this name. The previous or contrary process, where the loss is caused by stimulation or activity, he calls *dissimilation*. Having to use these terms very often he denotes them by the letters A and D respectively.

These two processes result from the knowledge of physiology in general, and if they are correct, there is no reason why, as heretofore, only one of them, D, should be admitted to a theory of visual perception, and the other, A, excluded from it. The author's theory of the black-white sensation, therefore, embodies the proposition that *the sensation of white corresponds to dissimilation, and that of black to assimilation of the visual substance*, so that our visual sensations furnish a psychical expression of the correlation of the changes in the matter of this substance.

The following propositions are easily deducible from this principle.

The degree of lightness or darkness of a colourless visual sensation corresponds with the proportion between the intensities or magnitudes of the D and A actions respectively. For the medium gray these actions are equal, $\left(\frac{D}{A} = \frac{W}{B} = 1\right)$, so that the state of the visual substance remains constant. For a lighter gray D is greater than A, while for a darker gray the reverse is the case.

If we call all stimulating actions which favour dissimilation, D stimuli, and if we borrow from general physiology the proposition that the magnitude of the reaction with which an organ answers to its stimulus depends also on the mass of the excitable substance it offers to be acted on, we get the principle that the *magnitude of the dissimilation caused by a* D*-stimulus depends not only on the force of this stimulus, but also on the quantity of the excitable substance present.*

But the ability of an excitable substance to be set by a stimulus, in a state of excitation, is called its excitability (*Erregbarkeit*), and the previous proposition may be thus expressed:—

Every increase of the excitable substance necessitates a raising, every decrease a lowering, of the D*-excitability of the visual organ.* Hence the sensation of medium gray implies a uniformity, every brighter sensation a decrease, and every darker sensation an increase of the D-excitability. And it follows that if, at the same time, images of different brightness fall on two places of equal D-excitability, the place of the brighter sensation will have its excitability lowered, and *vice versa.*

The author further explains the law, that in any compound sensation, the prominence of any particular single one is expressed by the ratio which the magnitude or "weight" of that sensation bears to the sum of all the sensations present. For example, in a gray, the prominence of white $= \frac{W}{W + B}$. If the sensation of yellow is also present in an amount $= Y$, it will be $= \frac{W}{W + B + Y}$, and the prominence of yellow will be $= \frac{Y}{W + B + Y}$.

These being the chief features of the author's theory he goes on to show how it is applied to explain the various phenomena already mentioned, particularly those of subjective vision.

The first point necessary to be explained is what may be called the normal state of the visual organs, *i.e.*, the sensation experienced when the eyes have long been closed and darkened, as on awaking in a perfectly dark room. It has already been explained that this sensation, although dark, is far removed from what we know as black. It follows from the theory that in this state the D and the A actions should be in equilibrium, *i.e.*, about equally great or $\frac{D}{A} = 1$, according to which the sensation should correspond to the medium gray.

The author remarks on the fact that, comparing the actual sensation with the brightest sun-light on the one hand and the blackest known velvet on the other, it would seem to be far nearer the black than the white; but we have no reason to believe that the darkest sensation we can get at all approaches absolute blackness. He thinks it possible that if we could get rays as near the black end of the scale as sun-light is near the white end, we should find their effect as powerful. But such rays do not exist in nature, and in our ignorance of them we cannot define accurately what may or may not be the true medium gray.

Next is given an explanation of *Simultaneous Contrast.* The before-mentioned experiments have shown that when one part of the visual organ is stimulated by light, the effect is to darken the sensation in the parts around. The theory admits of the explanation of this in several ways; but the author prefers the following:—In a partial stimulus by light a reaction is set up not only by the parts directly stimulated, but by the surrounding parts; the former through increased dissimilation, the latter through increased assimilation, which, however, is most powerful close to the lighted part, and diminishes fast with the distance from it.

This explains why, in a lighted room, the parts in shade appear black, much darker than our sensation with closed eyes, although the D-stimulus is equally active in both cases; and not only do the so-called dark parts really reflect some light, but a portion of dispersed light by objective irradiation enters the eye, which latter is strongest in the immediate neighbourhood of the bright object. But the increase of the assimilation prevents the perception of this light, and thus the ground is darkened, and the boundaries of the bright object are more sharply defined and brought out.

It is a result of this theory, that when two neighbouring parts of the retina are both stimulated by light at the same time, each reacts on the other by increased assimilation, the effect of which is to reduce the brightness of both. Hence, a small white surface is brighter than a large one of the same objective material. This may be easily seen by putting a large sheet of white paper, and a small strip of the same, both on a black ground. Or hold against the sky a large sheet of black paper, near the edge of which a small hole has been pierced; the point of light thus produced will be far more intense than that perceived round the edge of the paper. This is also the explanation of the great apparent brilliancy of the stars, the objective illumination of which is so very weak.

Explanation of *Simultaneous and Successive Light Induction.* Following up the process above described for simultaneous contrast, suppose the white object on the black ground to be further steadfastly observed for a longer time. The increase of assimilation in the parts immediately surrounding the white will cause an increase of the excitable substance, and will thus bring about an increase of excitability there. Hence the constantly working inner stimulus and the weak dispersed light of the black ground will acquire more dissimilating effect, while the assimilation gradually becomes weaker. Hence will follow an increase of apparent brightness on the parts previously darkened by contrast; this is *simultaneous light induction.* At the same time that the ground brightens in this way, the part of the visual organ impressed by the white surface suffers, by the prolonged dissimilation, a diminution of the excitable substance, whereby the excitability diminishes and the apparent brightness consequently diminishes also. If the contrast be made with only a slight difference in shade, and if the observation be carried on long enough, a phase will ultimately set in, in which by the gradual brightening of the ground and darkening of the whiter surface, they will both acquire the same appearance, and the distinction between them will disappear. This may be easily proved by experiment, but to prevent the confusing effect of the outlines, it is better shown by making, on white paper, dark patterns with shaded edges, when the effect will be soon apparent.

As the illumination of the light surface decreases it loses its power to favour the assimilation in the neighbouring dark parts, while the dissimilation under the influence of the inner D-stimulus not only goes on, but finds a greatly increased excitability to work upon; *i.e.*, according to the theory, the proportion $\frac{D}{A}\left(\frac{W}{S}\right)$ becomes greater, which means that the sensation increases in brightness. Hence, after sufficiently long steadfast observation, the bright-light space appears, and when the eyes are shut the sensation remains, as before described, giving *successive light induction.*

The explanation of *Successive Contrast* is given in four illustrations:—1. Observe fixedly a white stripe left between two large black surfaces; it will be seen that the original brightness gradually diminishes, and if the black surfaces be suddenly removed so as to leave an entirely white ground, the stripe will appear upon it as an after-image of a dark gray. This is, acccording to the theory, the result of the sudden bright illumination of the neighbouring parts; before this took place the dissimilation was powerful on the stripe, and (as before explained) excited an assimilation on the neighbouring black parts; this increased the D-excitability, and when the black surfaces were removed the white suddenly began to act with great power, setting up an assimilating action on the stripe where the excitability had been just before diminished, and so resulted the darkening effect on the latter.

2. Observe a small black stripe between two large sheets of white paper; it will at first appear very dark, but will gradually become lighter, and if the white sheets be suddenly removed, it will appear light on the black ground. This is the ordinary simultaneous and successive light induction already explained.

3. Lay a narrow white stripe on a black ground, observe it for a time, and then suddenly remove it; the place where it was will then appear blacker, and its neighbourhood lighter, than before. While observing the white stripe, the excitability upon it was diminished, and that around it increased, on the principles already explained: and on its removal the neighbouring parts were more impressed, and the place of the stripe less so, by the inner stimulus and the faint light of the general black ground.

4. Observe a black stripe on a white ground, and then suddenly remove it, leaving the whole field white. The place of the stripe will appear a brighter white surrounded by a darker space of a gray tinge. This is simply the converse of No. 3. The excitability was raised on the stripe and lowered around it; and when the whole field became active as a stimulus, the sensation was more powerful in the former place than the latter.

Lastly, the author devotes a chapter to the consideration of the *fatigue* of the visual organ. He says this may arise from two causes. When a light-stimulus is received, both a D-action and an A-action are set up, as previously explained: the D-action will naturally fatigue the organ by the dissimilation of the visual substance, but a similar result may follow also from the A-action if the assimilation goes on at a greater rate than fresh matter can be provided by the blood-supply. After looking at any very bright object, as the sun, and then covering the eyes, the after-image is not at first negative, but positive, and this bright impression may last for a long time, although, if the vision be thrown on white paper, the image will appear darker.

The explanation is as follows:—While looking at the bright object there is set up not only a strong dissimilation, but also a very considerable though less strong, assimilation. By the first the D-excitability will be greatly diminished, and by the latter the material in store will be quickly used up. Hence in the darkened eye, the sensation caused by the inner D-stimulus will be opposed only by a very weak A-action, so giving an after-impression of light, but of no great power. As the blood affords fresh matter, the equilibrium will be restored, and the appearance will die away.

In making the experiments hereinbefore mentioned on subjective vision, many different phases set in; these, though generally attributed to chance, are really due, in a large measure to the complicated influences of fatigue, caused as above described, and to their interference with the regular course of the light-induction and other processes hereinbefore described.

The author states, in conclusion, that he is far from believing that the theory he has developed is perfect, or incapable of correction, but he considers it comes nearer the truth than any other. WILLIAM POLE

(To be continued.)