APPLICATION OF THE THEORY OF QUANTA TO PERIPHERAL VISION.

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The theory of peripheral vision developed in my former papers gives an explanation of many processes taking place during colourless vision.\(^1\) In the present article I wish to indicate some contradictions between the theory and experiment and to complete the theory in such a way as to explain these contradictions. For this purpose, as we shall see, it is necessary to apply the quantum theory of light and to develop the statistical point of view of the processes of vision.

As I have proved in the above mentioned paper, the sensation of intensity of light depends on the amount of ions produced by the action of light. The relation between the intensity of acting light \(I\), the concentration of visual purple \(C\), existing in the rods of the retina, and the concentration of the exciting ions \(C_i\) may be expressed by the formula

\[
C_i = \frac{\alpha_1}{\alpha_2} k I C
\]

\(\alpha_1, \alpha_2\) are constants, \(k\) the constant of absorption.

We see from this that increase of the intensity of light produces an increase in the concentration of ions. It seems that the increase of the quantity of ions with the intensity of light may explain the sensation of light of different intensity and one must assume that the nervous fibre can be excited and can convey stimulations of different intensities. In reality the process of stimulation is more complicated because the nerves cannot convey stimulations of different intensities, but either convey the maximum stimulation or convey nothing at all.

This law (all or none law) has been accurately proved for nerves.

and must be considered as a fundamental law of nervous activity.\(^2\) The explanation of the sensation of the intensity of light must therefore take into consideration not only the processes in the rods but also the action of the nerves.

Thus we observe no stimulation of the nerves at all if the stimulus is small; as the stimulus increases we reach the threshold of stimulation and the nerves are stimulated with the maximum intensity.

The further increase of stimulus cannot produce an increase of stimulation of the nerves. Therefore when the light is very weak, we cannot observe it, if the intensity is greater than the threshold we perceive this light with the maximum sensation.

We cannot explain by this theory the phenomenon of penumbra and in the external world we can therefore distinguish only light and darkness.

Nevertheless observation shows that we can perceive the shades existing in nature.

We can explain this contradiction if we take into consideration the structure of the retina which consists of separated rods having a pigment and the structure of light consisting of separate quanta bringing the energy emitted by the source of light.

The first investigations concerning the quantum theory of colour vision were carried out by J. Joly.\(^3\) Simultaneously I developed\(^4\) the quantum theory of peripheral vision, from which we obtain some quantitative laws verified by experiment.

We can assume that in every rod there exists a substance in which the stimulating products are produced by autocatalytic reaction under the influence of the products of the photochemical reaction in the visual purple.

If the chemical formula of visual purple is \(A\), that of its photochemical product is \(B\), that of the sensitive substance which under the action of \(B\) gives the stimulating ions is \(C\) and that of its stimulating products is \(D\), we can write

\[
A \rightarrow B \\
C \rightarrow D
\]

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\(^3\) Joly, J., Phil. Mag., 1921, xli, series 6, 289.

B acts as catalytic agent for the reaction in C and the reaction of transformation of C into D is an autocatalytic reaction.

The source of light emits \( n \) quanta of energy per unit of surface of retina in every second, and we assume that the sensation of intensity depends on \( n \).

The theory of quanta shows that the intensity of light \( I \) is connected with \( n \) and with the quantum \( q \) by the equation

\[
I = q \cdot n = h\nu n \quad (1)
\]

where \( h \) is Planck's constant and \( \nu \) the frequency of the radiation.

If the surface \( S \) of the retina is illuminated we have on this surface \( S \) the following relation between \( I \), \( S \) and \( N_1 \), the amount of quanta falling on this surface \( S \),

\[
I \cdot S = q \cdot N_1
\]

Every quantum, absorbed by the rods, produces a molecule of \( B \) and the molecule of \( B \) produces in that of \( C \) a molecule of stimulating substance \( D \). \( D \) produces in the substance \( C \) an acceleration of the reaction and the complete destruction of the substance \( C \) in an illuminated rod is produced. In the same time the visual purple is also destroyed.

Thus the absorption of one quantum of energy by the rod stimulates the nerve connected to this rod.

The minimum sensation corresponds to the amount \( N_2 \) of rods excited by the light per second and therefore for the threshold of stimulation we have

\[
I \cdot S = q \cdot N_2 = h\nu N_2
\]

In this formula \( N_2 \) and \( q \) are constant and therefore at the threshold of stimulation there exists the relation

\[
I \cdot S = \text{Const.}
\]

which was proved by myself\(^6\) by deduction from the generalised law of Fechner-Helmholtz.

Meanwhile we see that with the increase of the intensity of \( I \) we obtain an increasing sensation.

\(^6\)Lasareff, P., Z. Sinnesphysiol., 1913, xlvii, 171.
The theory developed above gives us, therefore, a method of explaining the simple facts of vision and we also wish to explain by the above theory the second contradiction with the observed facts, namely the process of change of sensibility of the eye, the process of adaptation.

It is known that an eye exposed to the light becomes less sensitive than an eye which has been for a long time in darkness. This change of sensibility has received the name of adaptation and depends on the amount of visual purple in the rods.\footnote{Lasareff, P., Arch. ges. Physiol., 1913–14, clv, 310.}

The phenomena of adaptation are also very difficult to explain theoretically as they exhibit some facts contradictory to the theory mentioned above.

Indeed let us assume that the retina after the complete destruction of the sensitive substance \( C \) begins to restore it. If the restoration is small (the concentration of \( C \) is small), the eye does not perceive the light at all because the destruction of one molecule of visual purple \( A \) in a rod producing the autocatalytic reaction in the sensitive substance \( C \) is not sufficient to produce the quantity of ions which is sufficient for the stimulation of the nerve.

If on the contrary the restoration of \( C \) is great enough the stimulation of the nerves is maximal and we cannot explain the variation of the sensibility, corresponding to the adaptation.

In order to explain the continuous change of sensitivity during adaptation we assume that the restoration of the sensitive substance in the rods, which produces the stimulating ions under the reaction in the visual purple, proceeds not simultaneously in all cells but is effected at different times in different rods and the number of rods \( N \) in which the restoration is accomplished in a second is proportional to the quantity of rods, in which the pigment has been destroyed.

This can be expressed mathematically, if we write

\[
dN = \alpha (N_0 - N) \, dt
\]

\( N_0 \) is a maximum number of the rods in which the restoration is accomplished, \( N \) the quantity of the restored rods at the time \( t \).

We can solve the above equation on the assumption that the pig-
ment is partially destroyed and we obtain a solution giving the state of the rods at the time $t$ in the form

$$N = N_0 \left( 1 - \gamma e^{-at} \right)$$

(2)

where $\gamma$ is a fraction on which depends the quantity of rods, which is restored at the time $t = 0$.

The number $M$ of rods, stimulated in one second by the light, is proportional to the product of the number $N$ in a unit of surface and the number of quanta $n$ falling on the same surface.

We have therefore for the number of stimulated rods the expression

$$M = nN = nN_0 \left( 1 - \gamma e^{-at} \right)$$

When the number $M$ reaches the threshold of stimulation $P$ we obtain the minimum sensation.

In this case, therefore,

$$P = M = nN_0 \left( 1 - \gamma e^{-at} \right)$$

By multiplying by the value of quantum $q = \hbar \nu$ we find

$$Pq = n\hbar \nu N_0 \left( 1 - \gamma e^{-at} \right)$$

$n\hbar \nu$ is the intensity $I$ of light (formula (1)) corresponding to the threshold of sensation and therefore the sensibility $E = \frac{1}{I}$ is given by

$$E = \frac{1}{I} = \frac{N_0}{Pq} \left( 1 - \gamma e^{-at} \right) = E_0 \left( 1 - \gamma e^{-at} \right)$$

$E_0$ is a constant. We obtain, therefore, the formula which I have deduced in another way and which is in good agreement with the experimental data.\(^7\)

\(^7\) Lasareff, P., Ionentheorie der Reizung, Bern and Leipzig, 1922, 18.