THE CONDITIONS NECESSARY FOR THE SENSATION OF LIGHT.

It is generally assumed that the only condition necessary for the production of the sensation of light by the action of radiant energy is, that the radiant energy must be of a certain wave-length within the limits of wave-length of the visible spectrum, namely, between wave-lengths 7.604×10^{-5} centimetres and 3.933×10^{-5} centimetres; that, when the eye perceives nothing, none of these wave-lengths can be present. It is worth while, therefore, to examine those physical conditions that result in giving the sensation of light to ascertain whether such assumption is warranted. As to the eye itself, it will not make any difference so far as this question is concerned, whether one accepts the Young-Helmholtz theory of vision, the Herring theory, or any other. The only important fact is, that, in either, *energy* is required and is expended in the eye; but it is important to know how to measure the energy, and to have a tolerably clear idea about its form. Without any question, a ray of radiant energy, such as is emitted by a heated molecule or atom of hydrogen, consists of a single line of undulations of a definite wave-length, for the molecule cools (that is, loses its heat-energy) by imparting it to the ether; and a 'wave-length' is simply the distance to which such a disturbance in the ether will be propagated during the time of a single vibration of the molecule. As each vibration of the latter imparts some of its energy to the moving ether, it follows that the energy of a ray of light must depend upon the number of vibrations per second; or, what is the same thing, the energy of the ray is proportional to its length. As all rays move with the same velocity in the ether, it follows that any object that should receive such radiant energy would receive an amount proportional to the time.

Suppose, now, that an atom of hydrogen be made to vibrate, no matter how, so as to give a wave-length $C = 6.562 \times 10^{-5}$ centimetres. If such a ray falls upon the eye, it will produce the sensation of redness, and, if the eye receives the vibrations for one second, it will receive 4.577×10^{14} vibrations; that is to say, it will receive as many undulations from the ether as the generating atom made in the interval of one second. Now, we know experimentally that the eye can perceive when the interval is as small as the millionth of a second, when the number of vibrations of such a ray as the above would be 4.577×10^{8}, a very respectable number. It would seem probable that that number might be considerably reduced, and still leave a sufficient number to affect the eye. If the time-interval should be made so short as the one ten-billionth of a second, there would then be 45,770 such undulations that would enter the eye. But there must be a limit to the number needed to produce the sensation; and it is also probable that this limit will differ in different persons. Admitting this time-limit, it follows that undulations of proper wave-length may exist about us, and yet not be sufficient in time-quantity to affect the eye. If other vertebrates or insects possess a shorter limit than man, it is certain that they will see when man cannot. But the energy of vibrations varies as the square of the amplitude; and hence, if one of two rays of equal length has a greater amplitude than the other, the latter might be seen, while the former might not, although they had the same wave-length.

According to the kinetic theory of gases, the molecules are in incessant motion, in which collisions result in changing the directions of the free paths of each of the molecules, and also in making each to vibrate, because molecules are elastic. This vibratory motion proper, being a change of form of the molecule, is what constitutes its heat-energy. The interval between encounters gives opportunity to each molecule to vibrate in its own periodic time or some of its harmonics. Maxwell computed the number of impacts per second for several gases,[1] and gives, for hydrogen, $17,750 \times 10^{6}$. If, then, we divide the number of vibrations per second by the number of impacts, we shall have the number of vibrations between impacts: $\frac{4.577 \times 10^{8}}{177.50 \times 10^{6}} = 25,700.$ This is on the supposition that the vibrations produced are all of the wave-length of the *C* hydrogen-line.

It is highly probable that this hydrogen-line is not due to the fundamental vibrations of the hydrogen molecule, but that it is some harmonic (the twentieth, according to Stoney). Whatever its harmonic relation may be, it must be highly probable that it will frequently be produced when the conditions are as they are in ordinary gas; but, in normal conditions as to temperature, that gas is not luminous. If this reasoning be right, the reason it is not luminous at ordinary temperatures and pressures is due solely to the slight amplitude of the vibrations of proper wave-length, not to their entire absence. When the gas is heat-

[1] *Nature*, Sept. 25, 1873.

ed, or is impelled with great energy from the terminal of an induction-coil in a Geisler's tube, it is not necessary to assume that the molecules are made to vibrate in wholly new periods, but that the amplitude of their vibrations in any and all periods has been increased, thereby giving greater amplitude, and consequent energy, to the radiant undulations emitted, sufficient to affect the eye.

When one considers the kinetic energy of molecules due to their temperature, it seems probable that all bodies — solid and liquid, as well as gaseous — must be vibrating in all possible periods continuously; but in solid sand in liquids the shortness of the free paths makes interference too frequent to allow any molecule to vibrate many times between impacts, and hence the harmonics suffer most, and are destroyed before they can have given rise to undulations in sufficient number or in amplitude to perform any optical service. By heating a solid, greater amplitude is given to all the vibrations, and we see the red or longer undulations first during the process of heating, because such are less easily destroyed by impact than the shorter ones, which cannot have at best so great an amplitude. This statement assumes that it is with molecules as it is with visible masses of matter: the greater the number of vibrations possible to it, the less the possible amplitude.

With these conditions as stated, it is readily seen why common objects are not at all times visible, that is to say, are not luminous. It is because our eyes are not sensitive enough to respond to the slight energy of the undulations due to both lack of amplitude and shortness of the rays, not because those rays are absolutely wanting. A. E. DOLBEAR.

RADIOMETERS WITH CURVED VANES.

AMONG the radiometers in a collection which I have recently examined were two with curved vanes of silver. The radius of curvature was less than 2 cm. When placed in front of a lamp, the concave side moves towards the source of heat. I have found no satisfactory explanation of these movements. According to a recent article by Dr. Pringsheim, the convex side of these vanes is supposed to be at a higher temperature than the concave side. The grounds for such an hypothesis are not obvious; and it would seem hardly possible that an appreciable difference could exist between the surfaces of a thin sheet of silver.

It is more probable that the air on one side of the vane is hotter than that on the other. Since the 'kick' of a molecule depends on its increase in temperature, the vane will move towards the side on which the air is the warmer.

Dr. Pringsheim mentions an experiment in which he brought the heat to a focus inside the radiometer at a point in front of the vane. He found that the air gave no evidence of being heated. I repeated the experiment with solar heat, using a lens of three inches diameter and four inches focal length. The heat in air was sufficient to ignite instantly a common parlor match. When the focus was kept in front of the vane of an ordinary radiometer for two minutes, no appreciable effect was observed: the instant it touched the vanes, however, they gave a start, and began to revolve. This experiment shows that the effects observed with curved vanes cannot be attributed to concentration of heat-rays from the vanes.

According to the kinetic theory, this rotation is set up only if the molecules arriving on the convex side of the vane receive a greater positive increment to their velocity than those arriving on the concave side. These conditions are satisfied in this way: if the vanes are warmer than the air, the particles leaving the vane in both directions have an increased velocity; but take, for instance, the particles moving in lines parallel to the axis of the concavity towards the vane from either side, those on the convex side are scattered by reflection, those on the concave side are brought to a focus at a distance (in this instrument) of less than 1 cm. from the vertex of the concavity. The molecules in the vicinity of this focus receive an increase of kinetic energy; and similar reasoning holds for the sets of molecules moving parallel to each other in any other direction. Hence the molecules on the concave side are hotter than those on the convex side, though not necessarily so hot as the vane itself. Since the molecules on the concave side receive a smaller increase of velocity from the vane, they give it a smaller reactive push.

The action of the case in a radiometer is very prettily shown by wetting it with cold water. The action is best examined with curved vanes, or with vanes of metal covered on one side with mica. The rotation is at first in the same direction as on heating, showing that the air has become cooled by contact with the glass, but is after a time reversed, showing, that, by quasi-conduction through the air, the vanes have become cool, while the glass is regaining its original temperature.

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