customed danger. Buffalimacco looked on from his bed, well pleased with his trick. And truly nothing could have been more marvelous than these lights imitating, on a small scale, the harmony of the spheres as it is represented by Aristotle and his commentators. The cockroaches were not seen, but only the lights which they carried, when these lights were tracing in the darkness more cycles and epicycles than Ptolemy and the Arabians had ever observed in their study of the planetary motions. . . . Tafi burst open the door and fled in terror from the presence (as he thought) of the devil and all his imps."—Translated for the SCIENTIFIC AMERICAN SUPPLEMENT from La Science au XXme Siècle.

LIGHT AND THE VISUAL SENSE.*

A STUDY IN BIOLOGICAL PHYSICS.

By HENRY A. FOTHERBY, D.Ph. (Camb.), L.R.C.P. (Lond.), etc.

"THE method by which a ray of light is able to stimulate the endings of the optic nerve in the retina in such a manner that the visual sensation is perceived by the cerebrum is not yet understood. It is supposed that the change effected by the agency of the light which falls upon the retina is, in fact, a chemical alteration in the protoplasm, and that this change stimulates the optic nerve endings."—(Halliburton.)

We know that the energy of light as well as heat and electricity are capable of producing chemical action. For instance, if a mixture of chlorine and hydrogen gases, which will keep indefinitely in the dark, is exposed to sunlight they will combine with explosive violence. The principle on which photography depends is the influence of light in producing chemical change in silver chloride, which becomes blackened owing to the reduction of silver. It is from the radiant energy of sunlight that chlorophyll, the green coloring matter of plants, derives chemical energy whereby plants are enabled to build up their tissues from the elements of carbon dioxide and water.

It has been observed that movements take place in the pigment granules of the retinal cells under the influence of light. The retinal cones also shorten in its presence and elongate in its absence. In the retinal rods of certain animals, notably frogs, there is a certain pigment called visual purple, which, though present in the dark, disappears in the presence of light, and reappears again directly the light is withdrawn. The visual purple is also found to undergo distinct changes of color when exposed to other lights than white light.

It was on observations such as these that Hering based his theory of color vision, consisting of six primary color sensations, in opposition to the Young-Helmholtz theory of three only. The former suggests that these consist of three pairs of antagonistic or complementary color sensations, black and white, red and green, yellow and blue, and that the stimulus producing each severally is caused by changes either of disintegration or assimilation taking place in certain three substances of the nature of visual purple, which it is assumed exists in the retina. Thus, in the case of the red-green substance, if assimilation is in excess of disintegration the sensation is red, if the reverse it is green, but when equal no sensation occurs. The Young-Helmholtz theory, on the other hand, teaches that there are only three primary elementary color sensations—red, green, violet—and that the end-organs of the optic nerve in the retina, the rods and cones, consist of three varieties, each one specialized to respond to one of these three color sensations, and

FIG. 6.—PATH FOLLOWED BY A WOUNDED INSECT. (AFTER BINET.)

that all the different shades of color are due to the different degrees in which they are severally excited, the sensation of white being produced only when they are equally stimulated. This latter is the more generally accepted theory of color vision. How these three colors, red, green, and violet, were selected and found to be the only fundamental color sensations would take up too much space to describe here. It must suffice to say that it was due to a series of experiments by which the retina was exhausted for various colors, with the result that the fatigue manifested itself in these three colors, and it was found also that these three color sensations could not be produced by any combination of other color sensations.

* Knowledge.

The eye is not only a complicated optical instrument, but it is at the same time a vital organ of extreme delicacy functioned for the purpose of receiving sensory impressions of radiant energy, the velocity of whose radiations lies between certain definite limits, and transmitting them to the optic nerve centers in such a way that they can be translated into sensations of light and color. It is owing to this fact that these rays have received the name of luminiferous ether. When the ether vibrations have acquired a velocity of 450 millions of millions a second they affect the retina and become appreciated as the sense of red; as the vibrations increase in velocity the color sensations

FIG. 7.—POSITION ASSUMED BY A NEREIS WITH ONE EYE BLINDED.

experienced are those of the solar spectrum from left to right, namely, from red through orange, yellow, green, blue, purple to violet, at which point the ether vibrations have reached the enormous velocity of 727 millions of millions per second. Beyond this point, what is technically called the ultra-violet portion of the spectrum is reached, where the vibrations become too rapid to be appreciated by the eye, and they consequently cease to be luminous. For example, "When a wire is heated in a spirit lamp placed in a dark room the particles of which the wire is composed are thrown into a state of violent vibration. As the heat increases the vibrations increase in rapidity. They are communicated to the ether, which surrounds and permeates everything; and the movements thus set up—infinite small waves in this infinite big ocean which fills all space—are sent off on their journey in all directions. At first the undulations are too slow to affect the retina, though they affect the skin. We perceive that the wire is hot if we hold it to our cheek an inch or two away, but our eye reveals no change. As the heat increases the rate of the waves increases, and when they reach to the enormous number of about 450 billions—that is, 450 millions of millions—per second, we see that the wire is glowing red. The ordinary physical cause of sight, then, is found in the fact that undulations or vibrations of almost inconceivable rapidity are affecting an organ specially adapted for receiving them, viz., the retina. . . . If we think this over we shall see that it involves the conclusion that what we call light does not exist in the universe apart from eyes to see it. The 'light rays' that physical science deals with are, in themselves, no more red or blue than the dark heat rays or than the X-rays of which we have heard so much of late; the sunshine would have no splendor, but from the eyes which see it. If eyes did not exist, the sun's rays would produce their beneficent effects on plants and animals just as they do now, but the splendor and beauty would not exist. They are due, not to the physical cause, but to the mysteries of a piece of living tissue, the retina, which has been given the power to select those rays composed of undulations of a certain degree of rapidity, and to somehow make them the occasion of mental facts of unspeakable beauty." (Ryland. "The Story of Thought and Feeling.")

Having examined the nature of light and vision thus far, the question which naturally suggests itself is, how is the energy of light converted into a nerve impulse, and if, as seems probable, there are only three primary color sensations, by what means are these severally differentiated?

The retina consists of several distinct layers of living protoplasmic cells, the most remarkable of which are the layer of rods and cones, which are found on the surface, and which, consequently, are the first to receive the impressions of incident rays of luminiferous ether. What happens in these cells under its influence? We know by examination of other tissues that protoplasm has the power of forming in its life processes certain bodies called ferments, which, under certain conditions and in the presence of favorable surroundings, produce chemical changes, either katabolic (destructive) or anabolic (constructive), without themselves being in any way affected. For instance, the gastric cells produce a ferment called pepsin, which is able to convert the proteids of food into peptones; so also the pancreatic cells possess a ferment called amylopsin, which is able to convert starches into sugar. With the evolution of various forms of energy, chemical, nervous, etc. Is it not possible, too, in case of the retinal cells, that the process by which the energy of light is converted into nervous energy may be a process of fermentation, and that the ions of luminiferous ether, acting on the ions set free by a ferment body present in these protoplasmic cells, may produce katabolic, and possibly anabolic, changes, which, liberating electro-vital force and nerve stimulation, are conducted by the filaments of the optic nerve to the visual centers in the brain, to be there interpreted by the consciousness as sensations of light and color?

That light will produce these changes in the retinal cells is well illustrated by Waller's researches, and that the presence of ferment bodies in protoplasmic cells may, through ionic action, give rise to nerve force is supported by Dr. Allchin in a lecture given by him on "Nutrition and Malnutrition," reported in the Clinical Journal, April, 1905.

The former experiments are described in Halliburton's "Handbook of Physiology," as follows: "The excised eyeball of a frog is led off by non-polarizable electrodes to a galvanometer. One electrode is placed on the front, the other on the back of the eye. A current of rest (demarkation current) is observed passing through the eyeball from front to back. When light falls on the eye this current is increased; on shutting off the light there is a momentary further increase, and then the current slowly returns back to its previous condition. Waller explains this by supposing that anabolic changes in the eye predominate during stimulation by light. With the onset of darkness, the katabolic changes cease at once, and the anabolic more slowly; hence a further positive variation. If the eyeball has been excised the day before the observations are made, or has been fatigued or injured, light produces principally katabolic changes, as evidenced by a negative variation. A slight positive effect follows when the light is shut off."

On the question of ferment bodies producing nerve energy, etc., Dr. Allchin expresses himself as follows: "The vital activities of the living cells would seem to consist essentially in the formation of ferment bodies which alone, or in combination, affect those integrations and disintegrations which liberate chemical energy, and that this by transformation produces muscular work, nerve force, and secretory function, the fundamental manifestations of life. That these enzymes do bring about these changes in such conditions of temperature and alkalinity or acidity as obtain in the body appears to be certain, and as an explanation of the activity of the bioplasm, which elaborates these bodies, there is postulated an ionic action on the part of the cell contents, and their surrounding medium whereby charges of electricity of variable strength and character are brought into conflict, and that from the play of ions the manifestations of vitality result." Whether visual purple is of the nature of a ferment, as seems to be suggested by Hering's theory of color vision, is not at present known, neither has its presence been demonstrated in the human retina as far as I am aware.

That ionic action should be produced by light in the presence of a ferment contained in the retinal cells would not be incompatible with the Young-Helmholtz theory of color vision depending on three primary color sensations, red, green, and violet, if we suppose that there are present in these cells three ferments capable of specially responding to each of these radiations (or one ferment even having the property of three separate reactions in an ascending scale of katabolism). It is important to note the position in the spectrum of these three radiations. On the extreme left are those which give rise to the sensation of red, of comparative long wave-length; that is, those which act least powerfully on the photographic plate; in other words, whose actinic or disintegrating powers are least

FIG. 8.—A SNAIL CRAWLING BETWEEN A BLACK AND A WHITE WALL.

powerful of the luminiferous rays; in the middle are those which give rise to the sensation of green, where actinic action occupies an intermediate position; while at the extreme right are those of shortest wave-length, which give rise to the sensation of violet. These are the so-called "actinic waves," whose actinic action is greatest, and which act most powerfully on the photographic plate.

Therefore, granting that in accordance with the Young-Helmholtz theory there are in the retina rods and cones which answer to each of these three primary color sensations, and bearing in mind the above facts that the radiations producing them respectively occupy three fixed points in the spectrum, left, middle, and right, in an ascending scale of actinism (power to produce chemical change), I would suggest that an

ionic action is induced by these radiations in association with three distinct ferments present severally in the rods and cones specialized to receive them, each ferment being specially capable of producing katabolic changes under the influence of the particular radiation concerned, and out of the energy thus liberated three corresponding degrees of nerve stimulation arise to affect the nerve cells in the deepest layer of the retina, which, on being transmitted by the nerve fibers to the nerve cells in the visual centers of the brain, are interpreted by the consciousness as the above color sensations. The various other shades and color effects seen in nature are probably due, as the Young-Helmholtz theory teaches, to the different degrees of stimulation these three-color terminals receive. Thus, if a large number of rods or cones, responding to the radiations to the extreme left of the spectrum, are brought under the influence of these rays, and those which respond to green and violet are hardly affected by their corresponding radiations, the sensation would be red. If, however, orange is the color sensation produced, then it will be owing to the red terminals or rods and cones corresponding to red that are considerably influenced, the green rather more, and the violet only slightly so, etc. In bringing this paper to a close I must acknowledge my indebtedness to Watson's "Text-book of Physics," Ganot's "Popular Natural Philosophy," and Halliburton's "Handbook of Physiology."

NITROGEN AND THE SOIL.

By E. B. VORHEES.

ONE phase of the nitrogen problem has been solved, but it has reference to the possible gain of nitrogen to soils, and thus in a sense compensates for the losses, though it makes the question of losses none the less important. I have reference now to discoveries that have been made in regard to the symbiotic action of certain bacteria which give to the leguminous plants their power of absorbing nitrogen from the air, and dispose of the question, in the sense that so long as the farmer judiciously uses any one of this class of crops in his rotation, it will be possible for him to not only maintain, but to even increase, the nitrogen content of his soils and thus make the question of exhaustion from that standpoint one not to be feared. It seems to me however, that we have but reached the threshold in these investigations, for while as a matter of fact such a practice will result in adding this important element to the soil, it does not dispose of the question of the full utilization of the nitrogen acquired. We have many instances of attempts made to improve soils, or to maintain their fertility by the introduction of leguminous crops, which have proved disastrous rather than helpful in promoting plant growth or of permanently increasing fertility in this respect. Furthermore, we have no definite knowledge as yet as to the conditions which are necessary in order that the plants shall appropriate nitrogen from the air rather than from the soil, nor have we any definite information as to how large a proportion of the nitrogen so gathered is retained in the soil for the use of cereal and other crops which depend entirely upon soil sources for their nitrogen. I feel certain that no agricultural chemist of the present day would dare to risk his reputation on a positive statement in reference to any one of these phases of the question. The nitrogen question in agriculture is far-reaching in its influence, affecting not only those who cultivate the soil, but those who depend upon its products for their sustenance and profit; it is a question which has occupied the student of chemistry from the earliest times and the various theories advanced have caused no end of controversy among them, yet in many of its phases it is still a problem to be solved.—Abstracted from a paper read before the American Chemical Society.

CONSTANCY TO LIGHT OF ARTISTS' COLORS MOST FREQUENTLY USED.

IN the Münchner Kunsttechnische Blätter the painter, G. Bakenhus, gives an account of experiments carried on by him during a number of years with colors ground in oil and also with distemper colors, with the object of ascertaining their constancy to light. The colors were exposed to the light at the window of his studio for six years. The following were completely fast to light: Krems white, zinc white, Naples yellow (light), cadmium yellow (light, medium, and dark), light ocher, Roman ocher, brown ocher, gold ocher in thin layers, burnt light ocher, terra pozzuoli, Indian red, English red (light and dark), caput mortuum, Indian yellow, red lead, red and blue ultramarine, cobalt blue, chrome oxide, permanent green, cobalt green, terra di sienna (unburnt and burnt), gold ocher (burnt), umber (burnt and unburnt), Cassel brown, Cologne earth, Van Dyke brown, and asphalt in thin layers. In thick layers these colors suffered some alteration in shade. The following were only slightly altered: Naples yellow, zinc yellow, yellow ultramarine, cadmium orange, Vienna green, alizarine red, alizarine carmine, artificial vermilion (probably red lead colored with alizarine red). In the following the change was very marked: Paris blue, Berlin blue, Prussian blue, madder purple, madder brown, chrome yellow. The following were very much altered: Yellow and brown lakes, e. g., stil de grain, etc., also various sorts of green lakes. Carmine, scarlet lake, vermilion, and Chinese vermilion were entirely spoiled. It is evident that the artist has a large number of colors constant to light to select from, but that he must exercise caution in making the selection.

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