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ON HEAT CONSIDERED AS THE RETINAL INTERMEDIATE OF LIGHT AND COLOR SENSATION.

BY L. WEBSTER FOX, M. D., AND GEO. M. GOULD, A. B.

Any one who brings to the study of Light and Color Perception any considerable training in physics and physiology, with an unbiased desire to explain the mystery that enshrouds these processes, must be astonished at the character and futility of the theories advanced to explain them. Let such an one read a score or more of the multitude of expositions and criticisms relating to the two theories that seem to occupy the greatest share of public attention, and if he has, apart from the mere facts incidentally learned, gained a single inch of advance into the comprehension of the manner and law of the transmutation of ethereal vibrations into color, we heartily congratulate him. In the language of an elder pious investigator, "The connection betwixt our ideas and the motions excited in the retina, optic nerve and sensorium, is unknown to us, and seems to depend entirely on the will of God."

It is not our purpose to enumerate the criticisms made, or possible to be made, of the Young-Helmholtz and of the Hering theories. That has been done *iterum atque iterum*. Of the first mentioned, Wundt pithily says: "Genauer betrachtet sagt jene Hypothese gar nichts Anderes als was schon im Mischungsgesetze enthalten ist, aber eine Erklærung des letzteren enthælt sie nicht; denn warum aus den drei Grundfarben alle Lichtempfindungen zusammengesetzt werden koennen, dies wird durch die drei Fasergattungen ebenso wenig begreiflich gemacht wie durch das Newton'sche Dreieck." [1]

A similar judgment is pronounced upon the Hering theory which, though to be preferred of the two, really succeeds in nothing more than in restating the problem in other terms.

These theories, although devised by practical color students, and in the full light of the nineteenth century methods of inductive science, seem to be entirely of the nature of deductions, superposed upon the facts, regardless whether they fit or not—much like the Hegalian metaphysic. Their vagueness excites suspicion at once. One is often in doubt whether the *location* of the process is situated in the retina, in the optic nerve or in the brain; the *Sehsubstanz* is said to extend from the retina to the brain, inclusive of both ends. The theory is made large enough to cover all possibilities of future discovery. The Roman's ox-hide can be made to cover many acres, if slit into a large enough network. Anatomical and physiological differentiations of function are ignored, and we wander in a maze of glittering generalities which seem oblivious of the elementary principles of physics and physiology.

But it is easy to be seen that the carefullest and largest minds are beginning to react against such *a priori* methods of procedure, and it is comforting to find that Wundt, the greatest living physiological psychologist, sets these theories aside and contents himself with the somewhat indefinite outlines of a theory

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1. This hypothesis when scrutinized more closely contains nothing more than the law of the mixture of colors—no explanation of this law. It as little makes comprehensible why out of the three primary colors, all color-sensations can be produced through the mediation of the three kinds of nerve-fibres, as does the deltoid color-chart of Newton."

that is not a mere figment of the imagination, but which in a large sense tallies with and is justified by the facts of ethereal vibration and physiological processes analogous to related phenomena in other functions of the body. The necessary indefiniteness of the subjoined epitome arises from the healthy endeavor to keep the theory within the bounds of fact, and if it does little more than state in succinct form the laws of these facts, such indefiniteness does not posit other and unknown mysteries for the known ones till confusion becomes infinitely worse confounded. Wundt is too trained a sportsman in the open fields of physics and physiology to adopt any shot-gun theory which, fired at the facts broadcast, might, by simple dispersion, strike some game however wide of the mark.

For the benefit of those readers who have not Wundt at hand we add a translation from the last edition in which he summarizes the elementary principles of his theory.

1. "Every retinal stimulation results in two different processes, a chromatic and an achromatic; the first is a consequent of the wave-length of light, and the second is likewise dependent on the same, in so far as relates to its relative strength, the maximum of its intensity being reached in the yellow space of the spectrum. Both movements with increased stimulus follow different laws, the achromatic process beginning with a weaker stimulus, but soon surpassing the chromatic in intensity. In the middle degrees of light stimulation the relative strength of the chromatic process increases, but falls behind the achromatic again under the more intense degrees.

2. The achromatic movement consists in an uniform photochemical process, whose intensity is in part dependent upon the above mentioned degree of the objective light stimulus, and in part upon the wave-length, reaching its maximum in yellow, and sinking toward both ends of the spectrum.

3. The chromatic movement consists in a multiform photochemical process, continuously changing with the wave-length, and therein presenting itself as an approximate periodical function of the wave-length, since the extreme differences of these produce approximately similar effects, while the effects of cer tain intermediately placed differences are opposed in such a way

that complete compensation is brought about as opposed phases of one and the same movement.

4. "Every photochemical process survives the stimulus for a time, and exhausts the sensibility of the sensory substance for that certain stimulus. The positive and similarly colored after-images are explained as the immediate results of this continuance of activity, whilst the negative and complementary after-images are explained by the consequent exhaustion."

So far Wundt, who plainly implies that the present state of inductive science does not justify any more decided specialization and detail as to the "photochemical process." In that word lies the *crux* of the question, and to solve the mystery hidden in it must remain the endeavor of every investigator. Our own aim in this paper is to ask if the term be not ill-chosen, and to propose another view, one, as we think, more in harmony with physics and more analogous to other physiological processes. It will be seen that we accept and stand upon the whole of the rest of Wundt's theory, since it but formulates in a general way the known facts of the results of the impact of ether-waves upon the retina. We only ask in substance if a more definite and exact and known term cannot be given for the unknown and indefinite one derived from photography.

The objection to the term, photochemical, is that, in the first place, there is little or no evidence that the result of ether-wave impact upon the retina is in any sense chemical. It implies a decomposition and a recomposition of retinal substance, which seems too gross a conception in view of the delicate structure and functions of the retina; and would necessitate an *amount of chemical work* done inconsistent with its limited powers and functions. The position and maximum elevation of the light curve of the spectrum as compared with the curves representing the ultra-red or dark heat waves, and the ultra-violet or actinic rays, indicate the same fact. The maximum elevation of the visible rays lies midway between the other two. That the ultra-red waves have no effect upon the receiving body of the retina, arises from several reasons; such rays are more varyingly and more wholly absorbed by the ever-present dust-clouds of the air, as also by all terrestial bodies, before the reflected rays reach the

eye; they are two powerful producers of molecular activity; they would too strongly upset the delicate equilibrium of the retinal temperature. Lastly, they are too irrefrangible to be bent by the weak ocular media, their inclusion with the other rays would lead to pronounced circles of diffusion. The ultra-violet rays are shut out for similar reasons: their great dispersion through their high refrangibility, by the two powerful atmospheres of the sun and the earth; because of their weak kinetic energies; because of their too easy refrangibility by the media of the eye.

These facts point to an action mediate between the strong effects of radiant heat or dark rays, and the weak effects of the chemical rays. The eye during its formative period had not only a limited range of wave lengths left at its disposal by the greedy forces of absorption and dispersion,[1] but had out of these to choose such as were not too powerful or too weak, not too obstinate on the one hand or too willing on the other—too stubbornly or too easily refrangible—for its delicate and limited powers and purposes. These chosen correspond to the uses and objects of the mind, which desires only intimations through their otherwise neutral instrumentality, of the sizes, distances and qualities of objects. All these classes of waves are, of course, of one and the same nature, absolutely identical in quality; we call one class heat-rays, because the molecules of all bodies vibrate responsively under the wave-strokes of these frequencies; the retina secretes molecules responsive only to the medium lengths, and these are called light waves in conseqnence; the chemical rays act on the haloid salts of silver as a reducing agent, and are called after their chemical or actinic effects. The qualitative differences called heat, light and chemical action are produced

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1. We realize how great is our loss by this power of atmospheric absorption and dispersion, when we learn that the spectrum of the electric-arc in its ultra-violet region alone is from six to eight times as long as the whole visible spectrum, while that of the sun shine, owing to its absorption by the two atmospheres, is very short. What our color-sense might have been had *das Unbewusste* had these stimuli to choose from, is of course beyond our imagination, as well as beyond possibility. We could not have had these and the air too, though our air might have been freer from its several mile thick dust-shell. Even in its high altitudes the ultra-violet region of the spectrum is much brighter.

by the receiving body, and result from the quantitative ones of the stimulus, from the varying kinetic energies of its different wave systems. Herein lies the physical origin of the shortness, less than one octave, of the "color-scale" as compared with the musical scale, a defect which is amply compensated for by the finer and richer perceptions of differences within the relatively short color octave.

The term photo-chemical seems to be a general and large one, chosen, because of a certain analogy to the process taking place in the sensitive plate of the photographer's camera. It is true that Boll and Kühne succeeded in *fixing* an optogram in the eye of a rabbit, but as the macula contains no rhodopsin or visual purple, it is considered that vision is inexplainable by the formation of optograms in the rhodopsin. The discovery of this substance which seemed to promise much in explaining vision, seems, indeed, to have left the subject exactly where it stood before.

In place of *photochemical* we humbly suggest the term *thermal*, and would endow the retinal end organs with an extreme sensibility to slight degrees and changes of heat, resulting from the impact of ether waves of varying lengths and frequencies. We state in advance the results we have reached by considering the retinal function as an intermediate between the objective stimulous and the cerebral result, and as not endowed with any specific energy of its own:

1. The retinal mechanism, in the first place, simply effects a pro-rata reduction of the highly delicate and infinitely divided kinetic energies of the ether-wave stimuli into such relatively finite quantities and differences of quantities, as alone can effect physiological or rather nerve-forces. It is a translator from the language of the imponderable and infinite (comparatively speaking) to that of the finite and known of neural vibrations.

2. It moreover transfers these degrees of stimulation which it has rendered finite and recognizable, to the nerve-fibres whose function it is to convey them to the cerebral color and light producer.

3. This process of reduction and transfer is through the mediation of molecular activities aroused in the retinal receptive or-

gan by the stimulus, and perceived by the end-organs simply and only according to the height and degree of the aroused molecular activity.

4. The whole conception is based on these facts of physics: *a.* Ether waves can only impart their energies to the molecular constituents of matter, i. e., to bodies of like size or vibrating periods to those originating the waves; *b.* That the reception of such energy manifests itself primarily and always as increased vibratory activity of the receiving molecules; *c.* That our indication, register, and name for increased molecular activity is HEAT.

The essential nature of the transfer is a delicate perception of slight thermal differences.

It is thus seen that this conception of the process is a total discarding of the fallacy of the old-time belief in specific energies of the end-organs, on which the theories of Young, Helmholtz and Hering rest. It is certainly time that this "physiological echo of the philosophy of Kant," this endowing the end-organs or even the axis cylinders with specific powers and capacities, were given up. They are one and all only mechanical or proportional receivers and transmitters. It is beyond all question that it is in the brain that are eliminated the qualitative products called light, color, sound, etc., etc. The progress of the new psychology in pushing back these phenomena to where they belong, and where all research proves them to arise, is slowly but certainly taking place. The confounding of the two functions has been from time immemorial; the old gods die hard, but their death is inevitable.

We may briefly epitomize several concurrent facts and arguments in harmony with our view under the following heads:

I.—PHYSICAL.

Ethereal undulations are started into being by atomic or molecular blows upon the ether pressing about them, and this carries forward the vibrations, whose length or number per second, and whose height or amplitude, are identical with those of the striking molecules. Now the science of spectrum analysis rests upon the fact that these ether waves can only set up energy in matter by imparting to its particles vibrations like those of the original starters of the ethereal oscillations. The receiving molecule

must be consonant or attuned to receive them, or, in other words, they must be of the same relative sizes and densities, capable of the same vibrational frequencies or potential energies. Only those parts of a body that are small and slight enough to be moved by the correspondingly delicate and imponderable energies of the ether wave can be affected by it. The "sympathetic" vibration of the piano string is set up by an aerial vibration started by another string whose vibratory period is consonant with that of the induced vibration of the second. But air-waves are ponderable quantities, while the potencies of ether waves, while as certainly positive, are of such infinite smallness, that only bodies of like smallness can be affected by them. In no other way can their effects be realized upon matter. In this way alone can they be supposed to initiate chemical change; the increase of the molecular agitation under their rythmic strokes increases till the molecules are swung beyond the restraining forces of chemical cohesion, just as a huge pendulum may be set vibrating by the timely recurrence, at periods consonant with the pendulum's beat, of a force of otherwise inappreciable delicacy. Spectrum analysis shows us the molecules of the sun's atmosphere, whose vibratory periods are consonant with those of the more heated, and so more actively vibrating molecules within his body, catching up the energies of the ether waves as they are passing outward past them, and thus causing the blank spaces or dark Fraunhofer lines of the sun's spectrum.

Now from the slowness of its propagation, and the powerfulness of its effect, we also perceive that the force we call nervous must be allied to the mechanical rather than to the atomic or imponderable order. It is a movement of masses rather than one of the atoms or molecules of masses. Since, therefore, ethereal cannot be changed into mechanical or nervous energy, except by the mediation of molecular energy, it follows that the primary retinal intermediate between ether waves and optic nerve tremors must be the increased molecular activity of some substance placed in or about the retinal end-organs. This increased molecular agitation we always call heat under any other circumstances, and by that name alone do we generalize these phenomena. If it be asked how heat or molecular activity is transformed into

nerve-force, we can only say with the science of physiology, we do not know.

The necessity of such an interposited substance may be shown in another way, from a simple consideration of the numbers of the ether-waves. Our inability to conceive or form any faint fancy of the tremendous number of vibrations striking the retina in a second, is only parallelled by the same inability to realize the minuteness of force conveyed by each individual blow. The number of waves per second is equal to the total number of people in four or five hundred thousand such worlds as ours. Such an approach to infinity is only equalled by the completed products of intellection we call the divine reason, and can not be an ingredient of any subsidiary process of physiology or sensation. Meynart estimates the cerebral cells remaining for new impressions at 600,000,000. What have these to do with six hundred million millions? It becomes evident from such numbers and minuteness, that to produce anything like physiological effects, and especially prompt ones, this infinity must be brought within the limits of finite recognition, and processes.

The thermal registration of such infinite molecular activities offers the means of such a pro rata reduction process, and we get a glimpse of the character of this reduction by consideration of the fact that a single spectrum color of apparently uniform tint to the eye is, in reality, formed at one extremity by waves differing from those of the other extremity by so great a number as 5 or 10 millions of millions per second. Blue, for example, seems the same to the eye whether made up of 651 or 637 million of millions of vibrations per second. Green may vary from 585 to 578; yellow from 521 to 516, red from 440 to 435. These are certainly sweeping reductions, for our minds are yet in no way fitted to conceive of such numbers as five or ten billions. The physiological process is thus seen to be a crude and heavy reaction compared to the unimagined delicacy of the impinging forces constituting the stimulus. But with such massing together of numbers and forces we realize vividly that they are even yet too slight for anything except signs and indications. The energy of nerve transmission must be supplied by the self-contained forces of the or-

ganism. The light is not transmuted into nerve force. The slight increments of force derived from the light waves is spent in setting up molecular activity in a delicately-poised and sensitive matter, which only serves as a releasing mechanism, a starting of the nervous discharge and regulating its degree, as the electric current may be too weak to notice or may set off a discharge of tons of dynamite.

It may be of interest to note in passing that this intercalation of a molecular activity between the stimulus and the reaction accounts for the greater duration of time in the psychic (so-called) acts of sight, as compared with those of sound and touch-perception. It is otherwise incomprehensible that touch should produce psychic response sooner than the noble sense of sight, yet the relative periods are given as 0.167 second for sound, 0.213 for touch and 0.222 for sight. The loss is easily explained, as the time necessary to superinduce molecular activity by the fragile ether-waves in the receiving substance of the retina. It is not improbable that the time lost in this reduction process was a great difficulty to overcome by evolution and natural selection. Mr. Romanes says of the eyes of the medusæ that the interval between the stimulus and the response is so great that, were it any greater, the animal could hardly derive any benefit from their existence.

II.—Physiological.

Heat is therefore, not directly perceived by the nerves of the skin. That vibrational frequency of the ether we call heat, or sunlight, proceeding from molecular agitation of a "heated" body, strikes the skin, but only affects its nerves by throwing the skin and matter about the nerve end-organs in the skin, into increased, or sympathetic vibratile energy. These vibrations, and not those of the sunlight or ether, are perceived or taken up by the nerve end-organs.

Now there seems to be no reason or justification for the tendency of many minds to endow the different nerve systems of the body with utterly different natures and functions. Paul Bert grafted the tip end of a rat's tail into its back, cut it off at its former roots, and transmitted through it messages quite as well backward as they wereformerly carried in the reverse direction.

The motor and sensory nerves may be made to exchange offices, and if "double conduction" is thus proved here, the principle of the uniformity of character of all nerve systems may be regarded as more than probable. The differences of result must consist primarily in the peculiar power and adaptability of the particular peripheral end-organs to receive and transmute the peculiar stimulus into the common language of the nerves, into neural tremors, homogeneous in all respects except in the ever varying intensities or degrees of stimulation. THE BRAIN DOES THE REST.

The reception of light waves by the retina and their transmutation into nerve messages by it must be of essentially the same nature as the reception of heat waves by the end-organs of the skin. Heat and light are different names for the same force. Both are one; both are ethereal undulations, though the slower are generally called heat, because they have a more pronounced sensational effect in that direction, yet light-waves are also and always heat waves, because all ethereal vibration is heat so long as heat is only definable as the energy of molecular or atomic motion, and so long as light-waves are the motions of ether. The logic is inexorable.

Temperature, then, is the unerring register of molecular activity. Double the amount of molecular motion and the resultant kinetic energy or heat, is proportionally increased. When the energy consequent upon any process is not guided by the environment into any particular form, it invariably manifests itself as heat; or in other words, when energy is not dissipated, it must be stored; and that storing is effected by increasing the molecular activity of the component parts of the body, or, as we commonly say, by augmenting the heat, or simply "heating" the body. We shall see later that the eye is jealously guarded against any dissipation of heat by its surrounding fat and capillaries.

We thus reach a point when we see that the retinal function need not be carried so far in the extreme of activity as that implied in the word chemical, and that the character of that function need not and cannot be essentially different from that of heat-perception. That the theory of the character of the retinal

intermediation as essentially thermal, may be acceptable, we have only to make the retinal end-organs much more delicate and sensitive to slight changes and degrees of temperature than the ordinary sensory nerves of the skin. That with every degree of possible light-change there is also a temperature-change, there can be no doubt. Is such a refinement of heat-perception possible? We see no inobviable objection to such a belief. If we consider for a moment the temperature sense of the skin, we can but marvel at its delicacy. The tips of the fingers can distinguish through their coarse and thick dermal covering differences of so slight an amount as 0.2° to 0.16° R, and even to such extremes as that of 0.05° C., according to Lindemann. But in pathological conditions, and when the epidermis has been removed by burns, or vesicants, or herpes zoster, the exquisiteness of sensibility to temperature is not only immeasurable, but is unbelievable by those who have not so suffered.

But consider ow the peculiarities and adaptations of the eye in reference to this matter of thermal sensibility. If many of its arrangements do not answer to this purpose, it is as if they did. Teleological arguments seem to stare at one immediately. The thick, warm comforting of inexhaustible orbital fat, certainly points to preservation of warmth. It is indeed a "bed," but it is certainly and more appositely a *warm* bed. The extraordinary, almost excessive, development and closeness of the meshwork of the chorio-capillaris, which wraps the whole retina about with its warm padding, also seems to correspond to the need for that high and uniform temperature, which would be demanded both for a registration of slight thermal differences, and a reinstatement of the normal after each disturbance or stimulation. That the periphery of the retina perceives colors less easily than the center may be due to its more exposed and less blanketed condition. Its subnormal temperature results in decreased sensitiveness.

To prove this the authors have applied a pencil of ice to the exposed sclerotic of the converged eye and then thrown colored images obliquely upon the cooled retina. Under the influence of cold a brilliant color can quickly be reduced to black, and as quickly brought back to its normal by the removal of the

ice, or more speedily by the application of a heated sponge in place of the same. The sensitiveness and quickness of response, even of the peripheral portion of the retina, to these changes seemed to us to point to an interference with a process more delicate than ordinary physiological ones, and which would correspond to the enormously fine degrees of molecular activity which, as we believe, lie at the basis of color distinctions.

Our theory would suppose a highly sensitive and delicately poised receptive medium in a state of unstable equilibrium, normally responsive to ether vibrations between the frequencies of 392 millions of millions per second, and 757 millions of millions per second. Within these limits its molecules are varyingly and persistently capable of responding by their own vibrations to those of the impinging ether. The layer of pigment cells may be supposed to constitute or contain this receiving and reacting medium. Into this layer the long and blunt-pointed rods dip deeply, and doubtless serve as the transmitters of the raw material or nerve intensity corresponding to the sensation of simple light, or common day light, which is the most constant and pervasive of the stimuli, forming the background, as it were, of all light and color sensation. The delicately pointed cones do not extend into the substance so far, and by this fact and their shape and structure, plainly point to the function, more subtle and minute, of distinguishing those fine distinctions of difference, out of which color and tint are finally produced. This theory of the differentiation of function of the rods and cones, is borne out by many considerations, principal of which are these: The absence of rods from the macula, where color definition gives greater precision to vision of small objects than simple light could do; the absence of cones in nocturnal animals, who do not require any color perception, etc.

III.—Chromatological

Sunlight is made up of the following proportions:

Parts	Estimated Wave Length.	Approximate Wave Frequency. Bill. per Sec.
54, Red	0.0007000 mm	425.
140, Orange-Red	6347	475.
80, Orange	6094	500.

114, Orange-Yellow	5900	515.
54, Yellow	5713	525.
206, Greenish-Yellow	5500	535.
121, Yellowish-Green	5300	550.
134, Green and Blue-Green	5100	570.
32, Cyan Blue	4900	600.
40, Blue	4760	625.
20, Ultra Marine and Blue Violet	4500	650.
5, Violet	4059	700.

According to Fraunhofer the comparative luminous values of the principal spectral lines and colors are as follows:

Red	B	32.
Orange	C	94.
Reddish-Yellow	D	640.
Yellow	D--E	1000.
Green	E	480.
Blue-Green	F	170.
Blue		31.
Violet		5.6

From the last table we see that the curve of the light-producing energy of the colors reaches its maximum elevation in yellow, or between yellow and green, dropping upon either side to zero in extreme red and violet. This point corresponds to the mean wave length, and also the mean wave frequency of all the colors producing sunlight according to the first table. We see that the quantities of light above and below this dividing line of greenish yellow are about the same, so that the two parts of the spectrum may be considered complementary to each other, and we likewise find that when one color is complementary to another their mean wave length, if the proportionate intensities of the components be also considered, falls near the average wavelength of sunlight white, i. e., near 0.00053-4 mm. We therefore find the character of white changeless, however the intensity of illumination or quantity of light may vary. From the gray which is scarcely indistinguishable from black, on to the most dazzling brilliancy of the sun's glare, it is simply a question of a preservation of the proportions of the compound, whatever be the quantity of light. This is explained by considering the history of the eye. Diffuse daylight, since eyes began to be, has been their most persistent and continuous stimulus, overwhelming all other stimuli combined, in proportion and constancy. By day or night, whatever the circumstance, a combiation of the proportions of white light as given in the first table,

has in ever varying strength been the stimulus of the eye. It is not, therefore, strange, but were it otherwise it would be so, that the eye has developed its most natural reaction and easiest response to such a stimulus: it is natural that the secretion, arrangement, and natural paths of the responsive retinal molecules should have become consonant with this peculiar and composite nature of the stimulus: it could not be otherwise. We consequently find that the subjective gray we perceive with closed and covered eyes (without pressure), and which is that low molecular activity arising from the retina's own heat and pressure, is the feeble activity of the molecules in the same manner of response as to feeble objective stimuli of the weak daylight we call night. Subjective color vision is rarer than various strengths of achromatic sensations. In traumatism vision is usually brilliant white, while by pressure on the ball and in cerebral disease all normal activity gives place to illogical mixtures of colors and of white in every degree and order. All this was to be supposed.

Achromatic luminous sensation is, under all variations of intensity, a preservation of relative proportions of stimuli. Colors arise when the proportions are modified and changed in any way. But, in this connection, three important facts must be borne in mind. 1. Color-perception cannot arise till a certain elevation of molecular activity has been reached in the retina, until either the color-producing waves have a certain strength of themselves, or until a general illumination by (weak) white has taken place. We should suppose *a priori*, that a certain elevation of molecular activity would be a prerequisite of a perception of changes in proportion. 2. All colors appear most saturated or pure at that degree of illumination we call diffuse daylight. This also was to be expected from the history of the eye, and from the supposition of our theory. The eye would, of course, learn best to perceive a change of proportions when acting under its most continuous and normal stimulus. The reaction to diffuse daylight being the normal and healthy degree of retinal molecular activity, it judges most accurately any departures from that standard precisely at the full of its normal response. 3. But increase the intensity of the stimulus producing color, and color is quickly remerged into neutral and brilliant white, which, with still increased intensity, changes in quantity but not in quality.

On any theory based upon the supposition of specific energies, these protean changes of intensity into quality and quality again back into intensity, must be inexplainable, twist and turn it however one please. But, if all these differences of quality are relegated to the differentiating center—of the brain—and the retinal mechanism be considered a responsive apparatus, always consonantly registering the height to which the molecular activity is aroused by the stimulus (which at last varies only in degree or intensity)—if we so face our facts about, light falls where before was mystery.

Another result of experiment is that different spectral colors require different periods of impact to bring forth the resultant color-sensation. On the supposition of specific energies why should a green nerve take a longer time to react than a blue one, and why either a longer than a red one? But, if green is produced only by a higher degree of activity of the retinal molecules, blue by lower intensity, and red by a still lower, then clearness again takes the place of darkness.

Another related fact also finds its explanation in the same way: that color and tint change by continuous observation. If continuously observed, pure colors may be merged into white; the whole spectrum may, in this way, become dichromic, blue and red alone remaining with a white interspace, or even these may fade into achromatic luminosity. This, in our view, bespeaks a cumulative effect of the repeated ether blows, which increase the retinal activity beyond the point of normal differentiation of color difference. The apparently correlated fact that after long-wearing of colored glasses, for example, blue, one is unable to distinguish blue colors, we think is due to cerebral rather than retinal fatigue.

After-images logically follow from the theory. That the retinal activity of the molecules must continue for a period after the cessation of the stimulus, would be a simple result of the laws of physics. As the molecular activity falls to the sensation of relative black, the sensations run through the scale of colors corresponding to the different levels of molecular agitation successively reached. It is especially consonant with our theory that the purest colored after-images are seen only after the extremest ac-

tivity has been set up by brilliant white, and that no after-image is ever of a color of higher intensity than the causing stimulus; a stream cannot rise higher than its source.

Students acquainted with the heterogeneous mass of facts included under chromatological optics will, at once, see the range of applicability the theory has, but the whole field is in such an untilled and disorderly state that we forego further application for the present.

IV.—Psychological.

It may be said this view of the subject only pushes the mystery farther back, only relegates to the inscrutable processes of the coordinating center the real problem to be explained. To this accusation we shall only be too glad to plead guilty. If that much of definiteness could be reached, it would be well. It is far better to know just where the mystery is than to know not where it is; likewise it is better to know where it is not, than to know that it is everywhere. We are not vain enough to suppose that we have done more than to localize the mystery, to push it a step or or two farther back, and indicate the direction in which investigation might be prosecuted to bring the function of the retina into understandable processes analogous to those of other sensory organs. How, at last, the brain or the mind creates color and light from the raw material of neural tremors not unlike those of other nerve systems from which it eliminates very different products; how it makes of the one light, of another sound, of yet others, heat, muscular sensation, odor, taste—all this no witling would, at the present standpoint of science, attempt to intimate. It is not too much to say, no human intelligence has the faintest glimpse of an idea of the method. That the creation of light and color is absolutely and purely cerebral, there can be not the slightest hesitancy in affirming. Among a hundred other proofs is this striking one that two complementary colors thrown independently on identical spots of the two retinæ are (barring certain conditions and only apparent exceptions) perceived as the homogeneous resultant, white, by the fusing and unifying power of the mind. How the nerves transmit their messages is likewise mystery, but how they transmit degrees and differences of temperature is less a mystery than how

they might transmit colors already formed, and of infinite variety. It is a plain fact that fine gradations and changes of thermal differences are recognizable and transmissible by them; and it is as certain that the only endowment we need to give them to explain their function from our stand point, is that of heightening and rendering their natural power of transmitting degrees of stimulus more delicate and precise. The simple fact of the specification of this or that end-organ as stimulated, the location of the position stimulated by the message of the connecting nerve-thread, is the basis of the fruitful theory of LOCAL SIGNS, whereby the mind, by habit and comparison, learns of the direction and position of the external object. By the power of the end-organs and of the nerves to perceive and transmit the exquisite differences of thermal stimulation, the mind likewise elaborates corresponding states of feeling we call color and light, as the psychical analogues of the variations of ethereal wave-length, frequency and amplitude.

V.—PATHOLOGICAL.

The semi-pathological facts and condition of color-blindness are often considered to be the test and touchstone of theories of color perception. How do we square our account? Our demands are once more of the most praiseworthy modesty; we simply "await the time in patience" till something more is learned, if it be possible, of the anatomical causes. Color-blindness may turn out to be either a result of retinal deficiency, or it may be purely cerebral, or both. If it is retinal it must certainly appear in time whenever an eye markedly color-blind, is secured for microscopical examination. So far this seems not to have been done, though there are some 4000 color-blind men in every million about us. One feels like ticketing his color-blind friend, or, perhaps, like putting to him the quizzical though pointed query of the medical student to the young lady with a remarkable peculiarity of the elbow-joint, "Where does your family bury?"

The differentiation of function, whereby the cones have become the intermediates of the more strictly color sensation, is, as we have observed, borne out in proof by the facts of comparative anatomy, and by many other more general considera-

tions. Disuse is followed by atrophy, and if color-blindness is retinal, that is, if it is caused by the malformation, pathological condition, or absence of the cones, such facts must appear under the microscope. Whether some of our ancestors were, for example, the cave-men, and more particularly some household slaves or drudges of this tribe, who were never permitted to go forth by day—to whom, by the subtle laws of atavism, our color-blind neighbors hark back for their peculiarity—all this is, as yet, in the dim domain of speculation. More probably the color-blind, if we may again beg their pardon for the second calumniating inference, might go back to the night-howling apes in their genealogical tree. Unfortunately, we have as yet been unable to catch any of the present descendants of the night-howlers, however prevalent they are in modern civilization, and however gladly we would like to do so, in order to more fully investigate in the laboratory whether the two characteristics of color-blindness and nocturnal bellowing still go hand in hand!

Of course it is possible that the retinal defect, if such it be, may also reside in the pigment layer where the molecules, sympathetically responsive to vibrations of certain rapidities are wanting or deficient, or, from any imaginable cause, fail in functional activity.

It is more difficult to suppose the seat of the defect to be in faulty neural transmisson, yet even this might be. In either of the latter cases the morbid histological anatomy would not be shown by the microscope, certainly not in the former of the two.

We incline to think the *locus* of the functional failure will eventually be found to be cerebral; in which case any present attempt to reason about it would be quite as profitable as to discuss the famous Germanic question: *Utrum chimæra bombinans in vacuo posset comedere secundas intentiones?* It would be just as wise to repeat with old Porterfield the quaint, "It is the will of God," and there let the matter rest.

RESUME.

Ethereal vibrations can only impart their energy to molecules of a like minuteness to those originating the vibratile energy. The instant and constant result of such imparted energy is the

increase of molecular activity in the receiving body. Our name for that increased molecular activity, however minute and slight it be, is heat, which is the precise register of it in all ways and degrees. The retinal end-organs are not essentially different in function from those of the nerve-end organs of the temperature in other parts of the body, only more refined, more exposed, more percipient of the exquisiteness of change. The pigmentary layer is the seat of the molecules, suspended in delicate poise of unstable equilibrium, whose function it is to respond sympathetically to the impinging ether waves, and whose answering vibratory activity is perceived by the rod-tips as the achromatic stimulation of white, or common day-light; and by the more delicately pointed and retracted cone-tips as those finer gradations of vibrational frequency, finally resulting in the cerebral product denominated color. The optic nerve tremors or transmissions are not unlike those of other nerve systems which transmit delicate differences and amplitudes of stimulus, and from which raw material, the cerebral artificer fashions the marvellous products, light and color with infinite cunning and by inscrutable methods.

That the feeling of light or color is specifically and utterly different from that of heat, gives us no pause or trouble. The whole range of retinal temperature change, within which and by which the infinitude of color-change must play, is probably far less than that of a single thermometric degree. That also creates no questioning astonishment in us. Students of physical optics are struck at every point of their investigation with the inexpressible complexity and infinite detail harmoniously resultant from the simplest and most single of causes. We, moreover, acknowledge the homeliness and simplicity of the present theory. The plain and barren phenomena of heat sensation seem, at first sight, to be beyond reach of analogy or likeness to those brilliant results of astounding subtlety and beauty, which we call light and color. But let us have a care of scorning simple and near-at-hand causes. It is by such, as we have at last learned, that Nature produces her most dazzling, most complex and far distant aims and results. The day of heaven-topping theories is happily past. In science as also in metaphysics, we

are fast learning that the poet's verse is as well justified as in matters of every day life:

"Our best things are nearest us,
Lie close about our feet;
It is the distant and the dim,
That we are fain to greet."

To be acceptable to the cultivated inductive mind of this age, a theory must not contradict the evident laws of physics; it must not contradict the evident facts which it is seeking to explain; it must explain the unknown by analogy with the laws of the known; it must have the crowning merit of unity or simplicity, whence multiplicity of result proceeds logically from singleness of cause; it must, lastly, more properly localize the mystery yet remaining, and say "Here is light, there it is not." We modestly submit that previous theories, with the notable exception of that of our leader, Wundt, do not answer to these demands of the scientific spirit, and that our own, in a more or less perfect manner, does do so.

Postscript.

Since the above article was written we have stumbled upon an article, previously overlooked, by Dr. Burnett, printed in the July, 1884, number of the *American Journal of the Medical Sciences.* This accomplished writer takes essentially the same ground as ourselves in regard to the fundamental nature of the retinal process. We do not wish "maledictions on him who discovers our good things before we did."

The most cursory examination of our articles will show that, though we arrive at the same result, it is by entirely independent roads and through a different country. And so, though at the time of writing, we had no knowledge that any other had struck upon the same thought, it gives us all the more confidence in the security of the result to find such a powerful ally.

Dr. Burnett's reference to Preyer's article in Pflüger's *Archiv*, sends us all to Preyer as the real author of the conception that the retinal function is a refined temperature-sense, though so far back as 1877 Pflüger had stated his belief in the *phylogenetischer Zusammengehœrigkeit des Wœrme-und Licht-sinns.* Of this, however, Preyer was as ignorant as we of Burnett's article.

It is a pity that Preyer should have adopted the semi-exploded doctrine of specific energies of the retina. His division of two neighboring axis cylinders each into two cones, each of which separately perceives only one of the four principal colors, each set uniting a "cold" and a "warm" color, is quite as perplexing as Young's three-fold, or Hering's triplicate polar divisions. The many analogies he draws between vision and the dermal temperature or tactile senses seem to us forced and beside the mark. In brief, there seemed little in it to repay the difficulty we had in securing its perusal.

On the other hand we were pleased to find Dr. Burnett throwing aside the whole machinery of specific energies, together with the theories of Young and Hering, built upon it.

We wish that the argument from embryology were as "conclusive" as Dr. Burnett inclines to think it. It is not quite true that the eye in vertebrates is formed from the skin and grows inwards to the brain. It would be true, if we could consider the sclerotic and the humors as the eye; but, functionally, these are only its adjuncts. The eye is *par excellence* the retina, and instead of this all-important organ growing inward from any dermal modifications it is found, embryologically, that it grows outward from the brain, and joins the epidermic helps. The greatly impressive fact is that the brain comes out to see, and that it comes the whole distance, and not that the skin goes in to tell the brain what it has undergone. Vision is of all the senses the most purely cerebral, or psychical in character. It is true that the argument may be rescued by Prof. Ray Lancaster's ingenious, interesting, but improbable supposition that the eye of the Ascidian larva, supposed to be the parent of all vertebrates, was situated on its brain, the rays of light penetrating with ease its transparent body.

Or, the fact might be emphasized that brain and skin are both differentiations of the external larval layer or epiblast, so that, in a sense, nerve-center and nerve-terminal, inner and outer, mind and matter are all one! But in this way we could, of course, go back to the original undifferentiated protoplasmic cell.

In a word, the eye's temperature-sense will bear out no such

literal analogies to the skin's functions as Preyer would find, and the embryological argument would prove. The division of function was too far back; it must, as Genesis shows, have been the very next day after the "greater light" was placed in the heavens. About the only certain analogy which we can to-day draw between the two, is the very general one we have insisted on, of the perception of differences of molecular activities. But a cone with the pigment cells in front, and the complex machinery of numerous, not understood retinal layers behind, is a very different organ from the dermal corpuscles or end-bulbs of Pacini, Wagner, Krause or Merkel, and in the present state of our knowledge close analogies are drawn at a great hazard.