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Compliments of the Author

RETINAL INSENSIBILITY

— TO —

ULTRA-VIOLET AND INFRA-RED RAYS.

By L. WEBSTER FOX, M. D., and GEO. M. GOULD, A. B.

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FIG. ~~21.~~ 3

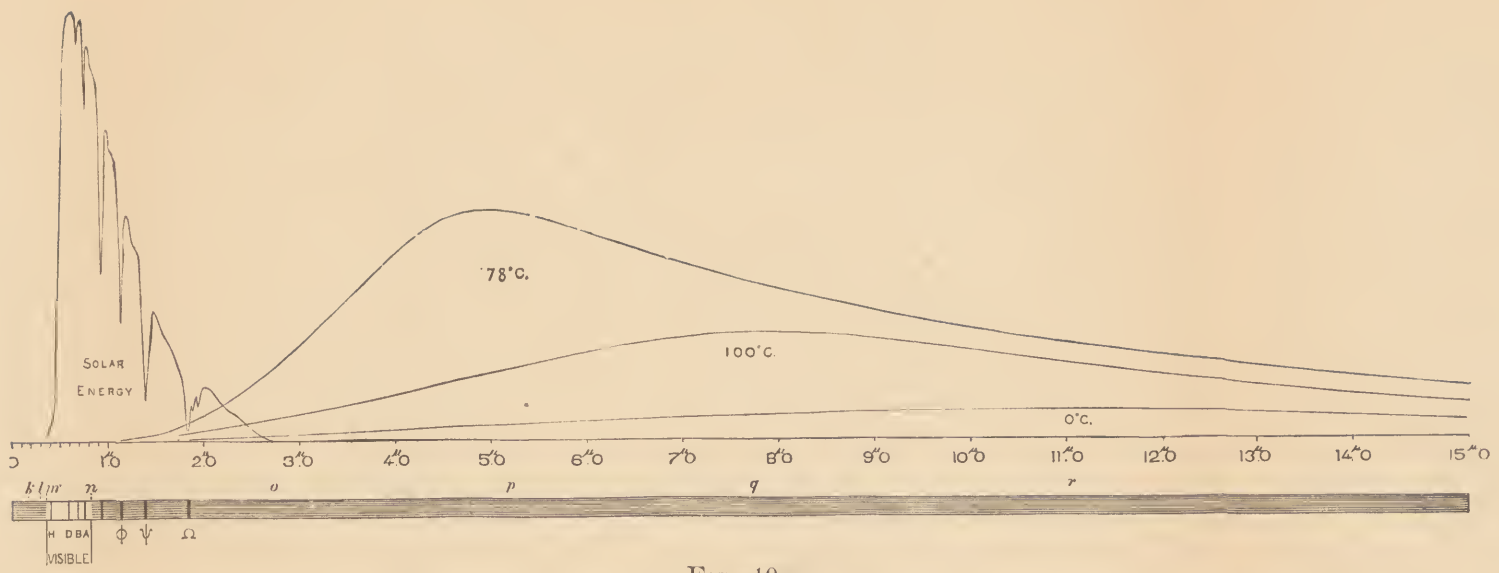
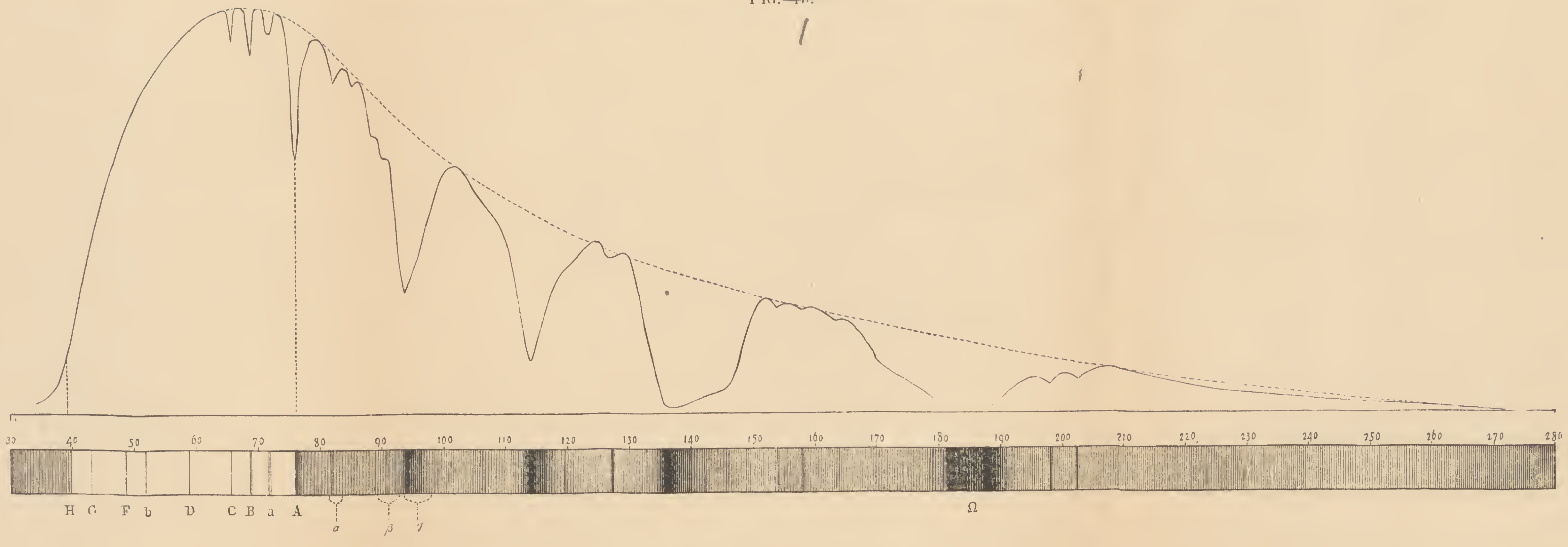


FIG. ~~19.~~ 1



NORMAL SPECTRUM.

FIG. ~~20.~~ 2

RETINAL INSENSIBILITY TO ULTRA-VIOLET AND INFRA-RED RAYS.

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

We have received from numerous friends and correspondents many queries concerning the questions discussed in our articles in the July and September numbers of this journal, and they are nearly all connected with an indistinctness or entire misapprehension of the real character and extent of the relative energies of different parts of the spectrum; there appears to be a want of clearness as to the essential nature of the retinal stimulus, and this indefiniteness seems to sum itself up in the question, "Why does the retina fail to respond to the ultra-violet and the infra-red ethereal vibrations?" To avoid the labor of repeating much the same answer to many, we beg the reader to excuse the intrusion of another communication in which we desire to give a *résumé* of relevant facts, and such hints of explanation as with the existing state of science seem possible.

Limits of Ethereal Wave-lengths that Have been Studied.

A glance at Fig. 1[1] shows the measurements of the waves that

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1The illustrative cuts accompanying this article are printed from plates kindly loaned us by Prof. Langley and the proprietors of the *American Journal of Science*. Our indebtedness to Prof. Langley and his most valuable researches is too evident to require notice. But our own gratitude to that eminent scientist is only a small fraction of that given him by science-lovers in general and light-students in particular.

have been studied. The figures 1, 2, 3, etc., give the wave-length in *microns*, (μ), or one-hundred thousandths of a millimetre; the heights of the curved lines give the relative values in heat units, or the relative absolute energies of the different spectra compared. The visible and invisible solar spectrum is the first to the left and extends from wave-lengths of a size of about one-third of a micron to those nearly three in length. The other curves represent the vibrations proceeding from terrestrial bodies heated to the degrees indicated. The first and most interesting fact that appears from this extremely condensed representation is the discovery it shows of the extension of our knowledge of wave-lengths into regions hitherto unknown. We now have knowledge of undulations eight times the lengths known to Newton; and this is due entirely to Prof. Langley and his marvelous bolometer, by whose aid he measures a degree of disturbance less than the $\frac{1}{1000000000}$ part, a delicacy of estimation so utterly beyond comprehension as to seem fabulous. The approximate estimate of minimum value assignable to the longest wave recognized by the bolometer in any heat from a rock-salt prism is given as 0.030 (units of a mm.) whilst the length of the shortest sound-wave corresponding to the highest musical note perceptible by the human ear (about 48,000 vibrations per second) is 14.0. So that, though the gulf between the shortest ærial undulation and the longest known ethereal is still a wide one, it is far less than before, and practically inconsiderable and uninteresting, except to the student of physical geography.

The smallest waves that have been measured are the extreme rays from aluminum in the induction spark, estimated at 0,185 μ. Of the solar radiations, the shortest that penetrates our atmosphere is 0.29 μ. The shortest visible to the naked eye is 0.35 , though by the aid of the fluorescent eye-piece of Soret, by photography and quartz trains, vision has of late been greatly extended. The longest waves to which the retina responds are about 0.81 μ, and the longest solar vibrations that penetrate our atmosphere are 2.7 μ. Thus we see that the range of vision (from .35 μ to .81 μ) is a little over one octave. All this is roughly shown in the figure (I) referred to. Let us now spread the solar spectrum out so to study it more exactly. This is done in Fig. II:

THE NORMAL SOLAR SPECTRUM

is here extended so that we have in about 12 inches a graphic delineation of what was before crushed into one-twelfth the space for purposes of comparison. In this way we get a comparative view of relative values of the visible and invisible spectra. At this point it may be well to throw in a word of explanation as to the unit of measurement used, or of the proper meaning to be attached to the broken curve; it represents the abstract kinetic value or absolute energy contained in the radiations apart from all considerations of the receiving substance. Much of the confusion existing concerning these questions arises from many misleading or positively absurd diagrams in old text-books or articles devoted to the "plebification" of knowledge concerning these matters. It is now agreed that the kinetic value of all ether waves is measurable in terms of heat, and that the greatest energy of the spectrum is in yellow; at high noon it is about wave-length 0.55 μ, whilst about sunset it is near wave-length 0.65 owing to the increased absorption of the shorter waves by the greater thickness of the atmospheric layer. The difference of effect produced by an impinging series of ether-waves arises solely from the merely accidental nature of the receiving medium. The energy of the ultra-violet rays is so small as to be almost infinitesimal, but because these rays happen to correspond in beat to the vibrational frequency of the molecules of the haloid salts of silver, and the highly important consequences resulting therefrom in the art of photography, their importance in an absolute or in a visual sense has been greatly overestimated. It is a startling fact that a photograph can be taken by the aid of these vibrations in a room absolutely black and without light to a normal eye. It has been a popular fashion to call these rays actinic, and the infra-red, "heat" waves; those be-tween, "light" waves. But every ray whatsoever is a heat ray, and the rays producing the greatest heat are precisely those producing, when falling upon the retina, the greatest visual effect. The energy-cure, the heat-curve, and the light-curve are in great part identical, and the apex of this curve is about wave-length 0.55, great as shown in the diagram. Thus a nomenclature that does not presuppose any theories, or unconsciously mislead the mind, is to call these three divisions by the simple names, ultra-violet, light, and infra-red.

Relative Energies of the Three Divisions.

The kinetic value of the ultra-violet rays is for our purpose too insignificant to consider. It is estimated to be not $\frac{1}{100}$ that of the infra-red rays. The enormous importance of these last has been unnoticed because of the great compression of these rays by the prism, and the inability hitherto of scientists to measure their values. At the present time, however, this portion of the sun's rays is estimated to include nearly $\frac{2}{3}$ of the total energy of the solar radiation penetrating our atmosphere. The exact figures are given as follows:

Luminous and ultra-violet energy, -	0.368.
Infra-red energy, - - - - -	0.632.
	1.000

The Influence of Atmospheric Absorption.

This is a highly important point, and needs careful consideration. In a word, the breaks and sudden dips of the energy-curve shown in the figure are due to the varying powers of absorption exercised by the solar or telluric atmospheres upon the rays in their passage through them. Speaking generally, the absorption increases with the decrease of the wave-length, viewing the spectrum as a whole, though there are local regions of exceptional absorption. The extent of the atmosphere's absorbent power upon the infra-red rays is strikingly shown in the jagged peaks and chasms of the line all the way from Fraunhofer line A., near the limit of visibility, to the end of the solar spectrum. Considering the visible spectrum only, it is found that in penetrating our atmosphere the light rays suffer a relatively larger loss than the infra-red. The atmosphere is also a better transmitter for the light-rays in the winter-season. The general effect of this atmospheric function is to move the maximum energy-point of the spectrum toward the red-end, so that our atmosphere plays the part of an orange or reddish glass. The larger particles of the great dust- and vapor-shell surrounding our globe produce a *general* absorption, rendering the whole spectrum less bright and less hot; with infinite degrees this manner of absorption passes into what may more specifically be called molecular, producing the dark telluric lines of the spectrun. The number of these lines increases rapidly from noon till at sunset the spectrum is crowded with them. In ascending a mountain many of the telluric lines fade out even from the spectrum of high-noon at sea-level. We get nearly as much light from the sky on an average as from the sun direct, and the total value of this absorbent power of the atmosphere is concluded by Prof. Langley to be as high as 40 per cent., double the estimate of all previous investigators. If, then, we could, with our eye as at present constructed, rise above our atmosphere, the sun would appear distinctly blueish, because the maximum energy-point of the spectrum would at this elevation be in the (at present) green part of the spectrum, our white light being a compound of only a part of the visible solar-rays, many of the longer ones having been quenched by the atmosphere acting like ever-present reddish semi-transparent spectacles. Fig. III gives a representation of the energy or heat curves of the visible spectrum, 1, outside our atmosphere; 2, within the same at noon, and 3, just before sunset. The apex of the curve is seen to be farther toward A. with each increase of atmospheric depth. Beyond our atmosphere it is at about wave-length 0.50 μ, whilst at noon and evening at sea-level, it is, as we have seen, at about 0.55 and 0.65 respectively. It should be borne in mind that though the light rays suffer a far larger relative absorption than the infra-red, the apex of the curve nevertheless remains comparatively unfissured and is always elevated far above any of the peaks of the infra-red rays.

The Exclusion from Visual Participation of the Ultra-Violet and Infra-Red Rays

seems natural from a glance at either of these diagrams, but especially so from the first and second. In a sentence, it is because the eye has learned to react to the strongest and most constant stimulus or classes of stimuli, and has learned to extinguish or exclude those vibrations that would only confuse by their weakness or inconstancy. Consideration of the difficulty of focalizing rays of wide differences of refrangibility must also not be forgotten. Were the extremes not shut out, chromatic aberration would certainly be more of a disturbance than at present; and, that the "difficulty" is real is also shown *e. g.*, by the fact of presbyopia. The inelasticity of the lens is complete before old age is reached. First, as to the ultra-violet, the insignificance of the total energy of these rays is perceived by noticing the tiny curve and extent of activity of these undulations figured in the little triangle beyond H. of Fig. II. Not only is the energy too inconsiderable to produce sufficient organic reaction of the ocular mechanism, as compared with the adjacent red space, but the varying quantities of such rays, resulting from the ever-changing remnants left over after the absorptions of the atmosphere have been satisfied, renders constancy of stimulus impossible, and the eye naturally fails to develop response to stimuli, or excludes them from the retina, because they are so weak and capricious. We must, moreover, not fail to recollect the exaggerated importance and mistaken supposition of extent of the rays of this part of the spectrum, naturally engendered by their influence in photography. A line must be drawn somewhere by nature, and the remarkable fact seems to be that the violet rays should not have been excluded from color-production. The limitation of the chromatic scale should not be a cause of critical complaint, but its extension is rather a source of delighted wonder.

In considering

The Infra-Red Rays,

so rich in the total amount of energy and so magnificent in the extent of their wave-lengths, it would at first blush appear that the preceding considerations could have no force or application; but this is a mistake. We think exactly the same reasons sufficient to account for their non-participation in vision. Observe first, that though three-fifths of the total energy of the spectrum is in this region, it is spread over a space six times as great. Now it is apparent that amplitude of range beyond a certain necessary and satisfactory amount, would be of no advantage. How ever great a spendthrift nature may seem in certain directions, she is still a more niggard economist in others. Extension of the visual function to these regions would imply immense complication of ocular and cerebral mechanism, a complication and intricacy that if in any way possible, would hardly give any considerable advantage to its possessor.

In the next place we must note that this great stretch is one continuous succession of peaks and valleys, or in other words, that its energies are not constant and regular. Cool places alternate with hot ones, and though the shorter wave infra-red peaks are as high as some parts of the visible curve upon the other side, they are not regularly so, and during a fall of the general supply of the radiant energy, as in an obscure day, or in the morning or evening, these valleys would drop down to a level where their maximum of energy would be very small or even *nil*. And this matter of a continual pulsation of the general amount of the stimulus must be borne in mind. It is not a sufficient argument to say that the great space from 0.80 to 0.90 contains an energy as high as that between 0.40 and 0.50. Upon this last side of the curve there is no valley at all, whilst just within A we have a tremendous one that with diminished general illumination would make a break, sharp and decisive, between the two visible portions. *Natura non facit saltum.* Nature is no giant such as Cruikshank and his fairy story picture, striding from mountain-top to top at one step. The existence of this deep and cañon-like chasm at A seems to us highly suggestive. At this point nature seems to have called a halt, and set up there the boundary line of visibility. This gap seems to have served as a legitimate excuse to set bounds to the hungry cry of the organism for greater pre-emption and extension.

Had this cool notch not have existed, it is easily conceivable that the retina might have learned to react to the stimulus extending so far as wave-length 0.95, or even to the next great cool space at 1.15, had there likewise been no such fall as is seen at 0.95. But the great ebb and flow of radiant energy every twenty-four hours, complicated always, and rendered more highly inconstant by the varying conditions of atmospheric cloud and dust, of shade, of vegetation or hill, of longitude and equinox—all these sources of variation and inconstancy served to show the hard tasked ocular and psychic mechanician that he could only rely with confidence on that part of the spectum, upon those wave-lengths that, under all conditions, were strongest and most persistent. His creatures had to gain the best intimations possisible of external objects during foggy and cloudy days, in twilight, moonlight, nay, even by starlight, and at these times the reduction or even extinction of energy in the infra-red regions would be too great or too common to give such indications. Hence the necessity of ignoring them.

We spoke in metaphor of the task of the creation of the retinal and cerebral response being a difficult one. No anthropological or teleological *arriere-pensée* was in our mind. We are as shy of that sort of thing now-a-days, as our fathers were fond of it. What was meant was simply this: None but they who have deeply studied and pondered the delicacy of the force of these ethereal stimuli, have any but the most absurdly inadequate conception of their almost infinitesimal littleness. Prof. Rowland has ruled 160,000 lines to the inch in his concave gratings. The finest slit admitting a beam of light to this grating is one-fifth of a millimetre wide, yet this covers more than the distance between the two D lines, and in this space there are at least a dozen alternations between brightness and extinction. The astounding sensitiveness of the bolometer is far from discerning the absolutely homogeneous ray. Now it has been shown (by *Nichols*, *Amer. Jour. Sci.*, Oct., '84.) that the retina responds to an exposure to rays, (from the pigments of a Maxwell-disk) lasting only 0.00144 of a second. This was the time for yellow, and at the brightest of three degrees of illumination. For red the figures were 0.00209, for violet, 0.00286. Experiments with spectra of the solar radiation are still more remarkable. B. O. Pierce, Jr., (*Am. Jour. Sci.*, '83) found that the largest displacement needed by any observer corresponded to a difference in wave-length of about 0.000005 *mm.*, the smallest to a wave-length of about 0.0000005 *mm.* In all these cases, the extreme refinement of response is in yellow—precisely where the stimulus is strongest, most invariable and persistent. But what we wish particularly to emphasize is that the most trained imagination can get only the most impotent and inadequate fancies and glimpses of the marvelous sensitiveness of the retinal mechanism that can react to stimuli represented by the figures above given. Was it therefore not in reality a great feat of the organic mechanic, which, as dethroned Deity we familiarly call Nature, Life, Natural Selection, (we still compliment with capitals—how long will that last?) to develop retinal response, infallibly, swiftly, to such inconceivably fine stimuli? Nothing else in all the domain of the senses can be remotely compared with it, and only because, upon the quick perception of the half hidden gleam of approaching teeth, of concealed enemies, of disguised poisons and fruits—only because, upon the lightning-like recognition of a thousand such subtle and ever-varying indications, depended the safety and hourly existence of his creatures in air, earth or ocean, only by and under such prime necessities, could the inconceivable labor have been accomplished! One of our correspondents is puzzled to understand why the retina does not react to the ultra-violet and infra-red waves, the same as carbon and all ordinary absorbers. The question implies a strange analogy and a fatal forgetfulness of the object of vision, the organic needs to which the eye ministers, and the organic means by which this functional activity has been developed. The action of any organic tissue whatever, is only the outcome and epitome of its history. Chemical and mechanical forces have, in this sense, no history; their reactions are always and ever the same; but the moment we have to do with that mysterious somewhat we call life, at least in any but its very lowest manifestations, that moment we can predict the methods and laws of its activity only by a knowledge of the history of the organs through and by which it presents itself to us. Throw light upon the sensitive plate of the photographer, and the silver salts at once go through their paces utterly regardless of the past history of that light, whence it came, how generated, etc. But light thrown on the retina of an ant and upon the retina of a man is perceived as a wholly different sort of stimulus, as Sir John Lubbock has shown, and light from the pursuing hunter, and the self-same quality of light from the coat of its mate preduce quite different results somewhere in the receptive mechanism of the deer. In a word, as we have elsewhere tried to show, it seems strange that the great laws of evolution and natural selection should be so persistently and successfully used to explain the functions and reactions of other organs, and the visual activity be the last to which these principles are applied. But that delightful class of grubbers who have gone clean daft on materialism, and who would, with sublimely comic impertinence, explain life in terms of mechanics, and analyze a maiden's blush into ($C_{600}H_{960}FeN_{154}S_3O_{177}$ [Hæmoglobin]) + O + ($C_5H_{13}NO$ ["Neurine"]) = X.,—Q.E.D.!—these philosophers do not, to be sure, need even these paltry helps of historic study, to demonstrate truth, any more than did Punch's Humpty Dumpty, "who sat on the wall, to his nurse proving he never could fall, etc."

Besides the facts of the weakness and inconstancy of supply of the infra-red rays, and barring also the immense complication and increase of retinal and cerebral machinery it would have necessitated, we may pertinently ask of what advantage to the great kingdom of developing animal-life would it have been if retinal reaction had been extended to the infra-red rays? All existing objects become visible by means of the light rays; any object that would reflect these infra red rays already reflects the rays of the visible spectrum in sufficient strength and variety to give the visual mechanism full advices of the existence and qualities of the object. May it not be consistently supposed that the effect of these infra-red rays, if allowed to produce visual result would simply be productive of confusion? The object of color may generally be said to be to give evidence of the qualities of objects. Extension of the color-scale and response would not only give no possible advantage to its possessor, but it may be certainly said that such extension would assuredly disadvantage its unfortunate owner in the struggle for existence, not only by complicating the retinal machinery, but also by rendering the organism's response more uncertain and less lightning-like in rapidity.

Do the Ultra-violet and Infra-red Vibrations Reach the Retina or Visual Centers?

In this connection the question arises as to the means whereby the visual mechanism rids itself of the confusion that would naturally follow from the influence of these rays (or the impulses resultant from them) provided these were allowed access to the retina. It has been suggested that the ocular media may act as a strainer, or filter to these wave-lengths, quenching or absorbing their energies so that they do not in fact reach the retina. So far as we know the only definite answer to this question pertains alone to the ultra-violet undulations. A French scientist, M. de Chardonnet (*Comptes Rendus*, *Tome* 96, p. 144) utilized the power that these rays have to produce chemical changes in the sensitive plates of the photographer, to test the relative transparency of the different ocular media of man and the vertebrates to these rays. The crystalline, cornea and vitreous were tested separately. It was found that the adult crystalline of man quenched the spectral waves between Fraunhofer lines L and M. It required a long exposure of the plate to produce response therein by waves the length of those of line M. The vitreous was transparent to the rays between S and *s*, the cornea permitted weak traces to T. One or another of the media in animals was opaque to rays beyond L or M in the ox and frog, N or O in the fish, P in the cat, R in the calf, sheep and hog, S in the turkey and owl, T or U in the hawk. No eye whatsoever was found transparent to the ultra-solar rays[1], or to those shorter than T or U. So far then, as relates to the human eye, it was found that the vitreous and cornea were transparent to a much greater extent of the ultra-violet rays than the crystalline, and the problem narrowed itself to experiments upon living aphakial eyes. On p. 509 of the same volume of the *Comptes* M. de Chardonnet reports as the results of his experiments upon such eyes that he found the living normal retina sensitive to ultra-violet waves almost to S. Beyond this, of course, it was impossible to test because the cornea and vitreous became opaque at this point. It is of interest to note that the individuals thus experimented upon testified the suggestive fact that

[1] That is, to those waves of the electric light which are shorter than any penetrating our atmosphere from the sun.

their impression as to the color of the ultra-violet rays was that it was of a light blue or a delicate grayish blue hue. A word of explanation also as to why people without the crystalline lens do not complain of the bluish tint of objects[1]. Leaving out of consideration the fact that what habitually colors or changes the proportions or averages of rays so slightly as this, would, from mere habit, drop out of conscious recognition, it may be remarked that the excessive weakness and relatively small amount of the ultra-violet solar radiation reaching the eye would not, except perhaps to the sensitive retina directly after cataract operation, materially change the general tint of a multitudinously compound mass of rays such as naturally enters the eye at any one instant. But far more conclusive is the fact that *without* spectacles there is no emmetropic focalization of rays on the retina, only a multitude of diffusion circles; whilst *with* spectacles (which of course are commonly worn) these ultra-violet rays are absorbed by the glass and never even reach the cornea. Parenthetically, it may be noted that to this circumstance—the opacity of glass to the greater part of the ultra-violet radiation—is probably due our immunity from fatigue and from what would be a novel form of asthenopia or ocular disease arising from the electric light: the incandescent lamp being surrounded by a film of glass quenches those rays that in this light are very numerous and (comparatively) powerful. If this severe and unusual task were thrown upon the crystalline, it is reasonable to suppose a disturbance of its function might probably result.

Referring again to the straining function of the human crystalline, M. J. L. Soret (*Comptes. Tome* 97, pp. 314 and 572) finds that its absorbent power is not, as first supposed, due to the albuminous substance, globuline, forming the mass of the lens, but that it is effected by means of a crystalline substance secreted by the lens. Now, is there not in this fact evidence of a suggestive and convincing kind, since, as we have seen, the ocular media in the lower animals are generally transparent to

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1 We may remark that we have had patients just operated upon for removal of the lens exclaim that the objects first seen appeared distinctly bluish in tint.

much shorter waves than in man, that it has been found in the developement of the higher vertebrates, and especially in man, that the admission of the ultra-violet rays to the visual function has been undesirable and their participation in this way (and as it were purposively) guarded against? As the calf's eye was found transparent to shorter waves than that of the grown animal, so it may be predicted that the babe's eye will be found to permit the passage of shorter rays than the adult human eye.

The reason that different normal eyes are variously sensitive to the waves in the neighborhood of the ultra-violet demarcation-line is thought to lie in the varying degree of fluorescence possessed by different crystalline lenses. The normal crystalline is fluorescent to about the same degree as quinine, or in the higher animals to near Fraunhofer line O, or R.

Whether or not the visual mechanism of such animals as the hawk, turkey, etc., really react to the extremely refrangible rays allowed to pass by their ocular media, it was impossible to learn, owing to the evident reason that the human eye could not see in that "darkness" if motion followed the stimulus or not.

Turning at last to the far more important infra-red rays, we find only analogy and speculation to aid us. We know of no such experiments with these as with those we have just discussed. Here, indeed, photography can be of no aid, and only a thermometer so delicate as Prof. Langley's bolometer could give any result claiming correctness, by passing such rays through the living or but lately living eye, thus testing whether they were intercepted or not, and where was the line of demarcation. This has not to our knowledge been done. But a multitude of objections at once arise. To do this with the living eye is quite beyond possibility, at least with a normally living one, and the coexistence of pathological condition might justly be held to vitiate any result obtained. The objection would gather force as regards experiment upon dead tissues, and the experiments of M. Chardonnet are in this respect open to not a little criticism. The living eye might have a function or be without a function as a wave-filter, that would make the results of experiments upon the dead eye of a highly doubtful character. Moreover, the ocular media as such may be proved not to have this filtering action, and criticism is not checkmated by many moves; the layer of axis cylinders, highly complex and organized structures, of which there are some 800,000 spread out over the concave surface of the globe, may exercise an absorbent or modifying agency; not only does the entering light have to pass through these structures (except at the fovea) but it has also to pierce the still more highly organized and extensive eight or nine distinctly recognized strata of the retina before reaching the tips of the rods and cones or the pigmentary substance into which these extend. It seems wholly beyond the possibility of experiment to determine whether these may not, when instinct with quivering life, exercise an influence upon the transmitted rays. The inexplicable and apparently unnatural arrangement whereby the points of the retinal end organs are turned away from instead of toward the entering stimulus may not be disconnected from this interesting question. It must certainly have been another great task to make so complex an organizism as the retina so wonderfully transparent. Its transparency, however, may only be to the light rays, and it may possibly be wholly opaque to the infra-red. If it were proved that the rays in question do reach the pigment masses about the cone tips, it would conform to the theory of heat as the retinal intermediate that we have previously set forth, to suppose no receptive substance were there secreted whose vibratory phases corresponded to those of the infra-red rays. Lastly, it may not be held improbable that there is retinal response to these stimuli but no neural transmission to the brain; or, supposing there be such reports sent up, that, even as a final resort, the brain refuses to notice intimations that, from their inconstant, weak, or confusing character, are more wisely ignored. A thousand facts of experimental psychology show the cerebral co-ordinating centre to have such powers and to habitually exercise them.

The Retinal Stimulus of the Lower Animals.

An interesting question here presents itself, and may be alluded to in passing: Does the visual mechanism of other orders of animal life differently situated from ourselves respond to other wave lengths than our own? It is beyond question that every body whether solid, liquid, or gaseous, whether what we call "hot", as the sun or a red-hot stove, or whether what we call cold, as ice, is a continuous source of that radiant disturbance to the ether about its particles we call ethereal undulations; therefore the ether is vibrating at all rapidities from those already studied to those much slower, and probably down to those rapidities that may equal those of air. We have seen that the knowledge of a vast extent of these rapidities has lately been gained, almost bridging the space. Do eyes exist sensitive to the infra-red rays? Lubbock has shown that bees, ants, etc., respond to waves of the visible spectrum in a general way, as we do, but with some notable exceptions, especially in the more refrangible parts of the spectrum. That the vast majority of the higher animals whose life struggle has been under much the same circumstances of light and shade as ourselves, possess essentially the same visual response as we do, is reasonably certain. But it may be logically supposed that such animals as have been wholly differently situated may have developed reactions to the longer waves we have found most economical to ignore. But little study of the eyes of such low orders as the *Coleoptera*, *Annelida*, etc., has been done, but that little renders it highly probable that they have a receptive mechanism for vibrations between the upper limit of aur auditory frequency and below that of our light perception. The study of the eyes of nocturnal insects, of the inhabitants of the sea at different depths, of electrical and phosphorescent animals, etc., may prove highiy instructive in this respect.

Again returning to the human eye and to our subject, we may ask what reason would there be for the extension of retinal reaction to the longer ethereal vibrations when the possibilities of color are infinitely far from being exhausted within the limits of the visible spectrum? The average visual sense commonly perceives as one and the same color, waves differing in their frequencies of arrival by such stupendous numbers as millions of millions in a second of time, as was pointed out in a previous article: Instead of straining its energies to develop response to those weak and capricious stimuli, the infra-red rays, nature were more wise to expend its energies in differentiating the possible color differences at its own door, and within the already accepted limits. Without seeking out the distant heathen, this missionary spirit could be wisely spent in the conversion of the crowds in its own neighborhood and native land. And this is precisely what nature seeks to do. The Roman mosaic workers are said to have used 30,000 different tints; 28,000 shades of wool are used at the Gobelins manufactory, and speculation has run riot in attempting to calculate the numbers of the perceptions of color-differences possible to the cultivated eye. Exercise, as we know, develops delicacy of color perception, the Quakers being deficient in this respect, whilst the trained eye can easily detect differences of hue that another cannot perceive at all. A common and superficial remark has been that the eye with its response to but one octave of the color-scale is so much poorer than the ear that reacts to many octaves of the sound-waves. The truth is that if the possibilities of hearing were multiplied a thousand or a million fold, they would not begin to rival the infinite complexity and inconceivable opulence of varied result existent and possible with the single octave of the visual stimulus. Both the human eye and the bolometer are so far from reporting the absolutely homogeneous wave-length that the distances and numbers are utterly beyond the mind's powers of appreciation. The range of hearing practically extends from wave-rapidities of about 40 to those of about 4,000 per second, and trained musicians are said to be able to detect a difference of $\frac{1}{64}$ of a semitone in the middle registers, so that the addition of a single vibration per second becomes recognizable to a highly-cultivated ear. It would therefore appear that the refinement of auditory sensibility had reached, if not its limits, at least that degree of exquisiteness reasonably desirable. But turning to ethereal vibrations we find that the eye perceives no difference in the tint of two bands of color caused by wave-systems differing in their rapidities by numbers beyond mental comprehension. The lengths of ærial undulations vary from $\frac{1}{5}$ of an inch to 33 yards; those of ethereal vibrations(visible spectrum) from .29 to .81 one hundred thousandths of a millimetre; but the delicacy of actual and possible visual sensation is proportionately multiplied with this descent into the infinitely minute, so that progressive extension and refinement of the color-sense even within the octave, stretches out illimitably. Therefore in yet another sense this divine endowment of vision that seems to be *par excellence* the intermediary between the objective world of infinitely extended matter and space, and that other world of mind as wholly infinite in its way, binds us also to a third infinity, time, in the progressive education and spiritualization of the limitless color-sense which we see is possible in Humanity's onward march. The truest and tritest of truisms is that of our utter inability to conceive what human or animal existence would have been without the sense of vision. We could not have gained the intellectual eminence of a mole or the blind-fish of the Mammoth Cave because these are products, however degenerate, of ages of vision-endowed ancestry. Even the grasshoppers of the Mammoth Cave have lost their wings. Intellect surely became possible only through and by vision; and all the objects and products of our intellectual activity are indissolubly bound up with the results and processes of ocular activity. But what finally underlies and renders possible all this sublime extension and developement of the higher life? Simply this all-penetrating, all-surrounding somewhat, that we can only adequately think of as the spirit or as the spiritualization of matter, that we can only describe by using nearly all the old terms which theology and philosophy have heretofore jealously reserved as the exclusive attributes of the deity. The ether is certainly in a strictly legitimate sense a creator of us, since man, as man, could not have developed without vision of the external universe, and vision is the common product of life and ethereal energies. The microcosm exists because the macrocosm sublimed its essences to a quivering impalpable spirit of a sufficiently high tenuity, delicacy and expansiveness, to interpenetrate and enfold all material particles, and stretch to the confines of creation. No scientist or philosopher sees the faintest hint on purely material grounds of its *raison d'etre.* Its genesis is the blankest of mysteries. It seems a somewhat, and yet utterly distinct from what we commonly call matter. It appears to be of a completely distinct and different category of being from gravitation, neither giving nor asking of it service; suns and worlds could have wheeled on their courses without it, and life of an eyeless, non-intellectual, non-spiritual and sluggish variety might perhaps have arisen where it was not. As blinded bats by means of their interdigital extension of sensitive cutaneou ssurface, avoid obstacles in flying by a fine perception of the greater barometric pressure near such objects, so man, developing without light, might be mentally pictured as at the best a sort of huge diabolic pterodactyl-like bat flapping his way through the cimmerian landscape! (The picture may stand for the edification of a stray critic or two who has kindly and vaguely hinted that we were over-interested in our ether-waves. *Sua cuique voluptas!*)

But, seriously once more, if we consider the facts that electricity and magnetism (which are its stresses) would not have been our daily aids and delights, that life on all but self-heated worlds would have been impossible without the heat-transferring agency of the ether, that all vegetation is its creation, and animal life is to us almost inconceivable without vegetation—when we think of these physical facts the rapture and adoration of sun- and light- worshipping religions and peoples becomes reasonable. These and other reasons, we think justify our studies of ethereal activity which many doubtless have thought needlessly ly long and labored. But to any one whose mind is not content to live incurious of the many mysteries among which we vulgarly swim, this superlative mystery of light and the laws of ethereal activity offers the most brilliant and absorbing, and at the same time satisfying of all fields of study. But it is when we think how the mind of man only came into being by its aid; how almost all reasoning, *i. e.*, operations of the intellect, are by means of the metaphors and pictures of light and color; and lastly how the Beautiful, that smile of God which we may also call the splendor of truth and the sign-manual of the world's divine architect and owner, is solely by means of its undulations, —it is only when we ponder upon these things that we are lost in wonder, and recognize that if anywhere in the doubtful maze of cosmic circumstance purposive and supernatural agencies become visible, it is in the creation of that subtle mystery and, for the existence of intelligent and spiritual beings, transcendently important and necessary essence, we call the ether.