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SOME RECENT SPECULATIONS ON THE NATURE OF LIGHT[1]

FOUR weeks, one day and four hours ago I was sitting on a sofa in the Cosmos Club, Washington, chatting with your distinguished director during a brief interval between long committee meetings. That was when, but I know not just how or why, I was caught by that wily hunter for this particular repast. This time he was not after big game—merely angling for a poor fish.

There is no need to import any outsider into the Jefferson Physical Laboratory to talk about light. Here you have Pierce with his wave lengths in hundreds of meters and Duane with them in fractions angstroms, a range of 10^{14}. Here the celebrated Lyman region was found and explored. You have in Saunders one who has followed series spectra from Ritz to Bohr and beyond. Then there is infra-red Kemble and band-spectra Mulliken, and for recent speculations on the nature of light why look further than Slater? The whole range of factual and deductive and speculative optics is here, and nowhere else in greater variety or completeness or perfection. If Count Rumford were alive he would perhaps feel that you were all out for the Marathon that leads to his medal and premium—and all likely to win.

The count spoke of light and heat. To-day light and heat and electricity have come together. Therein lies our difficulty and thence issue our speculations. While light stood alone we had reached a satisfactory theory of its nature as a wave motion in a medium. When it passed to heat and we became interested not in the transparent but in the black body we were in trouble at the short end of the spectrum and that trouble has been confirmed and accentuated by photoelectric phenomena. A score of years ago Ritz[2] in a masterly critique of electromagnetic theory suggested strongly that the time had come when it might be no longer useful and might perhaps even be harmful to consider energy as localized. We have proceeded, in the most contrary way, to emphasize more and more the localization of energy, especially radiant energy, and to endow this energy with momentum, angular momentum, with mass, inertia and weight. The quantum theory and the Bohr orbit have certainly been

[1] An address before the Physical Colloquium, Jefferson Physical Laboratory, May 24, 1926.

[2] W. Ritz, "Gesammelte Werke."

increasingly with us, and are likely to remain for some time.

Perplexing as our situation is, we should be happy in it. For it is wholesome, healthy and young. We have become again as little children to whom everything is new and wonderful, and we are learning facts so fast that their systematization is not to be expected. In due time we shall come again to a period of senility in which we shall understand and no longer learn. It will be some precocious, maybe I had better say some prematurely senile young man from whom will issue this virus of sclerosis.

AN INTERPRETATION

Light came into the world on the first day, and it was good. Sight is our best sense. To see is a synonym, not even colloquial, for to understand. A dog would say, "Do you *smell* that?" Optics is one of our oldest sciences. For long times there was dispute as to whether light issued from the perceived object into the eye or emanated from the eye to the object seen. It has remained till the year 1925 and to G. N. Lewis[3] to suggest that the eye and the object are in contact and that the relation is mutual. Let us examine this speculation of Lewis's. Einstein interpreted the Lorentz transportation as relativity, not the relativity of Newton nor of the later Einstein, but the special relativity of electromagnetic theory. Minkowski gave an elegant mathematical formulation of this relativity which Lewis and I elaborated in 1910–1912 and printed in the latter year in the *Proceedings of the American Academy*. One may say that fundamentally neither space nor time are of separate physical significance, they are individually anthropomorphic, if not conceited, conceptions based on the notion that the individual observer is at rest, probably at the center of the universe, and everything else in motion. Physically the important thing is the local time, the Eigenzeit, $d\tau = \sqrt{c^2dt^2 - ds^2}$, a fusion of space and time. Along the path of light $d\tau = 0$, and there is no lapse of space-time; a particle moving with velocity less than that of light has a past and future defined by its space-time path, but not so for light itself. Hence, says Lewis, we make the interpretation that there is contact between the perceiving eye and the object perceived and more generally between any two objects in radiative interchange. To some this sounds bizarre if not impish.

Let us for a moment consider what is the function of mathematical physics. In a certain sense we get out of mathematical physics only what we put in. This is a purely mathematical implication and means merely that if our mathematics is water-tight every conclusion must follow deductively from the premises. But in another and more physical sense we may and we ordinarily do hold that when we interpret our mathematical conclusion as a fact of nature we get new physics. In this way Hamilton got conical refraction, and it was a sound way to get it provided that observation verified deduction. Suppose observation had belied deduction. Then we should have been forced to conclude not that the demonstration was in error but that the premises on which it was based were inadequate for, or contained elements extraneous to the theory of light, or were contradictory within themselves; *i.e.*, they were logically inconsistent or inconsistent with nature. Many other instances of obtaining from mathematics new physics could be adduced, and also many, perhaps more, instances of obtaining too much or too little. It is the interpretations that determine the value of mathematical physics and that make it as Darwin pointed out in 1912 a more exacting science than pure mathematics. Now Lewis has made an interpretation. It is a reasonable interpretation of the mathematics fundamental to relativity. Without prejudicing the mutuality of the relationship of contact, I may be permitted to say anthropomorphically that the interpretation can not fail to throw light upon the subject.

AN ADAPTATION

For a long time there was a dispute as to whether light moved faster in the optically denser medium or more slowly. On the corpuscular theory it was believed that the potential energy was constant in each uniform isotopic medium but changed in the interface, *i.e.*, that the normal component of the velocity of light changed across the interface but the horizontal component remained the same. This led to the view that the velocity was greater in the denser medium—for such an interpretation is forced by the law of refraction. Moreover, this theory may be supported by the law of stationary or varying action. It is only necessary to take the law in the form[4] $\delta \int v\,ds = 0$ with $v = nc$, where c is the velocity of light and n is the index of refraction, to obtain the proper relation $\delta \int n\,ds = 0$ of geometrical optics. On the other hand the wave theory leads to the conclusion that the velocity is less in the denser medium, and this view was early urged by Fermat in connection with his principle of least time. Here we have $\delta \int ds/v = 0$, but $v = c/n$ and hence again $\delta \int n\,ds = 0$. The question of velocity as a physical fact was settled experimen-

[3] G. N. Lewis, Silliman Lectures, Yale University and Proc. Nat. Acad Sci., 12, p. 22.

[4] W. R. Hamilton, Trans. Irish Acad., 15 (1924), p. 69. See also H. A. Lorentz on Light, Encyc. Brit., Vol. 16, p. 618.

tally by Foucault and would in any case have been assumed as settled by the triumph of the wave theory even if the experiment had not been forthcoming at a time proper to the support of the theory. The equation $\delta \int n\, ds = 0$ remains and the principle of least action must be adapted thereto with the condition $v = c/n$ instead of $v = nc$.

As is usual in such cases the adaptation may be made in a number of ways. The most recent and perhaps the neatest is that due in 1925 to Cox and Hubbard.[5] They assume that a beam of light is made up of quanta $h\nu$, that the number of these quanta in the incident beam is equal to the sum of the numbers in the reflected and refracted beams, which is equivalent to assuming the constancy of energy. The momentum in vacuo associated with a quantum $h\nu$ is $h\nu/c$ and the authors assume that in a medium of index $n = c/v$ the momentum will be $h\nu/v$, so that a quantum has a greater momentum in the denser medium where it has the smaller velocity. This checks with our notions on the basis of the wave theory. If we define the element of action for the quantum as the product of the momentum $h\nu/v$ by the element of distance ds we have in the equation $\delta \int (h\nu/v.ds) = 0$ the principle of least action so adapted as to give the correct equation $\delta \int n\, ds = 0$ from which the laws of reflection and refraction flow. It should be remarked that in this theory we are dealing with large numbers of quanta. It would seem as though individual quanta must be either refracted whole or reflected whole. The constitution of the medium must therefore determine, and through its index of refraction specify, what fraction of a large number of quanta, *i.e.*, what is the chance that any one quantum, incident at a given angle, shall be refracted or reflected.

AN ABSTRACTION

Maxwell gave us an electromagnetic wave theory of light. Gibbs gave us an electrical theory.[6] These amount to the same thing if all magnetism is generated by the motion of electricity. But the method of Gibbs is totally different from the method of Maxwell; it is a real contribution, and though scarcely recent seems never to have made an impression on optics and hence is worth mentioning. He likened a transparent body to an area of marine piling and light to a ground-swell moving towards and through it. The piles will not affect the ground-swell much as a whole, there will still be an advancing periodic motion of the original frequency though of diminished wave length. But superposed upon that will be an irregular motion. Gibbs set himself the problem of calculating the part of the energy that would be found in the regular and the part that would be found in the irregular motion —not of course for the two-dimensional analogon of the area of piling, but for the transparent body and the light. On these very general assumptions of a fine-grained structure for his medium, of some general properties of simple harmonic waves and of a few basic principles of electrodynamic action he was able to explain the behavior of transparent bodies, including those optically active, and by a familiar analytical device using complex numbers further to extend the equations to absorbing media. I would emphasize the uselessness of special hypothesis for so much of optical theory as is derivable from abstract generalities. How this work would be adapted to the theory of quanta is not easy to see; before we get quanta fully adapted to the type of optical phenomena with which he and the older physicists were concerned such difficulties may be resolvable.

A PICTURE

Maxwell built his theory of electromagnetism on the work of Faraday with a good training, which Faraday did not have, in the work of Green and Stokes and other workers with continuous media. It is not easy to understand Maxwell in all places, one may even doubt if he fully understood himself. Kelvin never completely went over to him. Perhaps Heaviside was our only complete Maxwellian, more complete than his original. Presumably Maxwell attributed little physical reality to the Faraday lines of force; it would be unnatural for a student steeped in hydromechanics and the theory of elasticity to do so. J. J. Thomson has tended to return to Faraday and treat the lines or tubes of force as real and atomic. Writing in 1903 he said:[7]

> This view of light as due to the tremors in tightly stretched Faraday tubes . . . discrete threads embedded in a continuous ether, giving to the latter a fibrous structure . . . , on this view, then a wave of light itself must have structure, and the front of the wave instead of being, as it were, uniformly illuminated, will be represented by a series of bright specks on a dark ground, the bright specks corresponding to the places where the Faraday tubes cut the wave front.

And he went on to use this picture to explain the small amount of ionization produced by light. As a Faraday tube must start and end on electric charges, these charges must be separated by the wave front. This implies a separation of charge for which I have

[5] Cox and Hubbard, Proc. Nat. Acad. Sci., 11, p. 498.

[6] J. W. Gibbs, "Scientific Papers," Vol. 2.

[7] J. J. Thomson, Silliman Lectures, Yale University, published as "Electricity and Matter," p. 62.

never seen any physical evidence, unless we get around the difficulty by assuming that the Faraday tubes are in pairs, about one half running from negative electricity behind the wave to positive ahead of it, the other half from positive behind to negative ahead. If we can get around the difficulty of charge, there is a remarkable similarity between Thomson's suggestion of 1903 and Lewis's of 1925—the emitter and recipient electrons are in connection *via* a Faraday tube which is a light-path and from the viewpoint of relativity may be said to be in contact.

Similar as the two suggestions are, I can not see that Thomson's of 1903 has any similarity to Thomson's[8] of 1924, and I must confess to having had that difficulty before with some of Thomson's papers separated by an interval much shorter than twenty-one years. At any rate he appears to consider that there is some continuity between the papers because we find in that of 1924 a brief extract in quotation marks from the earlier paper. The Faraday tube is of course still with us, but so far as I can determine the tightly stretched strings whose tremors constitute light and which cut the wave front in the bright specks have quite disappeared. What the Faraday tube now does is to stay in the atom, but occasionally to get snarled up and throw off the snarls as light corpuscles. Let us quote Thomson: "The mutual potential energy of an electron E and a positive charge P is located in the tube of force stretching between E and P. If the electron falls from E to E′ this potential energy is diminished by the energy in the portion EE′ of this tube of force. During the approach of E to P the tube may be thrown in a loop, the closed part of the loop gets detached and goes off as a closed ring which rapidly becomes circular and travels with the velocity of light in a direction at right angles to its plane like a circular vortex ring." The process of absorption is the reverse—one of these rings gets foul of the Faraday tube in an atom in such a peculiar way that it reunites with the tube and pushes the electron out to a more distant orbit.

PSYCHICS

It appears as though the Faraday tube were a very obliging if not changeable fellow. To his tension, at one time, is due the tendency of positive and negative charge to get together, but now the electron under some circumstances can move in so fast that his tube can not follow and gets looped. And though in the process of getting looped a tube must apparently travel largely in its own plane, once it snaps off its loop the latter moves perpendicular to its plane and with the velocity of light despite the fact that previously it had not been able to keep up with an electron. The leopard has changed his spots. We need not insist upon sense in such matters. Bohr has written that an electron does not know it is in a stationary state until it has been around the orbit a few times.[9] This is humanly intelligible, it is sound behaviorism. All we need now is to have some physicist who has read up the new psychology as a minor tell us that the Faraday tube that draws the negative and positive electricity together is but a gross materialization of the real fundamental force of nature, the sex instinct, and our molecules have become as inhumanly lewd as we are alleged to be! There must always be mystery forces and mystical structures at the basis of physics, we can not explain except from unexplained postulates or define except in terms of the

[8] J. J. Thomson, *Phil. Mag.*, **48**, p. 737; **50**, p. 1181.

[9] N. Bohr, D. Kgl. Danske Vid. Sels Skrift, Nat. Math., Afd. 8, IV, Pt. I. German Translation by Hertz (pp. 28–29): Die Antwort . . . ob ein gegebener Zustand stationär ist . . . kann nicht gegeben werden, ehe die Teilchen nicht durch einen völlstandigen Zyklus von Zuständen hindurch gegangen sind und sozusagen Kenntnis vom ganzen Kraftfeld und desen Wirkung auf die Bewegung genommen haben. . . . '' It may be remarked that the quantum theory originated with Planck in connection with an empirical equation for black body radiation and that in the first edition of his Wärmestrahlung he proves the formula from the Maxwell theory and classical mechanics. Later Poincaré showed that the conclusions were inconsistent with the premises and in subsequent editions of his book Planck suppressed the proof in question and substituted a quasi-axiomatic procedure. Bohr's work and its elaboration into an astounding detail by him and others was based on a combination between dynamics of a particle (central forces) and the quantum conditions. Lapsing into a psychological mode of expression is no retraction of accomplishments but an indication of perplexity as to the future; it is only in the most recent months that we are learning from Born and Heisenberg how to set up the quantum theory on its own feet independent of classical mechanics or electromagnetics and in a way which if successful may lead, as implied in the text, to a redefinition of fundamental concepts in terms of it.

[Note added in proof. Another hopeful formulation of the quantum theory on its own feet, which was appearing as this lecture was in preparation, is Schrödinger's undulatory theory of mechanics, now available in *Physical Review*, Vol. 28, 1926, pp. 1049–1070, and apparently largely transformable into the system of Born and Heisenberg, but inspired by the contributions of de Broglie mentioned in the final paragraph and by the optical investigations of Hamilton cited above, ref. 4. The Bohr orbits seem to have gone and to be superseded by structure represented by vibrational types in a distributed charge, a suggestion which in different mathematical guise was put forward long ago, I think by J. J. Thomson.]

undefined. It may be an advantage to have our primitive propositions and undefined symbols translated into graphic language.

I shall pass over the quantum theory itself as a recent speculation on the nature of light. It is both too well and too little known to require mention. But I should perhaps say a word about the two-electron jumps of Saunders and Russell,[10] be it only to ask how soon we shall find three-electron or four-electron jumps. The two-electron jump seems to me almost too much of a good thing for the good simple old quantum theory. We shall soon have to add to the conception of the electron's nose for its home some sort of supernormal telepathic intercourse with other electrons. Certainly many of the mathematical relations which are now attached to the quantum theory have come to stay just as has the sine-law of refraction; but it was long after the discovery of that law that we knew whether the velocity of light was greater or less in the denser medium and we do not yet know whether light is a wave motion or corpuscular or how divided between the two. The orbit picture of the atom may disappear and be replaced by structure. So long as our notions of action remain as indefinite in a physical sense as they still are we shall be loth to constrain motion by quantum conditions based on action. The way out may be to get a keener appreciation of action itself and to replace conceptions now taken as primitive by definitions of them in terms of action. We used to write $\Delta E = h\nu$, we now write $\nu = \Delta E/h$ and the frequencies are not orbital frequencies. The question appears no longer to be why is $\Delta E = h\nu$ but how should $\nu = \Delta E/h$? Is frequency a temporal phenomenon at all? It is not the arithmetic but the interpretation of this equation which is physics.

THOMSON'S CORPUSCLE

Let us return to the light corpuscle of Thomson. The energy of the ring may be calculated. If f is the electric polarization the energy is $E = 2\pi f^2 \times$ the volume of the ring which is $2\pi r \pi b^2$ if r be the radius of the ring and b that of its generating circle. But the total amount of electricity represented by the tube in the loop can not exceed e, and $f\pi b^2 = pe$ where $p \leqq 1$. Hence $E = 8\pi^2 p^2 e^2 (r/b)^2 (1/2\pi r)$. We assume that the rings are similar so that the energy varies inversely as the radius. The introduction of the facultative fraction p jars on the picture. Apparently there may be several Faraday tubes from a single electron, possibly of varying electric equivalents, of which only one or some become looped and shuck off a light-corpuscle. We next assume that the frequency of light associated with the ring is $\nu = c/2\pi r$, which means that the wave length is the circumference of the ring. Then $E = 6.2 \times 10^{-28} (pr/b)^2.\nu$ and we have Planck's $E = h\nu$ provided $pr/b = \pi$ or something very near to π. If $p = 1$ and $r/b = \pi$ the corpuscle makes a good commercial doughnut. For visible light of 6,280 angstroms, $r = 1000$ angstroms $= 10^{-5}$ cm. and the doughnut has a volume of $2\pi r \times \pi b^2 = 2r^3 = 2 \times 10^{-15}$ cm.^{3} The volume held by an atom is of the order of magnitude 10^{-23} cm. and the doughnut would contain 50,000,000 atoms. Somewhere I have seen it stated that a quantum of visible light is supposed to engulf a great many atoms, though it materially affects very few. Of course if we take p as a small fraction, the ring becomes like a child's hoop and will cover fewer atoms in proportion to p^2 but then we must have many Faraday tubes of which only one may get kinked. If we go down to X-rays of wave length $10^{-8} = 2\pi r$ the volume of the ring is $10^{-24}p^2/4\pi^3$ and is much less than that of an atom.

Thomson follows out the consequences of this corpuscular model and makes out a case for its satisfactory explanation of a goodly number of known experimental facts. We shall not follow the details. One characteristic of his theory of the nature of light is that it is dual. We have these corpuscles and we have ordinary Maxwellian waves like the Hertzian wireless waves. Some of the emission is corpuscular, some is ordinary. The fraction of the emitted energy which appears in the one or the other form depends on circumstances and on wave length. The corpuscles are accompanied by an aura or embedded in an umbra of old-fashioned waves which even in the case where the waves have but little of the energy serve to direct or guide the corpuscles and thus determine phenomena like diffraction and interference. This seems to me somewhat to smell of trigger-action which has recently been much in disgrace but with a dreadful social callousness insists on showing up again—for instance, in Bohr's electron sniffing about its tracks to determine whether it is at last home in a stationary state or off on another false scent. My belief is that trigger-action like mystery forces will long be with us. The amount it is allowed to disport itself in public is a measure of our lack of confidence as to where we are at.

WHITTAKER'S MAGNETON

In a recent paper Whittaker proposed a model to explain some photoelectric phenomena. It was a magnetic model, a sort of magneton. I presented this work a while ago to the staff seminar of this department on a Monday evening and it was howled down. I rather liked the model—it was so definite, but I

[10] Saunders and Russell, *Physical Rev.*, 22, p. 201.

shall not revert to it. Now Whittaker[11] comes to Thomson's aid with a demonstration that the ring corpuscle is possible on the basis of Maxwell's equations so modified as to include magnetic current after the manner suggested by Heaviside. These equations are (in the absence of electric charge)

$$\triangle . \mathbf{E} = 0, \ \triangle \times \mathbf{H} = \dot{\mathbf{E}}/c, \ \triangle . \mathbf{H} = \mu, \quad -\triangle \times \mathbf{E} = \dot{\mathbf{H}}/c + \mu \mathbf{v}/c,$$

when we allow for permanent magnetism μ and its connection current $\mu \mathbf{v}/c$. (We could use $\triangle . \mathbf{E} = \varrho$ and $\triangle \times \mathbf{H} = \dot{\mathbf{E}}/c + \varrho \mathbf{v}/c$ if we wished to get in the charge.) There is also the expression $\mathbf{F} = \mathbf{H} - \mathbf{v} \times \mathbf{E}/c$ for the mechanical force acting on the magnetism. If we write

$$E_x = H_x = 0, \ E_y = H_z = -z(a-r) f(x-ct), \quad E_z = -H_y = y(a-r) f(x-ct) \quad r > a$$

$$E_x = E_y = E_z = 0, \quad H_x = H_y = H_z = 0 \quad r > a$$

$$\mu = -(2a - 3r) f(x-ct), \ r < a, \quad \mu = 0, \quad r > a,$$

we have a solution of the extended Maxwell equations which makes $\mathbf{F} = 0$ so that the solution does not suffer distortion. This does not give an annulus but is circularly symmetric about the line of motion which is the x-axis. The total free magnetism is zero. (Note that if we have a closed line of magnetic force we have electric current passing through the circuit and that the ring corpuscles have closed lines of electric force which should imply magnetic current through the circuit. By the circuit is here meant the cross-section of the annulus in its plane.)

So far as I can see the factor a–r may be replaced by any function $\varphi(r)$ provided the appropriate change in the expression for μ be made, namely, $\mu = -(2\varphi + r\varphi') f(x-ct)$. The factor $f(x-ct)$ ensures propagation with velocity c along the x-axis. The velocity $\mathbf{v}$ (above) is here put equal to c, the velocity of the pulse. This is apparently an ether theory with the velocity $\mathbf{v}$ measured relative to the fixed ether. Whittaker points out that the magnetism allows magnetic force or electric current to grip the corpuscle and deflect it—a possibility postulated by Thomson. The corpuscle has a substantiality in excess of ordinary radiation. He refers to his earlier paper and remarks that it seems as though magnetic currents have the special function of making it possible to reconcile the quantum theory with the classical. Thomson did not postulate that the electric force on the inside and outside boundaries of his ring were zero. He speaks definitely of discontinuities in the electric force within and without the ring, whereas Whittaker has adjusted matters so that E shades off to 0 at $r = 0$ and $r = a$ and the total magnetism is null.

The magneton may help in reconciling heat and light, quanta and classical theory, free propagation of radiant energy and interchange of energy between radiation and matter. It may be doubted whether it will be sufficient. There was a time when positive and negative electricity were supposed to be alike save for sign. We have known for some years that the electron and proton are very different in mass. Presumably they have other differences—perhaps one in size. Then we have the atomic nuclei. In the case of helium four protons and two electrons are supposed to cleave together in the nucleus. Ordinary interchanges between radiation and matter involve protons and electrons in addition to corpuscular light. We still have, I believe, some quantum difficulties with helium, despite the prodigious amount of ingenuity that has been spent on the matter, and possibly with the hydrogen molecule H_2 which involves two protons and two electrons. Then there is the existent, if somewhat unstable, H_3 or H_{3+}. There are still many unknowns at the kernel of physics. It is a little early to say wherein will lie the special function which shall some day reconcile quantum theory with our older conceptions.

BATEMAN'S DOUBLET

We must not overlook Bateman. His introduction of new and unexpected solutions of the Maxwell equations was mighty work. As a mathematical discovery it has not appealed to mathematicians so strongly as the finding of a new periodic solution in the problem of three bodies, but perhaps some day it will. As a physical tool it has not so much appealed to physicists as I believe it should. Bateman is probably the most powerful and consistent mathematician now working in electromagnetic theory. Sir W. H. Bragg used to maintain that the corpuscular form of radiation carried electricity with it. His original notion of a neutral pair (electron plus proton) has not found favor. I may mention that on account of the duality of electric and magnetic phenomena one could from some points of view just as well take Thomson's circular tube of electric force to be an annulus of magnetic force, and then Whittaker's solution would require not magnetic current but electric current and we should have a neutral pair associatetd with the corpuscle and moving with the velocity of light. Bateman's solution is of this sort, electromagnetically symmetric to Whittaker's; analytically it is[12]

[11] E. T. Whittaker, *Proc.* Roy. Soc. Edinburgh, 46 (1926), p. 116.

[12] H. Bateman, *Phil. Mag.*, 46 (1923), p. 977.

$$E_x = H_x = 0, \quad E_y = H_z = \frac{\partial\Omega}{\partial y} f(t - \frac{x}{c}),$$

$$E_z = -H_y = \frac{\partial\Omega}{\partial z} f(t - \frac{x}{c}),$$

where Ω is a function by y and z whose derivatives are large near some parts of the y-z-plane and small elsewhere. This gives $\nabla.\mathbf{H} = 0$ but $\nabla.\mathbf{E} = (\partial^2\Omega/\partial y^2 + \partial^2\Omega/\partial z^2)\ f\ (t - x/c)$ and thus leads to a charge wherever f does not vanish and Ω fails to satisfy Laplace's equation. The ponderomotive force vanishes. The solution is more general and earlier than Whittaker's, as the latter states. We may notice that the total charge in the pulse is zero if the average value for f on x is zero, as it will be if f is simply harmonic like $\sin(t - x/c)$, or if the plane integral of $\nabla.\nabla\Omega$ vanishes, *i.e.*, if the sum of the boundary integrals of the magnetic force is zero.

Bateman works with the special function $f(t - x/c) = f(u) = (\sin 2\pi\nu u)u$ which gives as the energy of the pulse $2\pi^2\ cW\nu$ where W is the energy in the plane of y and z, *i.e.*, $W = \int\int (\nabla\Omega)^2\ dxdy$. With $2\pi^2 cW = h$ we should get for the universal constant $W = 1.1 \times 10^{-38}$ with dimensions mass times length. If we take out the mass of the electron we have a universal constant 1.25×10^{-11} with dimensions of length, and dividing by c we have 4×10^{-22} as a universal constant of time—these correspond to a wave length of a little more than one thousandth of an Angstrom, which is about one twentieth of the wave length that on the quantum theory would be emitted if an electron at rest blew up and dissipated its energy into radiation. Presumably, however, we are not ready for such numerical speculations, fascinating and modish as they are. Another interesting point about this example is that on reflection by a plane mirror moving with velocity u we find the quantum reappearing with the same type of f but with its frequency changed as required by Doppler's principle. Now Doppler's principle is derivable from very general considerations on waves and pretty as the above demonstration is, it would be prettier to reverse it and find what restriction the principle puts on types of function f.

I have not ventured into de Broglie's light-molecules and his statistical investigations with them, nor mentioned the apparent necessity that quanta be of two kinds, right- and left-handed. I have not gone into the work of Born which he has but so recently discussed at length in his lectures at M. I. T., or the propositions of L. V. King in a pamphlet that I have not seen, or even of Barla's phenomena in X-rays, which seems to be contesting the explanation of the Compton effect. To cover all the recent speculations on the nature of light would be fairly well to cover the interesting and disputed parts of modern physics. That can not be done in an hour. Some years ago A. G. Webster in commenting at the American Academy on the difficulties we have been discussing said that the modern physicist had a perfectly good coat and an equally good pair of trousers but was completely naked between the two. It sometimes seems as though the still more recent discoveries and disputations had tended dangerously to fray out the nether part of the coat and the upper portion of the trousers. We shall sometime have a beautiful whole new suit, possibly with spats and cravat and patent leathers and a plug hat, but those will be the evil days when the grinders cease because they are few and those that look out of the windows be darkened. Let us enjoy our present gamin life.

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THE CONCEPTION OF A SPECIES[1]

IN the light of recent experiments and researches in genetics, cytology and taxonomy it is now possible to present a more precise conception of a species.

A species is a group of individuals of common descent with certain constant characters in common which are represented in the nucleus of each cell by constant and characteristic sets of chromosomes.

Since the discovery of Mendel's law, genetics, with its experimental analyses of hereditary units, has thrown considerable light on the nature of variation in plants and animals. It is now clear that hereditary variations are due to discontinuous mutations in the chromosomes, but it is equally certain that the most minute variations perceptible may be inherited, as demonstrated in the eye-colors of *Drosophila* and as I found in the minor flower-shades of the scarlet *Antirrhinum*. Genetics has provided us with a fairly complete understanding of the nature and inheritance of the minor variations of individuals, varieties and sub-species upon which Darwin rightly laid so much stress, and to which many modern systematists have given specific rank. Concerning the major variations that constitute species and genera in the broad Linnean sense little light can be expected from genetics alone, owing to the barriers of sterility between the larger groups.

Recently, cytology, with its modern refinements of technique, has made remarkable progress in the analyses of chromosome complexes. So far as my records go, at least 2,845 species of plants and animals, representing 1,326 genera, 417 families, 181

[1] Paper read at a joint discussion between Sections C, D and K, at the British Association, Oxford meeting, August 10, 1926.