Dewitt Bristol Brace
1859–1905

Larmor

SECTION B — PHYSICS OF ETHER

(*Hall* 11, *September* 23, 3 *p. m.*)

CHAIRMAN: PROFESSOR HENRY CREW, Northwestern University.
SPEAKER: PROFESSOR DEWITT B. BRACE, University of Nebraska.
SECRETARY: PROFESSOR AUGUSTUS TROWBRIDGE, University of Wisconsin.

THE ETHER AND MOVING MATTER

BY DEWITT BRISTOL BRACE

[**Dewitt Bristol Brace,** Professor of Physics, University of Nebraska. **b.** Wilson, New York, 1859; died, October 2, 1905. A.B. Boston, 1881; A.M. Boston, 1882; Ph.D. Berlin, 1885; post-graduate, Massachusetts Institute of Technology, 1879–81; Johns Hopkins University, 1881–83; University of Berlin, 1883–85. Acting Assistant Professor of Physics, University of Michigan, 1886. Vice-President of American Association for the Advancement of Science; Vice-President of American Physical Society. **Author of** *Radiation and Absorption.*]

THE question whether the luminiferous ether passes freely through matter or participates in the translation of the same, considered as a moving system, stands to-day without positive answer, notwithstanding the numerous experimental attempts and the varied hypotheses which have been made since the discovery of aberration by Bradley in 1726. The simple explanation of this phenomenon on the corpuscular theory may have caused the century of delay in the closer examination of the question until it became necessary to consider it from the standpoint of undulations in an ether. As compared with the many efforts to examine the question in the second or ether period we have perhaps but two belonging to the first or corpuscular period. Boscovich, in 1742, reasoning from this theory on the ground of a difference of velocity in air and water, proposed to examine the aberration of a star with a telescope whose tube was filled with water. This experiment was not carried out till long after by Airy in 1872, who found that the variation in the aberration was absolutely insensible. Arago, in the second instance, reasoning on the same theory, concluded that the deviation produced by a prism would vary with the direction of the earth's motion; but he was unable to detect any such change, a result verified later by more delicate means in the hands of Maxwell, Mascart, and others. This experiment, which demonstrated the absence of any effect of the earth's movement on refraction is of great historical interest. This negative result, which to Arago was inconsistent with the corpuscular theory, suggested to Fresnel the important hypothesis of a quiescent ether penetrating the earth freely but undergoing a change of density within the medium proportional to the square of its index and being convected in proportion to this excess of density, which would give an apparent velocity to the ether of $(1-\mu^{-2})\nu$, instead of the velocity of the earth. Stokes suggested, as a simpler idea, that we suppose the ether is not convected but passes freely through the earth, being condensed as it passes into a body in the ratio of 1 to μ^2, so that its velocity within the refracting medium becomes $(1-\mu^{-2})\nu$, from the law of continuity.[1]

Babinet in the second-century period attempted to test Fresnel's theory by examining the interference of two rays traversing a piece of glass, the one in the direction of the earth's motion and the other in the opposite direction. Stokes showed that a negative result was not contrary to the theory of aberration, since the retardation would be the same as if the earth were at rest.

He showed further, what Fresnel had not proven to be true in general, that on Fresnel's theory the laws of reflection and refraction for single refracting media are uninfluenced by the motion of the earth. In fact, Rayleigh has shown that, in using terrestrial sources, no optical effect can be produced by any system of reflecting or refracting optical surfaces moving as a rigidly connected system relatively to the ether, if we take into account the Döppler "effect," and neglect quantities of the second order of the aberration. Since, as Stokes says, the theory of a quiescent ether may be dispensed with, and as there is no good evidence that the ether moves quite freely through the solid mass of the earth, he proposes to explain the phenomenon of aberration on the undulation theory of light, upon the supposition that the earth and the planets carry a portion of the ether along with them, so that the ether close to their surfaces is at rest relatively to those surfaces and diminishes in velocity till at no great distance in space there is no motion. Cauchy had previously discussed the theory of a mobile ether, and had proposed to explain aberration by a shearing of the wave-fronts due to the translatory motion of the medium, but he did not develop his method sufficiently to explain how much the aberration would be.

On the other hand Stokes has specifically indicated his assumptions and formulated his conclusions. He examines the displacements of a wave-front in its passage from the ether at rest, across the region of transition to the ether in the neighborhood of the observer, which is at rest relatively to him. Adopting the same method which is used in the case of an ether at rest in determining the wave-front at any future time from that of a given one at any instant, he shows,

[1] If x is the velocity of the ether relative to the moving matter, and the density of ether within it is μ^2, the density of free ether being unity, we have from the law of continuity $\nu=(\nu-x)\mu^2$ and hence,

$$x = \frac{\nu\mu^2-\nu}{\mu^2}=(1-\mu^{-2})\nu$$

on the one condition, viz. that the motion of the ether is differentially irrotational, that if we neglect the square of the aberration and of the time, the change in direction of the ray as it travels along is *nil*, and therefore the course of a ray is a straight line, notwithstanding the motion of the ether. Following out the analysis on this supposition, a body, a star for example, will appear displaced toward the direction in which the earth is moving through an angle equal to the ratio of the velocity of the earth to that of light, when moving normal to the star's direction. This rectilinearity of propagation of a ray, which would likely seem to be interfered with in the motion of the ether, is the tacit assumption made in explaining aberration. If the physical causes, in consequence of which the motion of the ether becomes irrotational, could be adduced, the theory of Stokes would satisfy completely aberration and the negative results of the many and various experimental investigations which have thus far been made and whose validity is unquestioned, whether in refraction, interference, diffraction, rotary polarization, double refraction, induction, electric convection, etc. In an ordinary fluid, tangential forces proportional to the relative velocities destroy the irrotational condition in a steady state of motion. If we suppose these forces to be diminished indefinitely we obtain now a motion totally different from that for the steady state when these forces are assumed to be absent initially; and hence such a motion would be unstable. When, however, tangential forces depending on relative displacements in the ether are considered, it becomes possible to explain the irrotational condition. Any deviation from this state, for example at a surface of *slip*, would be dissipated away into space with the velocity of light by means of transverse vibrations. He illustrates such apparent incompatibilities in physical states by successive dilutions of gelatine. Such a medium shows elastic tangential forces for small constraints, and yet apparent fluidity for motions through it, mending itself as soon as dislocated. He regards these qualities as consistent and self-sufficient to explain the phenomena in question. Against the view of Stokes, Lorentz raises objection to his assumptions concerning the ether motions in the neighborhood of the earth, which he considers inconsistent, a difficulty which he is unable to set aside. Larmor demurs against an appeal to a highly complex medium, such as pitch, for studying the behavior of a simple one like the ether. A time-rate much shorter than the time of relaxation will of course provide approximate rigidity, while a time-rate much longer will provide approximate fluidity, but this requires inevitable dissipation. This objection would be valid for a viscous solid, but such Stokes apparently did not have in mind, since he specifically proves such a case unstable. A solid like pitch is a very different type of solid from that of a vesicular solid like jelly. An ether after the model of a viscous solid would always contain the viscous terms, so that even for the high time-rates of light-waves there would be dissipation however small. Such a condition, it can be proven, would give coloration to the remote members of the stellar system; a fact inconsistent with observation. On the other hand, a soft vesicular solid like gelatine may not necessarily contain the time-factor, and yet be so soft that dislocation may occur even with constraints of the order of aberration, but not of the square of that order. Such an ether without a *time of relaxation* factor would fulfill completely the conditions of a luminiferous ether, if, as Stokes tried to show, it could be reconciled with the phenomena of aberration and the motions of the heavenly bodies. The method of double refraction shows that a solution of gelatine of one part in a thousand is rigid, while at the same time it appears as mobile as water, and its rate of flow through small tubes does not vary largely from the same. This experiment illustrates very markedly Stokes's example. When such a solution is continuously dislocated between two surfaces in relative motion, the same double refraction is present, indicating that the stress is still active during dislocation. Also a metal, like copper, shows a similar stress while being strained beyond its elastic limit. If this takes place by *slip* or dislocation throughout the mass which, though irregular, may give a mean uniformity for sensible dimensions, such a medium might serve as our model. Any deviation from perfect regularity in molecular distribution and activity we might anticipate would give such minute irregular dislocations at the limit of elasticity. Such a medium would thus transmit completely any disturbance within this strain limit.

It is difficult, however, to conceive of the transmissions of a disturbance across a surface of dislocation. For many ordinary media, we should expect at such a surface total reflection. If we suppose such a transmission of disturbance, its mode is not apparent, even if we suppose a thin lamina in rotational motion which would diffuse at least a portion, if not all, of the incident disturbance. Similar difficulties would arise if we assume the ether a solid which becomes fluid under stress and thus allows bodies to pass through it (as, for example, through a block of ice, as Fitzgerald suggested). While such solutions may seem highly artificial and do violence to our convictions, the consequences of a quiescent ether may, when fully developed and tested, demonstrate its impossibility and command a more extended examination into the structural qualities of an all-sufficient medium than the single case of an essentially vesicular medium like jelly brought forward by Stokes and in a different form as a contractile ether by Kelvin. The theory of Fresnel of a quiescent ether in space presupposes a change of its density proportional to μ^2 within a ponderable medium, and a convection coefficient

$(1-\mu^2)\nu$. This hypothesis satisfies the phenomena of aberration and the uniformity of the laws of reflection and refraction of a body, whether in motion or at rest, and, as already mentioned, does not affect interference, as Stokes showed, so far as the earth's motion is concerned. That the ether apparently is carried along within moving matter not with its full velocity, but diminished to the extent indicated by Fresnel's coefficient of convection, Fizeau demonstrated in his famous interference experiment with streaming water, repeated later with greater refinement by Michelson and Morley. The significance of this experiment in its bearings on the question of the drift of the ether has perhaps been overestimated. In fact, neglecting the square of the aberration, it is exactly what we should expect from the dynamical reaction of a moving material system on a periodic disturbance, propagated through it without reference to the motion of translation of the interpenetrating medium, but simply to the frequency of the vibration impressed upon the system by this ether. Thus if we transform the ordinary differential equations of motion of the material system from fixed to moving axes, the form of the solution contains Fresnel's convection coefficient as a factor exactly, neglecting quantities of the second order of the aberration. This experiment cannot then be adduced as a positive result in favor of a quiescent ether. On account of its physical consequences, however, it should be extended to the case of gases and to absorbing substances, using light corresponding to the natural frequences of the latter if possible. Although negative results have heretofore been obtained with a gas, yet, with high pressures and greater dimensions and velocities, the test is within present experimental limitations. Results with solid bodies are still lacking, but a preliminary examination of the problem encourages us to expect successful results, at least with double-refracting substances. Reasoning in a similar manner as on the dynamical reaction of a moving system, we should look for the acceleration of a circularly polarized ray propagated coaxially within a rapidly rotating medium. This may possibly be brought within experimental limits. Again we have the important experiment of Lodge on the effect of moving masses upon the motion of the ether near them. This experiment, like that of the preceding one of Fizeau, is a first order test, *i. e.* the effect to be observed would arise from a change in the first power of the aberration factor. Two interfering beams were sent around several times in opposite directions between two rotating steel disks, and the effect on the bands noted from rest to motion or reversal. With a linear velocity not far from one two-hundredth that of the earth's orbital motion, and a distance of some ten meters or more, no influence on the interfering rays could be detected, thus making the effect, calculated from the aberration factor if the ether were carried around between the disks, something like twice the limit of observation. Lodge estimates from this experiment that the disks must have communicated less than the eight-hundredth part of their velocity to the ether. It is to be noted that the masses of these disks were not great, being only some two or three centimeters thick and about one meter in diameter. If we suppose the ether to be set in motion by means of reactions of a viscous nature, the experiment would be conclusive. To this extent, that the ether is not viscous, the test seems to be valid, but as there are other modes conceivable by which such movement might be brought about, it is not conclusive. If now we have to give up the notion of a quiescent ether, it will be necessary to suppose such motions are engendered in some way depending on the mass of the moving system, which we might imagine to be the fact in the case of the earth and the surrounding ether (possibly as, Des Coudres suggests, through gravitational action). It would be desirable to repeat this experiment, using great masses, and also testing to a much higher degree of sensibility (the third order would be possible) by means of double refraction. Michelson has recently attempted to determine directly whether the velocity of the ether diminished as we recede from the earth, but with negative results. He sent two interfering rays in opposite directions around the four sides of a rectangle of iron piping from which the air had been exhausted, the same being in a vertical east and west plane, the horizontal length of which was 200 feet and the height 50 feet. Assuming an exponential law for the variation in the velocity of the ether as we recede from the earth, he finds that if the earth carries the ether with it, this influence must extend to a distance comparable with the earth's diameter. The negative result in many of the experiments on refraction and interference which different investigators have obtained and which apparently follow on the assumption of a mobile ether have been usually experiments capable of giving only second order effects instead of the first order effects looked for, which, as mentioned above, are quite as consistent with a quiescent ether, as Stokes and Rayleigh have shown. Among these may be mentioned the experiments of Hoek, Ketteler, Mascart, and others on interference in ponderable media, over opposite paths relatively to the earth's motion; as also those of the two latter with double-refracting media. All of the experiments were first order tests, and hence should give negative results on either theory, since, with a terrestrial source of light, the phenomena are independent of the orientation of the apparatus neglecting second order effects.

The positive results of Fizeau and of Ångström have not been confirmed and should not be seriously considered. In the experiments of the latter, the variation of the position of the Frauenhofer lines, as obtained by a grating when observed in directions with and opposite to the earth's orbital motion, has never been noted since, beyond

the anticipated displacement calculated from the purely kinetical principle of Döppler. The experiments of the former, as a first order test, on the rotation of the plane of polarization of a ray after passing through a pile of plates has perhaps offered the greatest difficulty to the exponents of both theories in reconciling the observations with the results which should follow from each theory. In this experiment, performed in 1859, the optical systems was mounted so as to be rotated about a vertical axis alternately from east to west, or *vice versa*. This system consisted of the usual polarizing nicol or sensitive tint-system and analyzing nicol between which were placed several piles of plates and compensating systems for producing the rotations and the magnifying of the same, and also for compensating for the rotary dispersion and elliptic polarization of the transmitted light which was polarized in an azimuth of 45°. In a series of observations extending over some time the mean of the rotations of the plane of polarization showed a maximum excess in the direction toward the west at noon and at the time of the solstice. It is to be noted that light from a heliostat was reflected into the system alternately by two fixed mirrors when the system was rotated. This required an interruption and readjustment of the heliostat during a single observation, *i. e.* from east to west and west to east, the difference in the setting of the analyzer in the two positions to give the same field of view being, of course, the effect sought for. Fizeau refers to the irregularities arising from successive settings of the heliostat. The calculated effect was much below that which could have been observed directly with the usual polarizing system. To magnify any such effect, a second system of plates was used which gave an amplification as high as eighty times. Thus any residual rotation from whatever cause would receive the corresponding amplifications. Now, in experiments with polarizing systems using sunlight as a source of illumination, it has frequently been noted that any shift in the direction of the light through the apparatus, either due to a change in the direction of the beam (arriving, say, from the heliostat) or to a shift in the optical system itself, produced a change in the field of view, whether with a half-shade system or otherwise. In the former the match was destroyed, the change being of an order much greater than that which Fizeau anticipated from calculation. Further, with such limited beams of light, a mere shift of the eye may produce an effect of similar magnitude. Hence, in all polariscopic experiments where sunlight is used, it is absolutely essential that, during any single observation, the ray of light pass through the system and into the eye over exactly the same path. This Fizeau failed to carry out, and this is entirely sufficient to explain the very great discrepancies in his various series of observations, and probably the apparent constant difference in the results of his settings in the two directions.

In fact, Fizeau himself has stated since that his observations were not absolutely decisive. While the test is now probably within experimental limits with the more highly refined half-shade systems, other modes of experimenting on different optical principles with greater sensibilities have given negative results, thus disproving the existence of a phenomenon which Fizeau's experiment apparently established, and making a repetition of this experiment, which is of doubtful execution, unnecessary.

The effect of the motion of a natural rotative substance through the ether on the rotation of the plane of polarization is of considerable importance in its bearings on certain controverted points in some of the recent theories of a quiescent ether. Mascart, who first studied the problem in the case of quartz, was unable to detect any difference in the rotation when a ray was propagated in and against the direction of motion of the earth. This variation in the total rotation, which he could detect, was one part in 20,000, or one part in 40,000 on reversal. This experiment as thus carried out corresponds to a first order effect. Rayleigh quite recently has repeated this experiment with a sensibility five times as great, and obtained negative results, likewise. The impossibility of obtaining quartz in sufficient quantity and purity, or natural rotary liquids of sufficient power, to attain the extreme limit of polariscopic possibilities seems to make even an approximation to a second order effect entirely improbable, although the higher frequencies might be used, where the power may be ten times as great. On the other hand, the effect of the mechanical rotation of such a medium on the circular components is, however, probably not beyond experimental possibilities in polariscopic work.

On the electrical side several first order experiments have been made which likewise have given negative results. Des Coudres has attempted to determine the difference in the induction on each of two coils placed symmetrically, with respect to a third coaxial coil between them. On compensating for the effects of each on the galvanometer when the axis of the system was in the direction of drift, and then reversing the direction of the system, no influence on the galvanometer could be observed. The effect which should be observed corresponds to the second order of the aberration. However, without compensating factors, the theory of induction phenomena shows that second order effects should be looked for in systems moving through the ether. The same may be said of other electrical experiments.

The difficulties in formulating a theory which will explain the results of all experiments involving tests to the first order of sensibility only on the assumption of either a quiescent or a convected ether, are much easier met than when second and higher orders have to be taken into consideration. Here we find what, at first sight,

appear as rather startling assumptions; but it is only in this manner that present observational facts can be reconciled with a quiescent ether. With each advance in experimental refinement, theory has had to adapt itself by the adoption of new hypotheses. This has now been done up to second order phenomena for a quiescent ether. Thus far, however, no hypothesis has been brought forward to adapt specifically the theory of a quiescent ether to observations which have already been carried up to the third order of the aberration constant.

The first second order experiment was carried out by Michelson and Morley, and was an optical test in which the method of interference of two rays passing over paths mutually at right angles to one another was used. The apparent intent of the originators of this experiment was initially to look for a first order change in the aberration factor by means of a second order interference effect. The difficulty in reconciling the negative results of this test has, however, given rise to hypotheses involving second order dimensional factors, so that from this point of view it becomes a second order experiment. It could not, however, show a first order change in the velocity of the moving system, which latter, referred to the velocity of light, is taken as a magnitude of the first order, and hence the former change would count as a second order magnitude. In this experiment the entire system was mounted on a float so that the optical system could be rotated consecutively through all quadrants of the circle while the interference bands were being continuously observed. If now the difference in time of passage of one of the rays, say along the line of drift, and the other at right angles to it, is calculated on the basis of a moving ether, we find it to be equivalent to the time of passage over a length corresponding to a diminution of this length, in the direction of drift, proportional to the square of the aberration. Their results show that had there been an effect, it must have been probably sixteen times, certainly eight times, less than that calculated. It is understood that Morley and Miller will soon report as the result of a repetition, during the present year, of this experiment on a much larger scale, that, if there is any effect, it must be one hundred times less than the calculated value. This result is entirely consistent with a moving ether, but seemingly contradictory to a quiescent ether, as proposed by Fresnel. Apparently, then, either some condition in the fundamental hypothesis of such a medium has been overlooked, or a supplementary hypothesis must be imagined. Similar hypotheses were conceived of by both Lorentz and Fitzgerald independently, shortly after the publication of the experiments of Michelson and Morley in 1887. They assume that a contraction in the direction of motion takes place in a system moving through the ether, so that this dimension is reduced by a fraction of itself equal to one half the square of the constant of aberration. This of course, as an assumption, merely suggests a compensation to meet an apparent residual effect, and would be of no significance if it were impossible to incorporate such a condition into a consistent theory of ethereal action. This has been done by Lorentz and by Larmor in their theories of moving systems. Lorentz, who was the first to develop a satisfactory theory of a quiescent ether, assumes that, in all electrical and optical phenomena taking place in ponderable matter, we have to deal with charged particles, free to move in conductors, but confined in dielectrics to definite positions of equilibrium. These particles are perfectly permeable to the ether, so that they can move while the ether remains at rest.

If now we apply the ordinary electromagnetic equations of a system of bodies at rest to a system having a constant velocity of translation in addition to the velocities of its elements, the ether remaining at rest, the displacements of the electrons arising from the electric vibrations in the ether and the electric and magnetic forces are the same functions of the new system of parameters as for the case of rest, if we neglect quantities of the second order of the aberration. This theorem assumes that the distance of molecular action is confined to such excessively small distances that the difference in their local times would have no effect. An exception to this may be found in a rotary substance like quartz which, as mentioned above, has been examined by Mascart and Rayleigh to the first order with negative results, which seems to warrant the conclusion that the molecular forces are themselves altered by translation. This theory of Lorentz seems capable, then, of explaining the uniformly negative results of all the first order tests which have been described previously, without, however, necessarily establishing it finally, since we have not yet studied its adaptability to second and higher orders of the aberration.

The suggestion of a contraction, as stated above, lends itself in a similar manner and under like restrictions to that for the first order transformation. This requires the introduction of a second coefficient differing from unity by a quantity of the second order as did the coefficient used in the first transformation, but differing from the latter in that it is left indeterminate from the fact that there are no means as yet for giving it a definite value. Introducing these new parameters we again obtain a set of equations in which the velocity of translation does not explicitly appear. Such a moving system has therefore its correlate in a system at rest, the former having changed into the latter through the assumed contraction the moment motion begins. The occurrence of these coefficients as factors in the electric forces and the accelerations arising from the electric vibrations in the ether in the expression for the corresponding system at rest, necessitates that if the degree of similarity required is to exist

in the two systems, the electrons must have different masses depending on whether their vibrations are parallel or perpendicular to the velocity of translation. This startling conclusion of Lorentz is borne out by what we now know of the dependence of the effective mass of an electron upon what is taking place in the ether. Such an hypothesis as this would require that Michelson and Morley's experiment should always give a negative result.

Of electrical experiments on the drift of the ether we have one second order test carried out very recently by Trouton at the suggestion of the late Professor Fitzgerald. The latter, reasoning on the condition of a magnetic field produced by a charged condenser moving edgewise to the drift of the ether, and the consequent additional supply of energy of such a system on charging, thought that this might produce a mechanical drag on charging and an opposite impulse on discharging, just as might occur if the mass of earth were to become suddenly greater. This experiment was carried out in the form of a condenser mounted upon an arm carried by a delicate suspension, with negative results. A second and more sensitive test was made later in a modified form by Trouton and Noble. Since. edge on to the drift, we have a magnetic field, while at right angles it vanishes, the energy will vary with the azimuth, and we shall have a maximum in an azimuth of 45°. A delicate suspension carrying the armature of a condenser showed no movement, although the calculated effect was ten times the limit of observation. The negative results of these experiments may be accounted for on like assumptions with that of the Michelson and Morley experiment, namely a contraction or change in the dimensions of the condenser producing corresponding changes in density and potential difference of the charge.

The assumption of a contraction suggests at once, from what we know of transparent media, the anisotropic state which such media are thrown into under dimensional strain. Rayleigh has examined this question in the case of water, carbon disulphide, and glass without result. In the case of glass his sensibility was several times the calculated second order effect, and much more in case of liquids.

The degree of refinement to which the polariscopic test lends itself is perhaps beyond that of any other instance in physical application. Here then is an opportunity to examine the question beyond what theory has anticipated, and the test has been carried so as to reach safely a third order effect, with negative results. The experiments as performed by the writer consisted in sending a beam of sunlight plane polarized at 45° to the horizon, through 28.56 meters of water in a horizontal direction and examining the same by a sensitive elliptic analyzer. On rotating the entire system from the meridian, where the one component of vibration to the drift was parallel and the other perpendicular, into a plane at right angles to the meridian where both components would be at right angles to the drift, and therefore where no differential effect would be produced, no change in the field of view could be detected. Had there been a total difference of 7.8×10^{-18} of the whole velocity between the components, the effect would have been manifest. We may, therefore, conclude that there is no third order effect. How well the various theories of a quiescent ether will lend themselves to this further adaptation remains to be seen, but undoubtedly by properly choosing the coefficients it may be done; however, any theory which does not contain explicitly the exact and complete adaptation to all orders of the aberration must certainly impress itself as highly artificial in its successive auxiliary hypotheses and approximations.

Larmor, in reference to his theory, says, "It is, in fact, found that the Maxwellian circuital equations of æthereal activity, in the ambient æther referred to axes moving along with the uniform velocity of convection, v, can be reduced to the same form as for axes at rest up to and including $\left(\frac{v}{V}\right)^2$ but not $\left(\frac{v}{V}\right)^3$ by adopting certain coefficients." "If, then, matter is for physical purposes a purely æthereal system, if it is constituted of simple polar singularities or electrons, positive and negative, in the Maxwellian æther, the nuclei of which may be either practically points or else small regions of æther with internal connections of pure constraint, the propositions above stated for the first order are extended to the second order of $\frac{v}{V}$ with the single addition of the Fitzgerald-Lorentz shrinkage in the scale of space and an equal one in the scale of time, which, being isotropic, is unrecognizable." "On such a theory as this the criticism presents itself, and was in fact at once made, that one hypothesis is needed to annul optical effects to the first order; that when these were found to be actually null to the second order, another hypothesis had to be added: and that another hypothesis would be required for the third order, while in fact there was no reason to believe that they were not exactly null to all orders. Such a train of remarks indicates that the nature of the hypothesis has been overlooked. And if indeed it could be proved that the optical effect is null up to the third order, that circumstance would not demolish the theory, but would rather point to some finer adjustment than it provides for; needless to say the attempt would indefinitely transcend existing experimental possibilities." And further, "up to the first order the electron hypothesis, that electricity is atomic, suffices by itself, as Lorentz was first to show." "Up to the second order, the hypothesis that matter is constituted electrically — of electrons — is required in addition."

The necessity in view of the present experimental data for leaving indeterminate the units of transformation is here illustrated in the theory of Larmor.

In the most recent discussion by Lorentz, the necessity of a general treatment is shown for not only the second but also the higher orders. In a consideration of transparent media, his theory attempts to show that translation would not alter interference, diffraction, or polarization. He would thus, by means of the assumption of so-called "Heaviside ellipsoids" as the shape of electrons, explain the negative results of optical experiments, as well as the observations of Kaufmann on Becquerel rays.

Attention should also be called to the recent theory of Abraham, who gives as the ratio of the axes of the moving electron $1-\frac{4}{5}\left(\frac{v}{V}\right)^2: 1$, omitting fourth and higher orders. This would give a residual in double refraction of $\frac{1}{5}\left(\frac{v}{V}\right)^2=2\times10^{-9}$ for transparent media, which he acknowledges is difficult to reconcile with the experimental results which show no double refraction to the first order beyond this.

INTRODUCTORY NOTE

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