

## The Aether of Space

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(Dated: November 13, 2008)

### *Abstract*

The notion of an aether filling all the space appeared recently as the only one option towards building an intelligible theory of the physical world. A close scrutiny of what the natural philosophers of the past thought about the aether reveals an amazing and febrile quest for an accurate description of this medium. What we find by reading their works anew is not only that the existence of the aether was never questioned, but that the best researchers at the forefront of science struggled to come up with that theory of aether which would best explain the experimental evidence they had. Perplexed by the huge amount of literature dedicated to the aether, we decided to share with the readership of this journal some of the most significant ideas we found in these almost forgotten treasures of science.

*Keyword:* aether

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1. J. J. Thomson, *Electricity And Matter*, (Charles Scribner's Sons, New York, 1904).

“On this view of the constitution of matter, part of the mass of any body would be the mass of the ether dragged along by the Faraday tubes stretching across the atom between the positively and negatively electrified constituents. The view I wish to put before you is that it is not merely a part of the mass of a body which arises in this way, but that the whole mass of any body is just the mass of ether surrounding the body which is carried along by the Faraday tubes associated with the atoms of the body. In fact, that all mass is mass of the ether, all momentum,

momentum of the ether, and all kinetic energy, kinetic energy of the ether. This view, it should be said, requires the density of the ether to be immensely greater than that of any known substance.” [1, p.50]

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2. William Thomson, Lord Kelvin, *Baltimore Lectures on Molecular Dynamics and The Wave Theory of Light* (C. J. Clay And Sons, London, 1904).

“Green almost wholly shook off the molecular treatment, and worked out all that was to be worked out for the wave theory of light, by the dynamics of continuous matter. [...] Substantial additions are scarcely to be made to a thing perfect and circumscribed as Green’s work is, on the explanation of the propagation of light, of the refraction and the reflection of light at the bounding surface of two different mediums, and of the propagation of light through crystals, by a strict mathematical treatment, founded on the consideration of homogenous elastic matter. [...] The wave theory of light, treated on the assumption that the medium through which the light is propagated is continuous and homogenous, except where distinctly separated by a bounding inter-face between two different mediums, is really completed by Green.” [2, p.5]

“[...] it seems to me that it is rather a backward step from an absolutely mechanical notion that is put before us by Fresnel and his followers to take up the so-called electro-magnetic theory of light in the way it has been taken up by several writers of late.” [2, p.9]

“Luminiferous ether must be a substance of most extreme simplicity.” [2, p.12]

“[...] at present we neither see nor imagine any reason for believing ether to be other than continuous and homogenous through infinitely small contiguous portions of space void of other matter than ether.” [2, p.279]

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3. Agnes M. Clerke, *Modern Cosmogonies* (Adam And Charles Black, London, 1905).

“Ether is the fundamental postulate of physics. [...] A great deal is demanded from it. [...] If ‘action at a distance’ be inadmissible (as Newton himself held it to be), the pull of gravity must be exerted through a medium; and common-sense insists upon its identification with the transmitting medium of light, as well as upon the identification of that with the transmitting medium of electricity. A genuine conformity to these demands of reason is vouched for, not

only by Hertz's discovery that an electrical explosion starts an undulatory disturbance indistinguishable, except in scale, from luminous waves; but also by Dr. Lorentz's indicated conclusion that strains of the same ethereal essence bear the all-pervading mandates of gravity." [3, p.183]

"The ether is assuredly the seat of intense activities, which lie at the root, most likely, of all processes in Nature." [3, p.191]

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4. A.E. Dolbear, *Modes Of Motion or Mechanical Conceptions of Physical Phenomena* (Lee And Shepard Publishers, Boston, 1897).

"All of our experience, without a single exception, enforces the proposition that no body moves in any direction, or in any way, except when some other body *in contact* with it impresses its own motion upon it. [...] For mathematical purposes, it has sometimes been convenient to treat a problem as if one body could act upon another without any physical medium between them; but such a conception has no degree of rationality, and I know of no one who believes in that as a fact. If this be granted, then our philosophy agrees with our experience, and every body moves because it is pushed, and the mechanical antecedent of every kind of phenomenon is to be looked for in some adjacent body possessing energy; that is, the ability to push or produce pressure." [4, p.11]

"If the ether were [...] to be examined through higher and still higher magnifying powers, even up to infinity, there is no reason for thinking that the last examination would show anything different in structure or quality from that which was examined with low power, or with microscope at all. This is all expressed by saying that the ether is a continuous substance, without interstices; that it fills space completely, and, unlike gases, liquids, and solids, is incapable of absorbing or dissolving anything." [4, p.22]

"It is the general consensus of opinion among those who have studied the subject, that the ether is not atomic in structure." [4, p.27]

"[...] the testimony seems conclusive that the ether is a frictionless medium, and does not transform mechanical motion into heat." [4, p.38]

"As a ray of light continues a ray of light so long as it exists in free ether, so all kinds of radiations of whatever wave length continue identical until they fall upon some mechanical

structure called matter.” [4, p.48]

“Seeing that gravitation is ether pressure, it does not seem probable that its velocity can be infinite. However that may be, the ability of the ether to transmit pressure and various disturbances evidently depends upon properties so different from those that enable matter to transmit disturbances, that they deserve to be called by different names. To speak of the elasticity of the ether may serve to express the fact that energy may be transmitted at a finite rate in it; but it can only mislead one’s thinking if he imagines the process to be similar to energy transmission in a mass of matter.” [4, p.53]

“[...] the density of the ether is so far removed from the density of anything we can measure, that it is hardly comparable with such things. If, in addition, one recalls the fact that the ether is homogenous, -that is, all of one kind, - and also that it is not composed of atoms and molecules, then degree of compactness and number of particles per cubic inch have no meaning, and the term density, if used, can have no such meaning as it has when applied to matter. There is no physical conception gained from the study of matter that can be useful in thinking of it. As with elasticity, so density is inappropriately applied to the ether; but there is no substitute yet offered.” [4, p.56]

“The space between the earth and the sun may have any assignable amount of energy in the form of ether-waves or light, but not any temperature. One might loosely say that the temperature of empty spaces was absolutely zero; but that would not be quite correct, for the idea of temperature cannot properly be entertained as applicable to the ether. To say that its temperature was absolute zero would serve to imply that it might be higher, which is inadmissible. When energy has been transformed, the old name by which the energy was called must be dropped. Ether cannot be heated.” [4, p.60]

“We no longer speak of the wave motion in the ether which results from heat as heat, but call it radiation or ether-waves; and for a like reason the magnetic field ought not to be called magnetism (but a [...] condition in the ether).” [4, p.74]

“Action at a distance contradicts all experience, is philosophically incredible, and is repudiated by every one who once perceives that energy has two factors, substance and motion.” [4, p.87]

“From the necessities of the case, as knowledge was acquired, and terminology was essential for making distinctions, the ether has been described in terms applicable to matter; hence such terms as mass, solidity, elasticity, density, rigidity, etc., which have definite meaning, and convey definite mechanical conceptions when applied to matter, have no corresponding

meaning, and convey no such mechanical conceptions, when applied to the ether. It is certain that they are inappropriate, and that the ether and its properties cannot be described in terms applicable to matter.” [4, p.88]

“A substance which has none of the phenomenal properties of matter, and is not subject to the known laws of matter, ought not to be called matter. Ether phenomena and matter phenomena belong in different categories; and the ends of science will not be conserved by confusing them, as is done when the same terminology is employed for both.” [4, p.89]

“Vibratory motion of the matter becomes undulatory motion in the ether. The vibratory motion we call heat; the wave motion we call sometimes radiant energy, sometimes light.” [4, p.93]

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5. J. J. Thomson, *On the Light Thrown by Recent Investigations on Electricity on the Relation between Matter and Ether* (University Press, Manchester, 1908).

“[...] the electrified bodies [...] must be connected with some invisible universe, which we may call ether, and that this ether must [...] be set in motion when the electrified bodies are moved. We are thus surrounded by an invisible universe with which we can get into touch by means of electrified bodies, whether this universe can be set in motion by bodies which are not electrified, is a question on which we have as yet no decisive evidence.” [5, p.8]

“[...] when we move the body through the water we have to set in motion not merely the body itself but also some of the water around it, in some cases the increase in the apparent mass of the body due to this cause may be much greater than the mass of the body itself, this is the case, for example with air bubbles in water which behave as if their mass were many hundred times the mass of the air enclosed in them.” [5, p.9]

“Faraday and Maxwell have taught us to look for the seat of the potential energy of an electrified system in the space around the system and not in the system itself, each portion of space possessing an amount of this energy for which Maxwell has given a very simple expression. Now it is remarkable that if we calculate the mass of the ether gripped by the lines of electric force in any part of the space surrounding the charged bodies we find that it is exactly proportional to the amount of potential energy in that space, and is given by the rule that if this mass were to move with the velocity of light the kinetic energy it would possess would be equal to the electrostatic energy in the portion of space for which we are calculating the mass. Thus the total mass of the ether gripped by an electrical system is proportional to the

electrostatic potential energy of that system.” [5, p.9]

“I shall for the sake of brevity take the mass of the ether set in motion by an electrified system to be proportional to the potential energy of that system. The electrified body has thus associated with it an ethereal or astral body which it has to carry along with it as it moves and which increases its apparent mass.” [5, p.9]

“[...] the heat given out when the atoms of different elements combine will be equal to the diminution of the mutual electrostatic potential energy of the atoms combining, and therefore by what we have said will be a measure of the diminution of the ethereal mass attached to the atoms; on this view the diminution in the ethereal mass will be a mass which moving with the velocity of light possesses an amount of kinetic energy equal to the mechanical equivalent of heat developed by their chemical combination.” [5, p.11]

“Kaufman determined the masses of the different particles, and found that the greater the speed the greater the mass, the mass of the more rapidly moving particles being as much as three times that of the slower ones. These experiments also led to the very interesting result that the whole of the mass of these particles is due to the charge of electricity they carry. On the view we have been discussing this means that the whole of the mass of these particles is due to the ether gripped by their lines of force.” [5, p.14].

“The result [...] that the potential energy of a system charged with electricity is equal to the kinetic energy of the mass of ether bound to the system when moving with the velocity of light is another example of potential energy, being in reality the kinetic energy of an associated system, and indeed, [...] the study of the problems brought before us by recent investigations leads us to the conclusion that ordinary material systems must be connected with invisible systems which possess mass whenever the material systems contain electrical charges. If we regard all matter as satisfying this condition we are led to the conclusion that the invisible universe – the ether – is to a large extent the workshop of the material universe, and that the phenomena of nature as we see them are fabrics woven in the looms of this unseen universe.” [5, p.21]

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6. J. Ellard Gore, *Studies in Astronomy* (Chatto & Windus, London, 1904).

“Various views of the constitution of this medium, known as the luminiferous ether, have been advanced by eminent physicists. [...] Professor (Volson) Wood assumes that the ether is

gaseous in its nature [...].” [6, p.317]

“A [...] theory respecting the constitution of the ether has been advanced by Mr. S. Tolver Preston.” [6, p.322]

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7. Marion Marwin, *The Universe and the Atom* (Constable and Company Limited, London, 1915).

“The undulatory theory of light subsequently advanced by Huyghens, and developed by Young, Euler, Fresnel, and others, which explains the transmission of light from the sun and stars, through space, by waves passing through Ether, has so satisfactorily accounted for many optical phenomena, not otherwise explained, that the existence of the substance Ether is generally accepted by scientists.” [7, p.2]

“Alfred Sang [...] says: [...] ‘The fact that there may be pressure in space brings one back to the consideration of a gaseous ether, [...] and may not the pressure be a manifestation of the immeasurable energies which continually pulsate through space?’” [7, p.9]

“ [...] there ought not to be any necessity for burying the mechanical idea, under the names of ‘electricity’, ‘electric charge’, ‘electric displacement’ and ‘magnetic force’, the meaning of which Maxwell himself did not attempt to translate into the simple terms which define substance and motion. [...] These results have caused an almost total abandonment of the elastic solid theory of light, and a general acceptance of the electrical theory. But the trouble with it is that it does not explain.” [7, p.38]

“ The discovery, within the last few years, of the existence of the small particle to which has been given the name corpuscle, or electron, and its identification with negative electricity, has given a ‘material’ aspect to electricity, which adds to the call for a reexamination of the solid elastic theory of the ether, and of the mechanical operations involved in ether waves. If the chemical atom is to be regarded as an aggregation of electrons, there is so much the more reason for not accepting the electron as the final thing, and for discovering if possible, the mode of motion of substance which makes the electron.” [7, p.39]

“Professor Gibbs says: ‘It is evident that the electrical theory of light has a serious rival, in a sense in which, perhaps, one did not exist before the publication of Sir William Thomson’s paper in November last.’ [...] We have said this much on the subject of the elastic theory of

light waves, solely to justify us, in returning with the greater confidence, to an examination of the mechanical motions taking place in an ether wave on the elastic theory.” [7, p.41]

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8. Oliver Lodge, *Electrons or The Nature and Properties of Negative Electricity* (George Bell and Sons, London, 1906).

“Thus the hypothesis becomes more and more justified that units of positive charge are always associated with atoms, in operations which we can control, and are consequently always complete ions; while the units of negative charge appear in some cases with a separate existence, perhaps carrying with them part of the atom, in which case they might be called corpuscles, – having a material nucleus; perhaps pure disembodied electricity, whatever that may be – an electrical charge detached from matter, – a mere complexity in the ether, in which case they would correspond with those hypothetical entities familiar in theoretical and mathematical treatment as ‘electrons’.” [8, p.69]

“For whether there be any intrinsically material inertia or not, there certainly is an electrical inertia. [...] Quite possibly there is no other kind. Quite possibly that which we observe as the inertia of ordinary matter is simply the electric inertia, or self-induction, of an immense number of ionic charges, or electric atoms, or electrons. This is by far the most interesting hypothesis, because it enables us to progress, and is definite. The admixture of properties – partly explained, viz. the electrical, partly unexplained, viz. the material – lands us nowhere.” [8, p.96]

“The hypothesis to which we have been led is that the inertia of an electron is wholly of an electrical character, and is explained by the known magnetic effect of an electric charge in motion, and the consequent reaction to any change in that motion.” [8, p.122]

“Thus, then, it may be possible that electric inertia may depend in some fashion on speed, a thing unknown in ordinary mechanics. I do not say that such dependence must be *untrue* in ordinary mechanics; on the contrary, I feel reasonable sanguine that it will be found for matter also, when moving sufficiently fast [...]. But however this may be, there is no doubt that theory points to an increase in electro-magnetic inertia at excessively high speeds, and Mr. Heaviside long ago calculated its amount.” [8, p.123]

“It has been shown both by Mr. Heaviside and by Prof. J. J. Thomson that if the speed of motion *is* ever greater than that of light, the fan or radial plane of lines of force bends

backwards and becomes a conical surface, gradually closing up as the speed further increases; in accordance with the analogy of the conical surface of discontinuity aforesaid, which travels with a sufficiently rapid bullet, and is demonstrated in Mr. Boy's bullet photographs." [8, p.127]

"[...] we may proceed to discuss the further extraordinarily far-reaching hypothesis – first tentatively put forward by Larmor in 1894, *Phil. Trans.*, vol. 185A, p.813, with mechanical illustrations of a purely ethereal structure for such an electron – that the electrons constitute matter, that atoms of matter are composed of electric charges, that the fundamental inertia-property of matter is identical with self-induction." [8, p.129]

"Kaufmann concluded that when the speeds approached perceptibly near the velocity of light, the electrochemical equivalent  $m/e$  increased by just the amount required in accordance with pure electric theory – the theory which attributes the whole of inertia to electric influence." [8, p.131]

"Such a surprising agreement [...], between theory and observation, removes from my mind all reasonable doubt as to the truth of the hypothesis that the inertia of electrons is electrical inertia. I regard this closeness of agreement as specially surprising, for it was not the first deduction of the experimenter, W. Kaufmann, himself: his deduction rather was that the electrical mass constitutes about one-third or one-fourth of the whole; but then he used another formula for calculating it [...] which assumes that the charged body behaves like a conducting sphere." [8, p.134]

"[...] observe that though an electron has been shown to possess purely electrical inertia, the same proof has not yet been extended to an atom: the constitution of an atom is so far unknown, and is the subject of hypothesis only." [8, p.147]

"[...] an extremely recent paper by the same Physicist [J. J. Thomson] has tended to reduce the whole subject [of the theory of the nature of the atom] to a state of exaggerated uncertainty; since he gives reasons [...] for assuming that only one active electron is contained in a hydrogen atom, and that all other elements contain a number of electrons comparable to their atomic weight, reckoned on the basis that  $H=1$  [...]. This is an extraordinary and unexpected result, and at first sight appears very unlikely, since the ordinary chemical assumption of a unit atomic weight for Hydrogen has always been known to be a pure convention, made for convenience alone, and not likely to correspond with anything in nature." [8, p.151]

"As to the nature of the electron, regarded as an ethereal phenomenon, it is too early to express

any opinion. At present it is not clear why a positive charge should cling so tenaciously in a mass, while an outstanding negative electron should readily escape and travel free. Nor is the nature of gravitation yet understood. When the electron theory is complete [...] it is hoped that the gravitative property also will fall into line and form part of the theory; at present it is an empirical fact which we observe without understanding; as has been our predicament not only since the days of Newton but for centuries before [...].” [8, p.202]

“The view that an atom is composed of an equal number of interleaved or inter-revolving positive and negative electrons – that view is not Franklin’s; nor is it as yet but a guess.” [8, p.203]

“Especially must the inner ethereal meaning both of positive and negative charges be explained: whether on the notion of a right-and-left-handed self-locked intrinsic wrench-strain in a Kelvin gyrostatically-stable ether, elaborated by Larmor, or on some hitherto unimagined plan.” [8, p.203]

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9. Joseph Larmor, *Aether and Matter* (University Press, Cambridge, 1900).

“The time has fully arrived when, if theoretical physics is not to remain content with being merely a systematic record of phenomena, some definite idea of the connection between aether and matter is essential to progress [...].” [9, p.x]

“It results from very various experimental investigations some of which are mentioned above that, with a very doubtful but unique exception in the case of Fizeau’s experiments on piles of glass plates, the most varied optical phenomena, whether of ray paths or of refraction, dispersion, interference, diffraction, rotation of plane of polarization, have no relation to the direction of the Earth’s motion through space, though for many of them the test has been made with great precision. The most obvious conclusion from this *consensus* of evidence taken by itself would be the view that the Earth’s motion carries the aether completely along with it, and that all the relative optical and other phenomena are therefore just the same as they would be with both the Earth and the aether at rest. Such a view is also very temptingly suggested by the absolutely negative result, up to the second order, of the Earth’s motion on the Michelson interference experiment.” [9, p.17]

“[...] how it is that portions of matter can interact on each other which seem to have no means of connection between them. Can a body act where it is not? If we answer directly in the

negative, the spatial limitations of substance are to a large extent removed, and the complication is increased. The simplest solution is involved in a view that has come down from the early period of Greek physical speculation, and forms one of the most striking items in the stock of first principles of knowledge which had been struck out by the genius of that age. In that mode of thought the ultimate reality is transferred from sensible matter to a uniform medium which is a *plenum* filling all space: all events occur and are propagated in this *plenum*, the ultimate elements of matter consisting of permanently existing vortices or other singularities of motion and strain located in the primordial medium, which are capable of motion through it with continuity of existence so that they can never arise or disappear.” [9, p.23]

“In Newton’s cautious hands, the relation of material atoms to aether is not dealt with: his establishment of an exact law of gravitation indeed originated the school of action at a distance, which held bluntly that matter *can* be considered as acting where it is not [...]. This doctrine of the finality of action at a distance was however strongly repudiated by Newton himself [...].” [9, p.24]

“More recently, the following out into the modern developments of the mere idea of continuous transmission of physical actions gained for Faraday a rich harvest of fundamental experimental discoveries: while the general results obtained by von Helmholtz in the abstract theory of fluid motion have enabled Lord Kelvin to reconstruct on a precise scientific basis the notions of Leucippus and Descartes on the relation of matter to aether.” [9, p.24]

“This idea of a *plenum* with uniform properties throughout all extension, but permeated by intrinsic singular points, each of which determines and, so to speak, locks up permanently a surrounding steady state of strain or other disturbance, forms the ultimate basis of all developments relating to the constitution of aether and matter such as are here attempted.” [9, p.77]

“The basis of the present scientific procedure thus rests on the view, derivable as a consequence of general philosophical ideas, that the master-key to a complete unraveling of the general dynamical and physical relations of matter lies in the fact that it is constituted as a discrete molecular aggregate existing in the aether. At the same time all that is known (or perhaps need to be known) of the aether itself may be formulated as a scheme of differential equations defining the properties of a *continuum* in space, which it would be gratuitous to further explain by any complication of structure [...].” [9, p.78]

“The Roentgen radiation has been from the first ascribed to violent aethereal disturbances, set

up by the impacts of the rapidly moving particles of the cathode streams against the walls of the vacuum tube in which they travel.” [9, p.235]

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10. John Munro, *The Story of Electricity* (New York, MCMXII).

“The influence of the current on the needle implies a magnetic action, and if we dust iron filings around a wire we shall find they cling to it in concentric layers, showing that circular lines of magnetic force enclose it like the water waves caused by a stone dropped into a pond.” [10, p.57]

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11. H. A. Lorentz, *The Theory of Electrons*, 2<sup>nd</sup> Edition (B. G. Teubner, Leipzig; G. E. Stechert & Co., New York, 1916).

“[...] one of the most important of our fundamental assumptions must be that the ether not only occupies all space between molecules, atoms or electrons, but that it pervades all these particles. We shall add the hypothesis that, though the particles may move, *the ether always remains at rest*. We can reconcile ourselves with this, at first sight, somewhat startling idea, by thinking of the particles of matter as of some local modifications in the state of the ether. These modifications may of course very well travel onward while the volume-elements of the medium in which they exist remain at rest.” [11, p.11]

“Of course, we are free to believe, if we like, that there is some small material mass attached to the electron, say equal to one hundredth part of the electromagnetic one, but with a view to simplicity, it will be best to admit Kaufmann’s conclusion, or hypothesis, if we prefer so to call it, that the negative electrons have no material mass at all.” [11, p.43]

“On the other hand, I believe every physicist feels inclined to the view that all the forces exerted by one particle on another, all molecular actions and gravity itself, are transmitted in some way by the ether, so that the tension of a stretched rope and the elasticity of an iron bar must find their explanation on what goes on in the ether between the molecules. Therefore, since we can hardly admit that one and the same medium is capable of transmitting two or more actions by wholly different mechanisms, all forces may be regarded as connected more or less intimately with those which we study in electromagnetism.” [11, p.45]

“The theory of Stokes rests on the assumption that the ether surrounding the earth is set in motion by the translation of this body, and that, at every point of the surface of the globe, there is perfect equality of the velocities of the earth and the ether.” [11, p.169]

“There is one assumption which plays a very important part in Stokes’s theory and of which thus far no mention has been made. Stokes supposes the motion of the ether to be *irrotational*, or, in other terms, to have a velocity potential.” [...] Unfortunately, there is a very serious difficulty about this theory of Stokes: two assumptions which we have been obliged to make, namely that the motion of ether is irrotational and that there is no sliding over the surface of the earth, can hardly be reconciled. It is wholly impossible to do so, if the ether is regarded as incompressible. [...] The preceding reasoning fails however, if we admit the possibility of changes in the density of the ether, and Planck has observed that the two hypotheses of Stokes’s theory no longer contradict each other, if one supposes the ether to be condensed around a celestial bodies [...]. We cannot wholly avoid a sliding at the surface, but we can make it as small as we please by supposing a sufficient degree of condensation. [...] I am sure, Planck himself is inclined to prefer the unchangeable and immovable ether of Fresnel, if it can be shown that this conception can lead us to an understanding of the phenomena that have been observed. [11, p.171-174]

“The theory of Fresnel [...] was formulated for the first time in a letter to Arago, in which it is expressly stated that we must imagine the ether not to receive the least part of motion of the earth.” [11, p.174]

“In order to explain this absence of any effect of the earth’s translation, I have ventured the hypothesis, which has also been proposed by Fitz Gerald, that the dimensions of a solid body undergo slight changes, of the order  $w^2/c^2$ , when it moves through the ether. [...] The hypothesis certainly looks rather startling at first sight, but we can scarcely escape from it, so long as we persist in regarding the ether as immovable. [...] We can understand the possibility of the assumed change of dimensions, if we keep in mind that the form of a solid body depends on the forces between its molecules, and that, in all probability, these forces are propagated by the intervening ether in a way more or less resembling that in which electromagnetic actions are transmitted through this medium. From this point of view it is natural to suppose that, just like the electromagnetic forces, the molecular attractions and repulsions are somewhat modified by a translation imparted to the body, and this may very well result in a change of its dimensions.” [11, p.195-202]

“I cannot but regard the ether, which can be the seat of an electromagnetic field with its energy and its vibrations, as endowed with a certain degree of substantiality, however different it may

be from all ordinary matter. In this line of thought, it seems natural not to assume at starting that it can never make any difference whether a body moves through the ether or not, and to measure distances and lengths of time by means of rods and clocks having a fixed position relatively to the ether.” [11, p.230]

“The only equation by which the observed phenomena are satisfactorily accounted for is that of Planck, and it seems necessary to imagine that, for short waves, the connecting link between matter and ether is formed, not by free electrons, but by a different kind of particles, like Planck’s resonators, to which, for some reason, the theorem of equipartition does not apply. Probably these particles must be such that their vibrations and the effects produced by them cannot be appropriately described by means of the ordinary equations of the theory of electrons; some new assumption, like Planck’s hypothesis of finite elements of energy will have to be made. It must not be thought, however, that all difficulties can be cleared in this way.” [11, p.288]

“In a repetition of Fizeau’s experiment Zeeman has recently found for different wave-lengths displacements of the interference fringes which agree very satisfactorily with the formula I gave in no.164.” [11, p.319]

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12. A. Wilmer Duff, *A Textbook of Physics*, 4<sup>th</sup> Edition (p. Blakiston’s Son & Co., Philadelphia, 1916).

“To account for the transmission of waves through space containing no ordinary matter it seems necessary to assume the existence of a universal medium filling all space and even interpenetrating matter itself, as shown by the existence of transparent substances. That this medium can react on matter is shown by the fact that radiant energy is transmitted from ether to matter in the case of absorption, and from matter to ether in the case of emission of radiation by material sources. In recent years doubt as to the necessity for assuming the existence of an ether has been expressed by some who believe that it is sufficient to attribute the power of transmitting radiation to space itself. It may be doubted whether this is more than a dispute about terms. We cannot discuss the question here, but pending the settlement of the controversy it seems wise to continue to use the word ether, as at least denoting the power of space, vacant or occupied by matter, to transmit radiation. [12, p.571]

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13. John Tyndall, *New Fragments (ch. Thomas Young)* (D. Appleton and Company, New York and London, 1880).

“We now come to a critical point in the fortune of the wave theory. I need not again refer to the difference between the motion of a wave and the motions of the particles which constitute a wave. A wave of sound, for instance, passing through the air of this room would have a velocity of about 1100 feet a second, while the particles which constitute the wave, and propagate it at any moment, may only move through inconceivably small spaces to and fro. Now, in the case of sound, this to-and-fro motion occurs *in the direction* in which the sound is propagated, and a little reflection will make it clear that no matter how a ray of sound, if we may use the term, is received upon a reflecting surface, it will be reflected equally all round as long as the angle inclosed between the reflecting surface and the ray remains unchanged. In other words, the sound-ray has *no sides* and no preferences as regards reflection. Now Malus discovered that in certain conditions a beam of light shows such preferences. When caused to impinge upon a plane glass mirror, placed in a certain position, it may be wholly reflected; whereas when the mirror is placed in the rectangular position it may not be reflected at all.

Up to the hour when this discovery was made by mauls light had been supposed to be propagated through ether, exactly as sound is propagated through air. In other words, the direction in which the particles of ether were supposed to vibrate to and fro coincided with that of the ray of light. Those who had previously held the undulatory theory were utterly staggered by this new revelation, and their perplexity was shared by Young. He was for a time unable to conceive of a medium capable of propagating the impulses of light different from the propagation of the impulses of sound. To describe to the light-medium qualities which would enable it to differ in its mechanical action from the sound-medium was an idea too bold – I might indeed say too repugnant – to the scientific mind to be seriously entertained. Yet, deeply pondering the question, Young was at length forced to the conclusion that the vibrations concerned in the propagation of light were executed *at right angles* to the direction of the ray. By this assumption of transverse vibrations, which removed all difficulty, Young also removed the ether from the class of aeriform bodies, and endowed it with the properties of a semi-solid.

Fresnel’s memoir on Diffraction, upon which, as already stated, Arago had reported, initiated a lasting friendship between the two illustrious Frenchmen. They subsequently worked together. Fresnel, the more adventurous and powerful spirit of the two, came independently to the same conclusion that Young had previously enunciated. But so daring did the idea of transverse vibrations appear to Arago – so inconsistent with every mechanical quality which he could venture to assign to the ether – that he refused to allow his name to appear in conjunction with that of Fresnel on the title-page of the memoir in which this heretical doctrine was broached. Still, the heresy has held its ground, and the theory of transverse vibrations, as applied to the luminiferous ether, is now universally entertained.” [13, p.281-282]

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14. William Vernon Harcourt, *Letter to Henry Lord Brougham Containing Remarks on certain Statements in his Lives of Black, Watt and Cavendish* (Richard and John Edward Taylor, London, 1846).

“His [Newton’s] aether was not a mathematical or mechanical abstraction, but a material substance, of the actual existence of which, certain otherwise uninterpretable phenomena, especially of light, heat, and electricity, had convinced him, and which he conceived of, as being ‘much of the same constitution with *air*, but far rarer, subtler, and more elastic. [...] For if such aethereal spirit may be condensed in fermenting or burning bodies the vast body of the earth, which may be every where to the very centre in perpetual working, may continually condense so much of this spirit as to cause it from above to descend with great celerity for a supply: in which descent it may bear down with it the bodies it pervades with force proportional to the superficies of all their parts it acts upon. [...] And as the earth, so perhaps may the sun imbibe this spirit copiously, to conserve his shining, and keep the planets from receding further from him.’ [...] This supposition preceded the public announcement of the law [of gravity] by ten years; but Newton has himself stated that he had deduced that law from Kepler’s some twenty years before he published it. He soon, however, [...] abandoned this form of hypothesis for one in which he supposes the aether no longer a gradually absorbed, centripetal, atmosphere, but a *stationary* fluid [...] so arranged by the force with which the *pores of matter* repel the *aetherial particles* in proportion to their *magnitude*, ‘that from the top of the air to the surface of the earth, and again from the surface of the earth to the centre thereof, the aether is insensibly finer and finer;’ and in an aetherial atmosphere so constituted he holds that bodies would be propelled towards each other by the assumed greater repulsion of the larger particles of aether from their pores. In this letter he made a comprehensive conjectural effort to reduce the whole system of the laws of nature, whether bearing the aspect of impulse or attraction, under the dominion of *two kinds of repulsive force*, the one of mutual repulsion between the particles of aether, the other of repulsion between the particles of aether and those of ordinary matter.” [14, p.38-39]

“I suppose the rarer aether within bodies, and the denser without them, not to be terminated in a mathematical superficies, but to grow gradually into one another; the external aether beginning to grow rarer, and the internal to grow denser, at some little distance from the superficies of the body, and running through all intermediate degrees of density in the intermediate spaces; and this may be the cause why light, in Grimaldo’s experiment, passing by the edge of a knife, or other opaque body, is turned aside, and as it were refracted, and by that

refraction makes several colours’.” [14, p.132]

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15. Christiaan Huygens, *Treatise on Light*, Rendered into English by Silvanus P. Thompson (MacMillan And Co., Ltd., London, MCMXII).

“One can then in this way conceive of transparency in a solid without any necessity that the ethereal matter which serves for light should pass through it, or that it should find pores in which to insinuate itself. But the truth is that this matter not only passes through solids, but does so even with great facility; of which the experiment of Torricelli, above cited, is already a proof. Because on the quicksilver and the water quitting the upper part of the glass tube, it appears that it is immediately filled with ethereal matter, since light passes across it. But here is another argument which proves this ready penetrability, not only in transparent bodies but also in all others.

When light passes across a hollow sphere of glass, closed on all sides, it is certain that it is full of ethereal matter, as much as the spaces outside the sphere. And this ethereal matter, as has been shown above, consists of particles which just touch one another. If then it were enclosed in the sphere in such a way that it could not get out through the pores of the glass, it would be obliged to follow the movement of the sphere when one changes its place: and it would require consequently almost the same force to impress a certain velocity on this sphere, when placed on a horizontal plane, as if it were full of water or perhaps quicksilver: because every body resists the velocity of the motion which one would give to it, in proportion to the quantity of matter which it contains, and which is obliged to follow this motion. But on the contrary one finds that the sphere resists the impress of movement only in proportion to the quantity of matter of the glass of which it is made. Then it must be that the ethereal matter which is inside is not shut up, but flows through it with very great freedom. We shall demonstrate hereafter that by this process the same penetrability may be inferred also as relating to opaque bodies.

The second mode then of explaining transparency, and one which appears more probably true, is by saying that the waves of light are carried on in the ethereal matter, which continuously occupies the interstices or pores of transparent bodies. For since it passes through them continuously and freely, it follows that they are always full of it. And one may even show that these interstices occupy much more space than the coherent particles which constitute the bodies. For if what we have just said is true: that the force is required to impress a certain horizontal velocity on bodies in proportion as they contain coherent matter; and if the proportion of this force follows the proportion of their weights. Now we see that water weighs only one fourteenth part as much as an equal portion of quicksilver: therefore the matter of the

water does not occupy the fourteenth part of the space which its mass obtains. It must even occupy much less of it, since quicksilver is less heavy than gold, and the matter of gold is by no means dense, as follows from the fact that the matter of the vortices of a magnet and of that which is the cause of gravity pass very freely through it. [...]

The rarity of transparent bodies being the such as we have said, one easily conceives that the waves might be carried on in the ethereal matter which fills the interstices of the particles. And, moreover, one may believe that the progression of these waves ought to be a little slower in the interior of bodies, by reason of the small detours which the same particle cause. In which different velocity of light I shall show the cause of refraction to consist.” [15, p.30-32]

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16. G. W. De Tunzelmann, *A Treatise on Electrical Theory and the Problem of the Universe* (Charles Griffin and Company, Limited, Philadelphia: J. B. Lippincott Company, 1910).

“It does not follow from the fact that there are two kinds of electrification that there are necessarily two kinds of electricity.” [16, p.1]

“In the year 1837 a very interesting attempt was made by George Green to arrive at a general theory of the reflection and refraction of light at the common surface of two non-crystallized media. It was not a successful attempt, owing to its having restricted the elasticity to that of an ordinary elastic body; but in spite of this, the paper possesses a very exceptional interest, both because it contains the first definite enunciation of the principle of conservation of energy, and because it appears to represent the first realisation of the possibility which was inherent in Lagrange’s dynamical system, of deducing all the phenomena of any mechanical system free from viscous forces from a single analytical function expressing the total energy of the system in terms of its configuration and motion.” [16, p.61]

“An elastic solid was the only kind of body known which would transmit transverse vibrations, and though Fresnel did not succeed in accounting for the disappearance of the longitudinal waves, it was shown by Green, in his paper of 1837 referred to above, that these would be eliminated if the elastic medium was assumed to be practically incompressible.” [16, p.65]

“The plane of polarisation of a polarised ray is defined as a plane bearing the same relation to the ray as the plane of reflection would bear to it if the polarisation were due to reflection, so that, in the case of polarisation by reflection, the plane of polarisation is simply the plane of reflection. [...] According to Fresnel’s elastic solid theory, the displacements of the ether particles must take place in a plane at right angles to the plane of polarization, while

MacCullagh's theory leads to the conclusion that the displacements take place in the plane of polarization." [16, p.65,66]

"The view that I am putting forward, and which appears a very probable one, is that the molecules of matter are structures in the ether, and formed from the ether. The ether, whatever it may be, is most certainly not a structure built up of matter." [16, p.71]

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17. James Walker, *The Analytical Theory of Light* (Cambridge: At the University Press, 1904).

"The wave-theory, [...] was first presented in an intelligible form by Huygens, but owes its recognition to the work of Fresnel. This theory regards light as consisting in vibrations of or in a medium, that is supposed to fill interstellar space and to pervade all ponderable media. When however we enquire into the character of the vibrations and the properties of the medium, we find that the wave-theory has assumed different forms: according to the dynamical theories the vibrations are assimilated to those of a medium, that has either intrinsic rigidity, or a quasi-rigidity imparted to it gyrostatically; while the electromagnetic theory applies to the problem the equations of an electromagnetic field and regards the ether as a dielectric medium subject to a rapidly periodic electric displacement. These two forms of the wave-theory must be regarded as distinct, until it is possible to form a conception of an ether that is competent to coordinate optical and electrical phenomena: on the other hand the explanation of the physical properties of a stream of light is independent of the particular idea that we may formulate respecting the nature of the vibrations in a train of luminous waves." [17, p.2]

"A consideration of the state of things occurring in a luminous source, even of the simplest character, also leads to the result that the light emitted cannot be absolutely monochromatic. In the first place there is a gradual loss of energy from communication to the ether<sup>+</sup> [...]"

<sup>+</sup> Jaumann, *Wied. Ann.* LIII 832 (1894); LIV. 178 (1895). Galitzin, *ibid.* LVI. 78 (1895). Lommel, *ibid.* LVI 741 (1895). Michelson, *Astrophys. J.* II. 251 (1895)." [17, p.18]

"Observations of Jupiter's satellites show that in free ether the velocity of light is independent of the frequency, for were this not the case, the satellites would appear to be coloured at the commencement and at the end of an eclipse. It thus becomes natural to attribute dispersion to the influence of the molecules of the material substance, and the fact that these occasion the phenomenon may be ascribed to either of two causes: it may be that the coarse-grainedness of the substance introduces "a geometrical dimension in the ponderable matter which is comparable with the wave-length," or it may be that there is "a definite interval of time

somehow ingrained in the constitution of the ponderable matter which is comparable with period\*.” \*Lord Kelvin, *Baltimore Lectures*, p.8, Camb. (1904).” [17, p.336]

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18. Humphrey Lloyd, *Wave-Theory of Light* (London: Longman, Brown, Green, Longmans, and Roberts, 1857).

“It is obvious that when two waves – one proceeding from each source – arrive at any instant at the same point of space, the particle of ether there will be thrown into vibration by both; and we are to consider what will be the result of this compound vibration.” [18, p.56]

“It is strange that the department of optics, in which the wave-theory now stands unrivalled, should be the very one which Newton selected as affording the most decisive evidence against it: - “Are not,” says he, “all hypotheses erroneous, in which light is supposed to consist in pressure, or motion, propagated through a fluid medium? .... For pressures or motions, propagated from a shining body through an uniform medium, must be on all sides alike; whereas it appears that the rays of light have different properties in their different sides.” In this objection Newton seems to have had his thoughts fixed upon that species of undulatory propagation, whose laws he himself so sagaciously unfolded. When *sound* is propagated through *air*, the vibrations of the particles of the air are performed in the same direction in which the wave advances; and if the vibrations of the ether which constitute the light had been of the same kind, the objection would be insuperable. For, if particles of the ether vibrated in the direction of the ray itself, the ray could not bear a different relation to the different parts of the surrounding space.

But the case is altered, if the vibrations of the ethereal particles be performed in a transverse direction. Let us suppose the direction of the vibrations to be *perpendicular* to that of the ray: then it is obvious that if that direction be *vertical*, for example, while the ray advances *horizontally*, the ray will bear a relation to the parts of space *above* and *below*, different from that which it bears to those parts which are on the *righthand* and on the *left*. Such is, in fact, the mode of vibration which is now assumed to belong to the ether, in the wave-theory, the ethereal molecules being supposed to vibrate *in the plane of the wave*; and we shall find that, with the help of this assumption, all the complicated phenomena of polarization and double refraction are explained in the fullest and most complete manner.” [18, p135-136]

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19. J. A. Fleming, *Magnetic and Electric Currents*, 2<sup>nd</sup> Edition (London: E. & F. N. Spon,

Limited; New York: Spon & Chamberlain, 1902).

“It is important that the student should, even at this stage, realize that the mechanical actions occurring between magnetic poles are not due to action at a distance, as it has been called, or to magnetic poles pulling or pushing other magnetic poles across empty space without intermediary machinery; but they must be regarded as the visible effects of operations taking place in a *medium* called the *electromagnetic medium* or *ether*, which fills all space. The mutual dynamical action of magnetic poles can be accounted for by the assumption that this medium, when traversed by magnetic flux, tends to contract or shrink along the direction of the lines of magnetic flux, and tends to expand or swell out in a direction at right angles to them.”  
[19, p.67]

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