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Aether Thesaurus

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Abstract
This work brings to the readership of this journal another collection of some of the most significant ideas regarding the aether, which were prevailing at the dawn of the 20th century. The author, himself involved in the development of a theory of the aether, found in these quotes support, encouragement and precious thoughts for his work and hopes that they will be inspiring for others, too.

Keyword: aether

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1. John Gray M'Kendrick, *Hermann Ludwig Ferdinand von Helmholtz*, (T. Fisher Unwin, Paternoster Square, London, MDCCCXCIX)

"One of the main objects of theoretical research is to find the point of view in which the subject appears in its greatest simplicity." [1, p.53]

"Its [corpuscular theory] place is taken by the undulatory theory, first suggested by Huygens in 1690, reconciled to some extent with the discoveries of Newton by Euler, advocated by Hartley, and finally established by a study of the phenomenon of interference by Thomas Young and by Fresnel. This theory gives a complete explanation of all phenomena of light. According to this view, light, objectively considered, is simply a mode of motion of a substance called the luminiferous ether which pervades not only what is commonly regarded as space, but also all

translucent substances. By the molecular movements of luminous bodies, this ether is set vibrating in a series of waves." [1, p.113-114]

"In physical science he [Helmholtz] occupied himself almost wholly with profound discussions, of a highly mathematical character, into hydrodynamics, or the motions of fluids, whether liquid or aeriform; into the nature of the ether and its relations to electrodynamics and thermodynamics; into some of the phenomena of light; and into principles concerned in the movements of atoms and lying at the root of mechanics." [1, p.187-188]

"In 1858 Helmholtz investigated, mathematically, the laws of vortex motion in a frictionless fluid. In addition to the very remarkable theorems of hydrodynamics, to which Helmholtz was led and on which Lord Kelvin and others have based whole theories of the ultimate constitution of matter, the investigation has another important side. The mathematical formulae are identical with certain formulae in electromagnetism, so that, as Helmholtz himself pointed out, there is a striking analogy between the two apparently distinct classes of phenomena, hydrokinetics and electrokinetics." [1, p.196]

"In an incompressible frictionless fluid rotatory movements can neither originate nor disappear; the vorticity, or product of any section of the ring and the speed of rotation, then is an unchangeable quantity. As they move in the surrounding fluid they are always composed of the same particles. Thus the vortex rings have perpetuity. They may jostle against each other and undergo endless changes of form, but they cannot be broken or dissolved. They have the indestructibility which is believed to belong to the ultimate constituents of matter. Lord Kelvin made Helmholtz's investigation the basis of the splendid hypothesis, that the atoms of matter are composed of minute vortex rings in the ether, and he worked out in detail the analogy between such rotational movements and electro-magnetic phenomena. Even this idea as to ether being the basis of matter seems to have lurked in the all-embracing mind of Newton, for he says: 'Thus, perhaps, may all things be originated from aether'[1]. In later years, Helmholtz accepted Lord Kelvin's idea and contributed remarkable mathematical papers in its support. The element, according to this conception, is neither a solid atom, nor a mass of atoms, but a whirl in a fluid ether. The molecules of a particular element have one invariable and unchangeable mass; when the substance is incandescent, its molecules are vibrating, and emit the same kind of light, being tuned, as it were, to definite pitches. As Lovering said: 'The music of the spheres has left the heavens and condescended to rhythmic molecules. There is no birth or death or variation of species. If other masses than the precise ones which represent the elements have been eliminated, where, asks Clerk Maxwell, have they gone? The spectroscope does not show them in the stars or nebulae. The hydrogen and sodium of the remotest space is in unison with the hydrogen and sodium of the earth.'[2]. Finally, the theory of vortex motions

has made it possible to understand in some measure the transmission of magneto-electric effects through an intervening medium, and it has also helped to dispel the fiction of action at a distance.

[1] Letter to the Secretary of the Royal Society, Henry Oldenburg, Jan. 1676. (*Hist. of Royal Society*, by T. Birch, vol. iii, p.250).

[2] Joseph Lovering. *Address to American Association for Advancement of Science*. Hartford, Aug.14, 1874.

Some idea may be formed of the possible variety of forms of vortex atoms by simply looking at the illustrations of Professor Tait's remarkable papers upon Knots[1].

[1] Scientific Papers, vol. I, p.273." [1, p.198-200]

"In 1868, Helmholtz pressed farther the analogy between the equations of fluid motion and those of electricity and heat in a paper on movements in discontinuous fluids. He also endeavoured to account for certain discrepancies that exist between theory and experiment. He found that such discrepancies are greatest in cases where the current enters a wide space through an opening having sharp edges." [1, p.201]

"The seat of electrical action was to be sought in the tensions and strains that occur in the dielectric medium. Upon this basis Clerk Maxwell founded his theory of electrodynamics. This theory, carried out to its logical conclusion, required that any electric disturbance should be propagated through what had been till then the 'luminiferous' ether. Suppose a current passing in a metallic conductor in which there is a minute break or gap filled up by a non-conductor, such as air, the current, if sufficiently strong, will pass across the gap as a spark. If this action cause a disturbance in the dielectric, this disturbance should be propagated into space by the ether? An imperfect analogy may help the mind at this point. What occurs at the gap may be like the effect of a stone dropped into a still water, when a wave will be started and propagated from the centre of disturbance. Another disturbance will cause another wave, another a third wave, and so on. The shorter the interval of time between successive disturbances the shorter will be the waves. Is there anything analogous in magneto-electric action? Fitzgerald was the first to suggest an attempt to measure the length of electric waves; and Helmholtz propounded the question for a prize essay to be awarded by the Berlin Academy." [1, p.216-217]

"Among the last papers written by Helmholtz was one on Clerk Maxwell's theory of the movements in the free ether, in which he discussed profound questions as to whether it were free to move, to what extent and how it was associated with gross matter, and he shows that its incompressibility being assumed, all its changes and movements can be deduced from the laws of electrodynamics, and the principle of least action." [1, p.219-220]

“[…] and the last [paper], which was also issued in 1874, relates to the theory of anomalous dispersion. Finally, in 1892, there appeared a paper, important from a theoretical point of view, in which he applied Clerk Maxwell’s electro-magnetic theory of light to explain the dispersion of colour.[1]

[1]All the papers on light appear in Bd. ii. *Wissenschaftl.Abhandlungen*; that on colour dispersion in Bd. iii., s. 505.” [1, p.226]

“The phenomenon [of anomalous dispersion] had been examined by many physicists; but the explanations were unsatisfactory. Helmholtz’s first solution was founded on the supposition that in transparent media certain ponderable molecules participate in the vibrations of the ether surrounding them. Mathematical difficulties arise if we suppose that there is discontinuity between the surfaces of these particles and that of the ether everywhere in contact with them, so he further assumes that there is continuity, that is, that there is no abrupt transition. Now, imagine light falling on such an arrangement. Part of the vibrations transmitted by the ponderable molecules is transformed into irregular vibrations, that is to say, into heat. Thus part of the light is absorbed or disappears. The ponderable medium opposes to the movement of the vibrating molecules a resistance like that of friction. Each molecule of the ether is thus affected by (1) an elastic reaction of the ether; and (2) a force due to the ponderable medium, which is supposed to be proportional to the relative displacements of a molecule of ether and a molecule of ponderable matter. The ponderable molecule, on the other hand, is acted upon (1) by a force equal to, and in reverse direction of, the preceding; (2) a force due to the neighbouring ponderable molecules; and (3) a retarding frictional force proportional to the rapidity of displacement. These conditions mathematically expressed lead to the differential equations of motion. When there is no sensible absorption, the formulae indicate a normal dispersion, but when great absorption takes place, theoretical results are obtained in accordance with those observed in anomalous dispersion. Thus, as expressed by Professor Tait, Helmholtz’s explanation ‘depends upon an assumption as to the nature of the mutual action between the luminiferous ether and the particles of the absorbing medium, coupled with a farther assumption connecting the absorption itself with a species of friction among the parts of each absorbing particle.’ These assumptions were first suggested by Allenmeier, but they were fully applied by Helmholtz.

This explanation was offered in 1874, but he returned to the subject in 1892 and 1893, and endeavoured to account for the fact in accordance with Clerk Maxwell’s electro-magnetic theory of light, by the conception of pairs of oppositely charged particles (ions) of inert matter fixed in the ether. This paper probably contributed more to supporting the electro-magnetic theory than to an adequate explanation of anomalous dispersion, which is an easily demonstrable fact still incapable of explanation.” [1, p.230-232]

“As already explained, the notion of action at a distance was gradually abandoned, and its place was taken by that of a medium connecting masses of matter with each other, and transmitting force. But if this new conception is still mechanical, if particles of matter are straining upon invisible ties that bind them together, if all attractions and repulsions occur in the medium known as the ether, what is the simplest expression of the laws that control these dynamical operations?” [1, p.242]

“With the recognition of the true nature of heat came the great modern generalization of the conservation of energy. Heat is a form of molecular and ethereal energy; and dynamically this great doctrine of the conservation of energy is the earlier principle of the constancy of the potential and kinetic energies, if cognizance be taken of the invisible motions of molecules and ether as well as of the visible mass motions.” [1, p.246]

“In his paper on Maxwell’s theory of movements in the free ether […], Helmholtz plunges into questions of an extremely difficult nature, and on which all his powers of mathematical analysis and his capacity of wielding, like a Titan, the tremendous principles of the conservation of energy and of least action, are brought to bear. Ponderable matter is everywhere bathed by ether and is permeated by it. If the ponderable matter and the ether are in a close grip one with the other, one may reason from the movements of the former to those of the latter. But if we consider the spaces which are empty of ponderable bodies and filled with ether alone, then the question arises, has the ether any inertia? Again, suppose ponderable bodies to move in the ether, can the latter get out of their way, or does it pass through the ponderable bodies like water through a sieve, or does the ether remain at rest or is it partly dragged along by the ponderable bodies? Helmholtz finds, on the assumption that the ether is an incompressible frictionless fluid, having no inertia, that the electromagnetic law of Clerk Maxwell, experimentally proved by Hertz, holds good, and explains all the phenomena. He finally draws important conclusions as to the character of the discontinuity at the boundary of ether and ponderable matter, and the manner in which the electrical and magnetic forces originate. This paper was a fitting termination to the labours of Helmholtz in the lofty region of mathematical physics.” [1, p.248-249]

“In the tract on the conservation of energy, Helmholtz asserts ‘that Science, whose object is to understand nature, must start from the assumption of its intelligibility.’ In other words, nature must explain herself, and she must hold all the contents necessary for an explanation of everything.” [1, p.255]

“’[…] the purpose of science is to comprehend reality and the play of phenomena as regulated by law.’” [1, p.281]

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2. Dimitri Mendeleeff, *An Attempt Towards A Chemical Conception of the Ether*, transl. from Russian by George Kamensky (Longmans, Green and Co., London, New York and Bombay, 1904).

“There is some hope that gravity may in some way or another be explained by means of pressure or impact acting from all sides, but chemical attraction, which only acts at infinitely small distances, will long remain an incomprehensible problem.” [2, p.31]

“Neither gravity nor any of the problems of energy can be rightly understood without a real conception of the ether as a universal medium transmitting energy at a distance.” [2, p.33]

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3. Peter Guthrie Tait, *Scientific Papers, Vol.I* (Cambridge, University Press, 1898)

“I was led to the consideration of the forms of knots by Sir W. Thomson’s Theory of Vortex Atoms, and consequently the point of view which, at least at first, I adopted was that of classifying knots by the number of their crossings, or, what comes to the same thing, *the investigation of the essentially different modes of joining points in a plane, so as to form single closed plane curves with a give number of double points*.

The enormous numbers of lines in the spectra of certain elementary substances show that, if Thomson’s suggestion be correct, the form of the corresponding vortex atoms cannot be regarded as very simple.” [3, p.274]

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4. S. Tolver Preston, *Physics of the Ether*, (E. & F. N. Spon, London, New York, 1875)

“Firstly, this theory [of action at a distance] assumes that one mass of matter can move or act upon a second mass of matter, placed at a distance, without the intervention of material or physical agency; or the theory assumes that a mass of matter might be surrounded to a considerable distance by absolutely empty space, and yet that the mass might be put in motion without the penetration of matter in any form into this empty space surrounding the mass.

We will take the case termed “gravity”. Here it is assumed that a mass of matter can be accelerated or put in motion at different rates by a simple change in its position in empty space,

by which its distance from a second mass is varied, without the necessity for the presence of a medium or anything whose physical condition might be affected by the variation of distance between the masses, i.e. without the necessity for the presence of matter or any material means to produce and regulate the different degrees of energy with which the mass is acted upon in different positions; or it is assumed that the mass can be acted upon or moved with different degrees of energy (found to have a somewhat complicated relation to the relative distance of the masses), without the presence of any material means to regulate the varying energy with which the mass is acted upon in the different position: in short, a mass of matter may be wandering about in space some thousands of miles away from anything to control its motions, and yet it is assumed that the mass, by simply passing from one point of empty space to another, can have its velocity adjusted in proportion to the square of its distance from another mass. We can imagine nothing more opposed to reason than this, if the question be fairly looked at.

It is important to distinguish between the fact of this exact adjustment taking place, and the cause, for no one doubts the fact; but the theory would assume that there are no varying physical conditions about the mass required to produce the varying effects; or, in other words, that by mere change of distance the physical effects can vary, without the physical conditions about the mass having undergone any change. Surely the only conceivable way in which the mass could be differently affected at different distances, would be by the presence of something about the mass, whose physical condition might be affected by the distance, for the mass itself cannot possibly be physically affected by the distance." [4, p.1-2]

"A vibrating tuning-fork is known to attract a piece of card, or to cause a piece of card to exhibit a tendency to move towards it; but the term "attract" can evidently give no insight into the physical cause." [4, p.2-3]

"The ether being the means by which the entire energy received from the sun in the form of heat and light, &c., is transmitted to the earth, the ether therefore may be properly regarded as the most important of physical agents; this agent being a most influential one and everywhere present, to the ether therefore we must look as the agent concerned in the various molecular and other movements of matter, including the physical effects produced at a distance generally." [4, p.10]

"In returning to the consideration of the phenomena of "attraction" and "repulsion", we may first give some quotations from some papers contained in the 'Philosophical Magazine' (November, 1870; June, 1871), descriptive of experiments with masses of matter vibrating in air (tuning-forks, &c.), these experimental results being illustrative of the power of vibrating masses to disturb the equilibrium of pressure of the intervening medium, attended by the effects of attraction and repulsion.

These phenomena appear to have been experimentally investigated at about the same time, and independently, by Guthrie, Guyot, and Schellbach. In these papers numerous interesting experiments are detailed relative to the attraction and repulsion of various freely suspended substances, by tuning-forks and other vibrating bodies, and we may give the following quotations, as showing the striking and distinct character of the results obtained. We give, first, some quotations illustrative of the experimental results obtained by Mr. F. Guthrie.*

* 'Phil. Mag.,' Nov., 1870

41. Experiment 7. - "To one end of a splinter of wood 0.5 metre long, a card 0.08 metre square was fastened in such a way that the plane of the card was vertical, and contained in the line of the splinter. The whole was hung from a fibre of unspun silk, and counterpoised. The tuning-fork was set in vibration, and was brought towards the card in three relative positions. In all three cases the card moved towards the fork. The rate at which the card moved was greatest when the fork was sounding loudest. In all three cases it was possible to draw the card from a distance of 0.05 metre at least. […]

Experiment 8. – "The tuning-fork was fastened to the end of a rod 1 metre long; the end of the rod was counterpoised, and the whole was hung from a silk tape.' The description adds, that when a card was held near the vibrating suspended fork, the fork moved towards the card; this being evidently the exact converse of the previous experiment. […]

Experiment 9. – "Further, instead of a card, a second fork B was set in vibration and brought into the neighbourhood of the vibrating suspended fork A. In every case the suspended fork approached the stationary one. "Hence, to whatever cause the approach is due, the action is mutual." […]

42. These striking experimental facts carry their practical deductions with them, and in their application to molecules vibrating in the ether, there are only two conditions, important in a mechanical point of view, which require to be satisfied, viz. first, the existence of an ether pressure of a value commensurate with the high static value of the effects observed in the case of vibrating molecules; and, secondly, the vibrations of molecules must take place with an energy commensurate with the energy of the effects. The first of these two conditions has been already considered and disposed of; […]."

[4, p.28-30]

"[…] there exists no other conceivable process by which one mass or molecule of matter could move or act upon another mass or molecule placed at a distance than by means of vibration. For in the first place, in order for a mass of matter to be capable of moving, or physically affecting a second mass placed at a distance without approaching it, the mass must have a motion of some kind so as to be capable of disturbing the surrounding medium, which forms the only physical connection between the masses. Secondly, since the mass or molecule in acting upon a second molecule maintains a fixed position, it follows that the motion of the

molecule must take place in such a way that the molecule can maintain a fixed position, and nevertheless can disturb the surrounding medium. Now, a vibratory motion of the molecule constitutes the only conceivable means of satisfying these conditions, as by this form of motion the molecule can retain a fixed position by oscillating about a fixed point, and yet can disturb the surrounding medium by its motion. Hence, in a mechanical point of view, nothing can be more obvious or to the purpose than the vibratory motion of matter so constantly presenting itself in physical phenomena.

48. A molecule of matter surrounded by the ether cannot possibly be in motion without disturbing the ether, and thereby giving up or dissipating continually its motion in the surrounding ether. This disturbance of the ether by the motion of molecules is illustrated by the waves emitted by the molecules of substances, and the attendant loss or dissipation of the motion of the molecules is exemplified by the cooling (loss of molecular motion) of heated substances when suspended in the free ether. It follows, therefore, from this that the motion of molecules which is being continually dissipated in the ether must be sustained by some external source of motion, or otherwise the motion of molecules would soon cease. This is illustrated by the known fact that the motion of molecules is sustained by the sun, it being an important fact to observe that the character of the sustaining motion is a *vibratory* or wave motion traversing the ether." [4, p.33]

"Hence, taking this cause into account [art. 53] together with the one previously considered [art. 52] it may be observed that there exist two separate influential physical causes by whose action the vibrations of masses or molecules are in all cases attended by the communication of a *certain excess or surplus of energy* to the surrounding medium.

The deduction that by the vibrations of masses or molecules a surplus of energy is imparted to the surrounding medium, is clearly of direct and practical importance as regards the phenomena of "attraction," &c., for the communication of energy to the component particles of a medium implies necessarily, under certain conditions, an expansion or rarefaction of the medium, and a rarefaction of the medium is the very condition required for an "attraction." [4, p.36-37]

"Thus, if we take the case of a vibrating tuning-fork held in proximity to a lightly suspended piece of card, then the increments of velocity imparted to the molecules of the column of air intercepted between the vibrating prong and the card, accumulate by repeated reflections between the opposing surfaces of the prong and the card, producing a rarefaction of the air column, whereby the excess of pressure of the air at normal density at the back of the card coming into action, drives the card towards the prong. […]

66. The above deductions may be stated in one general conclusion, viz. that the vibrations of masses or molecules of matter are in all cases necessarily attended by a rarefaction or

displacement of the intervening medium: this conclusion holding, however distant the masses may be from each other, or however feeble the vibrations; the intensity of the effect becoming greater by an increased proximity of the masses, or by an increase of their vibrating energy." [4, p.43]

"The only conceivable way in which a vibrating suspended tuning-fork could be affected by the presence of a distant card, is that the medium about the fork is in some way affected by the presence of the card. Now, since the card does not itself vibrate, the only possible way that it can affect the medium about the fork is by reflecting the impinging waves back upon the fork, by which stationary vibrations are produced in the intervening medium, and to these stationary vibrations alone, therefore, can the approach of the fork possibly be referred. Further, since in the converse case when the fork is fixed and the card moveable, the card is acted on with precisely equal force, it follows, therefore, that the same physical cause, i.e. the stationary vibrations of the medium, must be solely concerned in this case also, i.e. in both cases, whether it be the approach of the vibrating fork or the approach of the card." [4, p.49-50]

"When the high intensity of the ether pressure, and the vast extent of surface exposed to this pressure, are conjointly taken into account, then the observed power with which molecules are controlled in stable equilibrium, and the observed extreme energy of the movements of molecules when the equilibrium of pressure is disturbed, as exhibited in the general phenomena of chemical action, combustion, &c., reconcile themselves with the ordinary principles of mechanics." [4, p.69]

"The air, therefore, constitutes an instructive example of concealed motion, and may form, as it were, a sort of stepping-stone towards the realization of the ether. If the motion of the air molecules and the attendant pressure be concealed, how much more cause is there for the complete concealment of the existence of the store of motion and the attendant pressure in the case of the ether, the cause of concealment being greater as the moving particles are more minute, and by their multiplicity the motion is confined within narrower limits, and the pressure more evenly balanced?" [4, p.76]

"However complex and varied, therefore, the molecular processes and changes may be which take place within the animal system in the passage of the motion through its intermediate stages, and however difficult it may be to follow the motion through the entire cycle, it is none the less certain that the ether is the primary source and final receptacle of the motion." [4, p.89]

"The ether […] must […] be the *source* of all the motions of matter, for matter cannot evolve motion out of itself." [4, p.90]

"[…] *all physical phenomena are fundamentally correlated as cyclical processes consisting in an interchange of motion, and in which the motion is derived from and passes to one universal source of motion, the ether.*" [4, p.100]

"*Translatory motion and vibratory motion are therefore mutually convertible, or the one will produce the other*. These constitute the two fundamental and interconvertible forms of motion, by the permutations of which all the varied molecular effects are produced. The mutual convertibility and dependence of these two fundamental forms of motion constitute, therefore, an important practical principle in connection with the working of physical phenomena." [4, p.105]

"As an analogous example of the *interconvertibility and mutual dependence* of translatory motion and vibratory motion, we may take the known fact that, in the case of gases, temperature and pressure are mutually dependent." [4, p.106]

"In regard to the phenomena of attraction produced through vibration, we have found it a simple and effective method for illustrating the results, to float the masses acted upon on the surface of water. Thus the simplest method is to take a small piece of cork and insert a narrow strip of card into a slit made in the cork, the cork being then placed on the surface of water, so that the strip of card is vertical. If a tuning-fork be then struck a sharp blow and approached to the card, the latter is distinctly attracted, and may even be made to turn round by holding the prong near the edge of the card and turning the fork round in a circle. The effect is much greater in close proximity to the card. To show the marked character of the effect, the fork may be held near the card, and on the latter receiving an impulse towards the prong, if then the fork (still vibrating) be suddenly brought round to the opposite side of the card, the movement due to the first impulse is checked and changed into a movement in the opposite direction. Another experiment consists in taking a short strip of tissue paper and placing it upon a table, when by holding the vibrating prong about an eighth of an inch above the strip of paper, the latter will spring up and adhere to the prong – a film of air being intercepted between the two – the paper dropping off when the vibration ceases. The effect here reminds one of the attraction of light substances by a rubbed piece of sealing-wax." [4, p.136]

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5. John William Strutt, Baron Rayleigh, *The Theory of Sound*, Vol. II (MacMillan And Co., Limited, London, 1926)

“253 b. In [art.] 253 a the effect to be explained is intimately connected with the compressibility of the fluid which occupies the interior of the resonator. In the class of phenomena now to be considered the compressibility of the fluid is of secondary importance, and the leading features of the explanation may be given upon the supposition that the fluid retains a constant density throughout.

If ρ be constant, (49) [art.] 253 a may be written

$$\int (p_1 - p_0) \cdot dt = -\frac{1}{2} \cdot \rho \int U_1^2 \cdot dt$$

showing that the mean pressure at a place where there is motion is less than in the undisturbed parts of the fluid – a theorem due to Kelvin[2], and applied by him to the explanation of the attractions observed by Guthrie and other experimenters. Thus a vibrating tuning-fork, presented to a delicately suspended rectangle of paper, appears to exercise an attraction, the mean value of U^2 being greater on the face exposed to the fork than upon the back.

[2] Proc. Roy. Soc. Vol. xix, p.271, 1887.” [5, p.43]

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6. Horace Lamb, *The Dynamical Theory of Sound*, (Edward Arnold & Co., London, 1931)

“The remarkable point here is that the force is independent of the velocity, and depends only on the *acceleration* of the sphere. If the mass of the sphere be M, and if it be subject to other extraneous force X, its equation of motion will be

$$\frac{dU}{dt} = X + X'$$

or

$$(M + \frac{2}{3}\pi\rho a^3) \cdot \frac{dU}{dt} = X$$

This is the same as if the fluid were abolished, and the inertia of the sphere were increased by $(2/3)\pi\rho a^3$, i.e. by half that of the fluid which it displaces. It was shown by Stokes (1843) that this conclusion is accurate even when the restriction to small motions is abandoned.

There is, we shall see ([art.] 79), nothing peculiar to the sphere in the general character of the above result, but the apparent addition to the inertia will vary of course with the shape as well as the size of the solid, and will usually be different for different directions of motion, as e.g. in the case of an ellipsoid. The theory here touched upon has had a great influence on recent physical speculations, and in particular was responsible for the suggestion that the apparent inertia of ordinary matter might be partly or even wholly due to that of a surrounding aetherial medium.” [6, p.237]

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7. A. B. Basset, *An Elementary Treatise on Hydrodynamics and Sound*, 2nd Ed. (Cambridge Deighton Bell and Co., London George Bell and Sons, 1900)

“The determination of the velocity potential, when a solid body of any given shape is moving in an infinite liquid, is one of great difficulty, and the only problem of the kind which has been completely worked out is that of an ellipsoid, which of course includes a sphere as a particular case.

We shall however find it simpler in the case of a sphere to solve the problem directly, which we shall proceed to do.” [7, p.49]

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8. Ludwig Prandtl, *Essentials of Fluid Dynamics With Applications to Hydraulics, Aeronautics, Meteorology and other Subjects* (Blackie $ Son Limited, London and Glasgow, 1952)

“[…] Bjerkens now goes farther and assumes that the periodic motion of the fluid is caused by another “pulsating” body. If the two bodies pulsate in the same rhythm, i.e. attain their greatest and least volumes simultaneously, it follows readily from what has been said above that the two bodies will attract one another; if they pulsate in opposite rhythms, they repel one another. In an unlimited fluid it is found that the velocities in the neighbourhood of a pulsating body are proportional to the inverse square of the distance and that the forces of attraction or repulsion are inversely proportional to the square of the distance, that is, the laws are those of electrostatic or magnetic “action at a distance”. Hence we may speak of “hydrodynamical action at a distance”. [8, p.344]

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9. John Scott Russell, *The Wave of Translation in the Oceans of Water, Air, and Ether* (Trubner & Co., London, 1885)

“If there is a sphere of infinitely refined air which is invisible and intangible, we must give it some fancy name like weightless fluid, or ether. We must either suppose that there are void spaces in the universe, or agree that what has been called a vacuum is only bulk occupied by ether, which cannot be touched, seen, weighted, or measured, but which fills all space.” [9, p.131-132]

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10. G. Carey Foster and Alfred W. Porter, *Elementary Treatise on Electricity and Magnetism*, 3rd Ed. (Longmans, Green, and Co., London, New York, Bombay and Calcutta, 1909)

“In order to explain the propagation of light across stellar space, and to account for the properties of light as ascertained by experiment, men of science have long recognized the necessity of supposing some medium, the so called “luminiferous ether”, possessing mechanical properties different from those met with in ordinary matter, to exist throughout all transparent substances and to extend through space.

After imagining one intangible, all-pervading ether, in order to explain optical phenomena, it seems highly artificial and complicated to imagine a second intangible medium to account for the phenomena of electricity and magnetism. It turns out, however, that these two hypotheses mutually support each other; that, in fact, the mechanical properties which must be attributes to the ether, in order to explain the transmission and properties of light, are just those which the electromagnetic medium must possess in order to produce the effects of electricity and magnetism. We may say, therefore, that the required electromagnetic medium has been found in the long-admitted luminiferous ether.

It appears, indeed, that in studying optics and electricity we are really investigating the properties of the ether from two different sides. In optics, we are dealing with effects due to vibrations of enormous rapidity; whereas in electricity we observe the effects of very much slower vibrations, or of steady, non-vibratory conditions of the ether. Such at least seems to be the fair inference from what is known so far.” [10, p.461-462]

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11. Arthur Schuster, *An Introduction to the Theory of Optics*, 2nd Ed. (Edward Arnold, London, 1909)

“There is at present no theory of Optics in the sense that the elastic solid theory was accepted fifty years ago. We have abandoned that theory, and learned that the undulations of light are electromagnetic waves differing only in the linear dimensions from the disturbances which are generated by oscillating electric currents or moving magnets. But so long as the character of the displacements which constitute the waves remains undefined we cannot pretend to have established a theory of light. This limitation to our knowledge, which in one sense is a retrogression from the philosophic standpoint of the founders of the undulatory theory, is not always sufficiently recognized and sometimes deliberately ignored. Those who believe in the possibility of a mechanical conception of the universe and are not willing to abandon the

methods which from the time of Galileo and Newton have uniformly and exclusively led to success, must look with the gravest concern on a growing school of scientific thought which rests content with equations correctly representing numerical relationships between different phenomena, even though no precise meaning can be attached to the symbols used. The fact that this evasive school of philosophy has received some countenance from the writings of Heinrich Hertz renders it all the more necessary that it should be treated seriously and resisted strenuously.

The equations which at present represent the electromagnetic theory of light have rendered excellent service, and we must look upon them as a framework into which more complete theory must necessarily fit, but they cannot be accepted as constituting in themselves a final theory of light.

The study of Physics must be based on the knowledge of Mechanics, and the problem of light will only be solved when we have discovered the mechanical properties of the aether. While we are in ignorance on fundamental matters concerning the origin of electric and magnetic strains and stresses, it is necessary to introduce the theoretical study of light by a careful treatment of wave propagation through media the elastic properties of which are known. A study of the theory of sound and of the old elastic solid theory of light must precede therefore the introduction of the electromagnetic equations." [11, p.v-vi]

"We imagine the luminiferous aether to be a medium, filling all space and permeating all bodies. Light is a wave-motion in this medium. The waves of light are distortional waves. The vectors defining the displacements in transparent and isotropic bodies are in the wave-front. Waves of the simple periodic form are propagated through the aether with a velocity independent of the wave-length." [11, p.35]

"Huygens drew attention to the observation that the passage of a beam of light through an aperture is in no way affected by the passage of another beam through the same aperture. As he pointed out, different people may look at different objects through the same opening without noticing any blurring due to the overlapping of the large number of waves which must pass through the opening. The waves cross each other at the aperture without in the least interfering with each other's course.

We explain this independence of the separate waves by the principle of superposition […] according to which the combined effect of a number of displacements may be obtained by adding the separate displacements, taking account of direction as well as magnitude." [11, p.56]

"The electromagnetic theory of light establishes for the propagation of a luminous disturbance, equations which in several instances, as will appear, fit the facts better than the older elastic

solid theory, but it should not be forgotten that it furnishes no explanation of the nature of light. It only expresses one unknown quantity (light) in terms of other unknown quantities (magnetic and electric disturbances), but magnetic and electric stresses are capable of experimental investigation, while the elastic properties of the medium through which, according to the older theory, light was propagated, could only be surmised from the supposed analogy with the elastic properties of material media." [11, p.233]

"According to the most general equations of the motion of an elastic substance […], a disturbance spreads in the form of two waves, the condensational longitudinal wave propagated with a velocity $\sqrt{(k+4n/3)/\rho}$ and the transverse distortional wave propagated with a velocity $\sqrt{n/\rho}$. The phenomena of light leave no room for a longitudinal wave propagated with finite velocity. The theories so far considered avoid the difficulty by taking the elastic body as incompressible, when the coefficient k becomes infinitely large, and the longitudinal disturbance is propagated with infinite velocity.

This elastic solid theory of the aether which has been discussed in the preceding articles, does not, as appeared, consistently lead to facts which are in agreement with observation: it fails to account for the laws of double refraction and for the observed amplitude of light reflected by transparent bodies. That theory was therefore considered dead, until Lord Kelvin resuscitated* it in a different form by showing how, dropping the hypothesis of "solidity", an elastic theory of the aether may still be a possible one.

*Phil. Mag. xxvi. p. 414. 1888.

The characteristic distinction of the new theory lies in the bold assumption that the velocity of the longitudinal wave, instead of being infinitely large, is infinitely small. This requires that $k+4n/3$ shall be zero, so that k is negative. A medium in which there is a negative resistance to compression would at first sight appear to be essentially unstable, but Lord Kelvin shows that the instability cannot come into play, if the aether is rigidly attached to a bounding surface. So long as there is a finite propagational velocity for each of the two kinds of wave motion, no disturbance set up in the medium can lead to instability." [11, p.246]

"All mathematicians who, previous to Maxwell, had discussed the undulatory theory of Optics, started from the elastic solid theory of the luminiferous aether. That theory was able to give a satisfactory account of a great number of the phenomena of light and was considered to be securely established. The phenomena of electricity were treated as independent facts, though no doubt many physicists held that ultimately electric action would be explained by the stresses and strains of the same medium which transmitted light. No one had, however, suggested properties of the medium different from those of an ordinary elastic solid. Maxwell attacked

the question with great originality from another point of view. Having asked himself the question, what the properties of a medium must be, in order that it should be capable of transmitting electric actions, he discovered that this electric medium was capable of transmitting transverse vibrations with the velocity of light." [11, p.251]

"[…] Sellmeyer's equation […] first showed that the velocity of light must depend on the periods of free vibration of the molecules embedded in the aether." [11, p.260]

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12. Richard C. MacLaurin, *The Theory of Light, A Treatise on Physical Optics*, Part I (Cambridge: at the University Press, 1908)

"In the first place we postulate the existence of the ether, an all pervading medium through which what we call waves of light may be propagated. This medium is literally metaphysical; but it is a substance that has some of the qualities of ordinary matter. Indeed it could not be so much as thought of, if it had not, since our conception of substance is necessarily derived from our sensations. It is an abstraction obtained by selecting some of the qualities from media, such as water or jelly, with which we are familiar, and rejecting other of the qualities. Our excuse for postulating such a medium is that we see no prospect of attaining our end without it, while with it great things can be accomplished, not only in the domain of optics, but in the fields of electricity and magnetism as well. At the same time we need not concern ourselves with the 'reality' of the ether, nor take the unphilosophic step of pronouncing it to be real merely because it is a conception that is convenient for our special purpose." [12, p.10]

"In the discussion of optical problems two vectors will appear throughout. These are the displacement at any point of the medium and the curl of the displacement. At any point (x, y, z) the displacement may be represented by its components (ξ, η, ζ), and the curl by its components (f, g, h), the relation between the two vectors being a geometrical one indicated by the equations

$$f = \frac{\partial \zeta}{\partial y} - \frac{\partial \eta}{\partial z} \qquad g = \frac{\partial \xi}{\partial z} - \frac{\partial \zeta}{\partial x} \qquad h = \frac{\partial \eta}{\partial x} - \frac{\partial \xi}{\partial y}$$

Before we can apply the dynamical Principle of Action to the discussion of the propagation of a disturbance in the ether, it will be necessary to obtain expressions for the kinetic energy T and the potential energy W in terms of the vectors (ξ, η, ζ) and (f, g, h). Taking the density of the ether as the unit density we have

$$T = \frac{1}{2} \cdot \int \left(\dot{\xi}^2 + \dot{\eta}^2 + \dot{\zeta}^2 \right) \cdot d\tau$$

where $d\tau$ is an element of volume. The form of W will depend on the assumptions made as to the nature of the elasticity of the ethereal medium. We shall suppose that the ether offers resistance to any rotation, but not to any translation, of its elements*. The work function for such a medium must, if the medium be isotropic, be given by an expression of the form

$$W = \frac{1}{2} \cdot c^2 \cdot \int \left(f^2 + g^2 + h^2 \right) \cdot d\tau \, .$$

Applying the Principle of Action to any portion of the ether bounded by a surface S we have to make

$$\delta \int \left(T - W \right) \cdot dt = 0 \, .$$

* This type of ether is analogous to the Elastic Solid Theory of Green and MacCullagh. For a complete discussion see Stokes: *Collected Works*, iv. p. 177." [12, p.32]

"So far in this chapter we have been considering the propagation of light in free ether. When we come to discuss the corresponding problems for material media, and to deal with reflection and refraction at the surface of a transparent isotropic body, we are faced with the difficulties connected with the relations between ether and matter. However, it will not be necessary to delay our progress until these difficulties are overcome. A large amount of experimental evidence goes to show that matter is not a continuum, but is made up of discrete particles or atoms; but even if we were satisfied with our knowledge of the nature of these atoms, we should not be concerned at this stage with the action of individual atoms on a wave of light. We are interested only in their average effect, the influence of all atoms in a finite portion of matter. We assume as a working hypothesis that the presence of matter affects the ether in such a way that the ether and matter may be replaced ideally by a continuum whose rotational elasticity is different from that of free ether, but whose density is the same. The elastic constant of this medium obtained by mentally smoothing out the atoms and spreading their influence uniformly throughout the body is no longer c as for free ether, but some other constant c/μ. With this slight change all the results previously obtained for the propagation of light in the ether apply to its propagation in any isotropic body." [12, p.37]

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13. George Gabriel Stokes, *Mathematical and Physical Papers*, Vol. II (Cambridge: at the University Press, 1883)

"The phenomena of aberration may be reconciled with the undulatory theory of light, as I have already shown (*Phil. Mag., Vol. xxvii. p.9*), without making the violent supposition that the ether passes freely through the earth in its motion round the sun, but supposing, on the contrary,

that the ether close to the surface of the earth is at rest relatively to the earth. This explanation requires us to suppose the motion of the ether to be such, that the expression usually denoted by $udx + vdy + wdz$ is an exact differential." [13, p.8]

"Before attacking the problem dynamically, it is of course necessary to make some supposition respecting the nature of that medium, or *ether*, the vibrations of which constitute light, according to the theory of undulations." [13, p.245]

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14. W. J. Spillman, *A Theory of Gravitation and Related Phenomena* (The New Era Printing Company, Lancaster, 1915)

"Newton pointed out that if there were a pressure in the ether about a body, and if this pressure diminishes as we approach the body, and if this diminution varies inversely as the distance from the body, gravitation would be accounted for. If, now, we can find some mechanism that will maintain a pressure in the ether like that just described, we can account for gravitation." [14, p.1]

"The ether is assumed to exist in the interstices of matter and in open space. It is assumed to be capable of distortion by finite force, and to oppose such distorting force with an equal opposite force. In other words, every point of the ether has a position which it normally occupies, and when removed from that position tends forcibly to return to it, the force being proportional to the distortion. It is further assumed that distortion at a given point in the ether tends to become distributed in the surrounding ether according to the law of inverse squares, and that such distribution occurs at a finite rate (the velocity of light)." [14, p.1]

"Newton's generalization to the effect that gravitational force is proportional to the product of the masses concerned was also an unsupported assumption. On this point J. E. Mills, in his excellent treatment of this subject in the *Journal of Physical Chemistry*, May, 1911, remarks: 'When Newton proposed his magnificent generalization he had *no proof whatever* that gravitational attraction did vary as the product of the masses of the attracting bodies.'

Mills further calls attention to the fact that the masses of celestial bodies have all been calculated *on the assumption that Newton's law is true*." [14, p.14]

"[…] If the attracting body were stationary in the ether, that is, if its attracting center were stationary, all bodies would be attracted exactly toward this center, no matter what motions the attracted bodies might have. But if the attracting body itself is in motion, then the attracting

center will be somewhere on the locus of the real center of the attracting body, behind the real center. In this connection Drude remarks[*]: ‘One can indeed deduce the general result, that by acceptance of the latter (i.e., the effect of the sun’s motion through space, if gravitational force is propagated at a finite velocity) anomalies in the motion of the perihelion of the planets may be explained.’ [*]*Ann. d. Phys. & Chem., Vol.62*.” [14, p.16-17]

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15. E. T. Whittaker, *A History of the Theories of Aether and Electricity* (Longmans, Green, And Co., London, New York, Bombay, and Calcutta; Hodges, Figgis, & Co., Ltd., Dublin, 1910)

“Until the seventeenth century the only influence which was known to be capable of passing from star to star was that of light. Newton added to this the force of gravity; and it is now recognized that the power of communicating across vacuous regions is possessed also by the electric and magnetic attractions.

It is thus erroneous to regard the heavenly bodies as isolated in vacant space; around and between them is an incessant conveyance and transformation of energy. To the vehicle of this activity the name *aether* has been given.

The aether is the solitary tenant of the universe, save for that infinitesimal fraction of space which is occupied by ordinary matter. Hence arises a problem which has long engaged attention, and is not yet completely solved: What relation subsists between the medium which fills the interstellar void and the condensations of matter that are scatters throughout it?

The history of this problem may be traced back continuously to the earlier half of the seventeenth century. It first emerged clearly in that reconstruction of ideas regarding the physical universe which was effected by Rene Descartes.” [15, p.1-2]

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16. R. T. Glazebrook, *James Clerk Maxwell and Modern Physics* (Cassell and Company, Limited, London, Paris and Melbourne, 1896)

“[…] What is Maxwell’s theory? Hertz himself concludes the introduction just referred to with his most interesting answer to this question. Prof. Boltzmann has made the theory the subject of an important course of lectures. Poincare, in the introduction to his “Lectures on Maxwell’s Theories and the Electromagnetic Theory of Light,” expresses the difficulty, which may feel, in understanding what the theory is. “The first time,” he says, “that a French reader opens Maxwell’s book a feeling of uneasiness, often even of distrust, is mingled with his admiration. It is only after prolonged study, and at the cost of many efforts, that this feeling is dissipated.

Some great minds retain it always." And again he writes: "A French *savant*, one of those who have most completely fathomed Maxwell's meaning, said to me once, 'I understand everything in the book except what is meant by a body charged with electricity.'"

In considering this question, Poincare's own remark –"Maxwell does not give a mechanical explanation of electricity and magnetism, he is only concerned to show that such an explanation is possible" – is most important.

We cannot find in the "Electricity" [Maxwell's Treatise] an answer to the question – What is an electric charge? Maxwell did not pretend to know, and the attempt to give too great definiteness to his views on this point is apt to lead to misconception of what those views were.

On the old theories of action at a distance and of electric and magnetic fluids attracting according to known laws, it was easy to be mechanical. It was only necessary to investigate the manner in which such fluids could distribute themselves so as to be in equilibrium, and to calculate the forces arising from the distribution. The problem of assigning such a mechanical structure to the ether as will permit of its exerting the action which occurs in an electromagnetic field is a harder one to solve, and till it is solved the question – What is an electric charge? – must remain unanswered. Still, in order to grasp Maxwell's theory this knowledge is not necessary." [16, p.216-217]

"[…] It is not necessary, in order to understand it [Maxwell's theory of electricity], to know what change in the ether constitutes electric displacement, or what is an electric change, though, of course, such knowledge would render our views more definite, and would make the theory a mechanical one." [16, p.219]

"Again, we have, it is true, an electro-magnetic theory of light, but we do not know the nature of the change in the ether which affects our eyes with the sensation of light. Is it the same as electric displacement, or as magnetic induction, or since, when electric displacement is varying, magnetic induction always accompanies it, is the sensation of light due to the combined effect of the two?

These questions remain unanswered. It may be that light is neither electric displacement nor magnetic induction, but some quite different periodic change of structure of the ether, which travels through the ether at the same rate as these quantities, and obeys many of the same laws.

In this respect there is a material difference between the ordinary theory of light and the electromagnetic theory. The former is a mechanical theory; it starts from the assumption that the periodic change which constitutes light is the ordinary linear displacement of a medium –the ether– having certain mechanical properties, and from those properties it deduces the laws of optics with more or less success.

Lord Kelvin, in his labile ether, has devised a medium which could exist and which has the necessary mechanical properties. The periodic linear displacements of the labile ether would

obey the laws of light, and from the fundamental hypotheses of the theory, a mechanical explanation, reasonably satisfactory in its main features, can be given of most purely optical phenomena. The relations between light and electricity, or light and magnetism, are not, however, touched by this theory: indeed, they cannot be touched without making some assumption as to what electric displacement is.

In recent years various suggestions have been made as to the nature of the change which constitutes electric displacement. One theory, due to Von Helmholtz, supposes that the electro-kinetic momentum, or vector potential of Maxwell, is actually the momentum of the moving ether; according to another, suggested, it would appear originally in a crude form by Challis, and developed within the last few months in very satisfactory detail by Larmor, the velocity of the ether is magnetic force; others have been devised, but we are still waiting for a second Newton to give us a theory of the ether which shall include the facts of electricity and magnetism, luminous radiation, and it may be gravitation.*

*For a very suggestive account of some possible theories, reference should be made to the presidential address of Professor W. M. Hicks to section A of the British Association at Ipswich in 1895." [16, p.220-221]

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17. Karl Pearson, *The Grammar of Science* (Walter Scott, London, 1892)

"[…] This new continuity is that of the *ether*, a medium which physicists conceive to fill up the interstices between bodies and between the atoms of bodies." [17, p.213]

"Returning now to our ether, we note that physicists conceive it incompressible, but that for some purposes they appear to treat it as a *perfect fluid,* for other purposes as a *perfect jelly*. […] We might, then, out of this series of jellies choose one which, for sliding strains of a certain magnitude, was sensibly a perfect fluid, while for smaller strains, such as are involved in the theory of light-radiation, it would act as a perfect jelly. This is the solution propounded in 1845 by Sir George G. Stokes,[1] and it may be termed the jelly-theory of the ether. The jelly-theory of the ether has undoubtedly been of value in simplifying many of our conceptions of physical phenomena, but how far it can be reconciled with any system of ether-motion as a basis for the prime-atom yet awaits investigation.[2]

[I] *Mathematical and Physical papers*, vol. i. pp. 125-29, and vol. ii. pp. 12-13. […]

[2] For example, Sir William Thomson's vortex atom would hardly be a possibility." [17, p.314-316]

"[…] Such rings are termed *vortex-rings*; and if we study the action of such rings not in air or

water but in our conceptual perfect fluid, we shall find that, like atoms, they retain their own individuality; they enter into combination, but cannot be created or destroyed. This is the basis of Sir William Thomson's vortex-ring theory of matter – a prime atom, according to his theory, is an ether vortex-ring.[1] By the aid of vortex-motion, or spinning elements of liquid in a liquid, we are also able to conceive a liquid stiffened up to a required degree of resistance to sliding strain, and thus to replace the ether as a perfect jelly by the ether as a perfect fluid in a turbulent condition.[2] We can then dispense with Sir George Stokes' hypothesis of slight viscosity. But however suggestive these ideas may be for the lines upon which we may in future work out our conceptions of ether and atom, they are very far indeed from being at present worked out, and there are many difficulties in the vortex-atom theory – notably that of deducing gravitation – which the present writer is not very hopeful will ever be surmounted.

[1] For a fuller account of this theory see Clerk-Maxwell's article "Atom," in the *Encyclopaedia Britannica*, or his *Scientific Papers*, vol. ii. pp. 445-84. See also as to spin producing elastic resistance Sir William Thomson's *Popular Lectures and Addresses*, vol. i. pp. 142-46 and 235-52.

[2] See G. F. Fitzgerald: "On an Electro-magnetic Interpretation of Turbulent Fluid Motion," *Nature*, vol. xl. Pp. 32-4." [17, p.317-318]

"In the course of our work we have frequently has occasion to notice the unscientific process of multiplying existences beyond what are really needful to describe phenomena. The canon of inference which forbids this is one of the most important in the whole field of logical thought. It has been very concisely expressed by William of Occam in the maxim: *Entia non sunt multiplicanda praeter necessitatem*. Sir William Hamilton in a valuable historical note (*Discussions on Philosophy*, 2nd edition, pp.628-31, London, 1853) quotes the further scholastic axioms: *Principia non sunt cumulanda* and *Frustra sit per plura quod fieri potest per pauciora*. So far these axioms are valuable as canons of thought, they express no dogma but a fundamental principle of the economy of thought. […]

Sir William Hamilton expresses Occam's canon in the more complete and adequate form: *Neither more, nor more onerous, causes are to be assumed, than are necessary to account for the phenomena*." [17, p.481-482]

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18. Mrs. W. Awdry, *Early Chapters in Science* (E. P. Dutton & Co., New York, John Murray, London, 1899)

"[…] radiation is a wave-motion, transmitted through an extremely elastic and subtle medium, that fills all space and pervades all substances, called the *luminiferous ether*.* This

“light-bearing” ether is, in fact, the same medium that transmits light to our eyes, and radiant heat may be called invisible light; for it travels with the enormous velocity of light, and obeys all the laws of light […]

*The young reader must not confound this word with the liquid ether sold by chemists. The luminiferous ether cannot be weighted, nor detected in any way by the senses, nor removed from any space; its existence is assumed for good reasons, by scientific men, and its properties are only inferred.” [18, p.257]

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19. Oliver Heaviside, *Electromagnetic Theory*, Vol. I (“The Electrician” Printing and Publishing Company Limited, London, 1893)

“[…] Let it not be forgotten that Maxwell’s theory is only the first step towards a full theory of the ether; and, moreover, that no theory of the ether can be complete that does not fully account for the omnipresent force of gravitation.” [19, p.x]

“Three years ago electromagnetic waves were nowhere. Shortly after, they were everywhere. This was due to a very remarkable and unexpected event, no less than the experimental discovery by Hertz, of Karlsruhe (now of Bonn), of the veritable actuality of electromagnetic waves in the ether.” [19, p.5]

“[…] The important thing proved is that electromagnetic waves in the ether at least approximately in accordance with Maxwell’s theory are a reality, and that the Faraday-Maxwellian method is the correct one.” [19, p.6]

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20. William Thomson, *Mathematical and Physical Papers*, Vol. VI (University Press, Cambridge, 1911)

“By ‘vacuum’ I mean space occupied only by the luminiferous ether.” [20, p.211]

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21. Ignatius Singer and Lewis H. Berens, *Some Unrecognized Laws of Nature, An Inquiry into the Causes of Physical Phenomena with Special Reference to Gravitation* (John Murray, London, 1897)

"As already stated, we shall have to amend Newton's conclusion, that 'all bodies attract each other proportionally to their mass,' by adding the proviso, *if in different states of excitation, and proportionally to this difference*. Of course, the quantity or *mass* (in its etymological sense) of matter is an equally important factor. But then we should not employ the term 'quantity' or 'mass' in the metaphysical sense used by Newton, but in the physical sense. Double the quantity of a substance will, under like conditions, exert a double power. This is a matter of course; we shall, therefore, disregard *mass* or quantity and simply consider difference in states of excitation. That *quantity* of matter in itself does not cause attraction, we have already shown by many facts; on the other hand, we have seen that all bodies can attract each other if free to move and *in different states of excitation*. [21, p.375]

"Let us imagine a mass of molten metal revolving in space, so as not to be influenced by one-sided attraction, as when such castings are made on earth; then, being exposed to identical influences all round, such a mass would be equally cooled in all parts of its surface, the particles of which would, therefore, be drawn inwards at the same time as the hotter particles of the centre were drawn outwards, and that for the following reasons:-
1. Bodies attract each other if in different states of excitation, and proportionally to this difference.
2. Bodies in equal states of excitation do not attract each other." [21, p.377]

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22. Robert Stevenson, *Elasticity a Mode of Motion* (Industrial Publishing Company, San Francisco, 1895)

"[…] I feel bound to support the prophetic saying of that great seer the Abbe Moigno, who in the Cosmos of 1852 declares: 'That if there is anything certain in this world it is that the molecules of bodies and bodies themselves are not really self attractive; is that attraction is not an intrinsic but only a developed force; it is that notwithstanding everything occurs as though bodies mutually attracted each other; it is incontestably true that bodies do not attract. Newton, as Euler, as every philosopher worthy of the name, has seen in Nature but two things, inertia and motion, originally impressed by a free will, the first and infinite mover. And it is with these two great facts of inertia and movement that advancing science shall ultimately explain all the phenomena of the physical world.'" [22, p.24,25]

"[…] I have already delivered a lecture at the Academy of Sciences, on the historical portion of the theory of gravitation, and there discussed the Newtonian theory of attraction; quoting

Newton's own words to show that he never believed in the innate and inherent force of attraction in matter, but he always hoped to be able to prove that attraction was caused by the motion of an aetherial medium. All the great natural philosophers since his day have worked at that problem, either to prove that apparent attraction was due to the vibrations of an aetherial medium, or to the vortices of radiant atoms." [22, p.29]

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23. Zacharian Allen, *Solar Light and Heat: The Source and the Supply. Gravitation: With Explanations of Planetary and Molecular Forces* (D. Appleton & Co., London, 1879)

"Two thousand years before Newton suggested the necessity of a connecting material medium between the heavenly bodies, to hold them together in circling orbits, the poet Homer, witnessing the glittering links of lightning suspended between the dark clouds and the earth, expressed this idea in Jupiter's address to the council of gods :

'Let down our golden, everlasting chain,
Whose strong embrace holds heaven to earth and main.'[1]

[1] Iliad, book viii.

The ancient philosophers taught the existence of an etherial medium occupying the space intervening between the grosser particles of bodies ; and for many ages after the doctrine was accepted, and transmitted to later times as "the theory of *phlogiston*;" – a term derived from the Greek PHLOGOS, *flame*. With modifications, the doctrine of a universal ether still prevails, and is confirmed by the conclusions of the most acute observers, as well as those of the most profound intellects of our day.

As to the nature of this ether, all we know is its capability of transmitting the slightest impulse of mechanical force. Beyond this, we must make the same acknowledgment of the limitation of human powers of perception as Faraday makes in reference to the essential nature of all kinds of matter, when he affirms, 'All we know of matter is its power of transmitting action ;' or, as does another eminent writer, in treating of molecules as merely "*centres of forces*" admitting them to be too minute to be distinctly recognized.

Passing by, then, all speculations as to the nature and constitution of the universal ether, it is sufficient to recognize the fact, that it is so preeminently sensitive to, and active in, the transmission of what men call electric, magnetic, and galvanic force, that we are well warranted in calling it "electric ether," even if it be not in its essence what men call the "electric fluid" itself.

Facts demonstrate that the impulse from the hand, applied to turn the crank of a Holtz electrical machine, disturbs and puts in motion a material medium, that transmits the impulses it receives in various ways, even to representing a little world in miniature. A dawning light

appears, rivaling the splendor of the rising sun. A breeze from a pointed wire on the conductor transmits sufficient force to turn a little paper windmill, and light paper-figures of men and women are excited to rise up from repose and dance. Rose-colored coruscations of the aurora and meteoric shooting-stars are represented in a glass tube exhausted of air. Flashes like lightning, and sounds as of thunder, are produced by the discharge of a coated jar, and combustibles are fired. Particles of solid bodies are scattered into vapors, and those of water decomposed and reunited, representing chemical action. Even the mechanical functions of the living human body are excited by the impulse. For when the machine puts in motion the electric ether through the five different arrangements of sensorial nerves, so as to reach the tribunal of human intelligence in the brain, the effect of the mechanical action imparted by the hand to the cylinder is recognized by as many different names as there are lines of telegraphic nerves leading to the brain. An identical electro-mechanical action transmitted through the nerves of the eyes is denoted LIGHT; through the nerves of feeling, HEAT; through the nerves of the nose, ODOR; through the nerves of the tongue, TASTE; and through the nerves of the ear, SOUND." [23, p.19-22]

"The currents moving along the adjacent wires in similar directions, by a process of induction, change the vibrations between them into conforming currents parallel with their surfaces; thereby partially neutralizing the vibrations against the nearest sides of the wires. The vibrations impinging against their outer sides then predominate, and propel the two wires toward each other, producing the phenomenon of Attraction. When the currents move in opposite directions along the adjacent sides of electrodes, their interference intensifies the vibrations between them; which then predominate over the vibrations impinging against their outer sides, and propel the two wires from each other, producing the phenomenon of Repulsion." [23, p.93-94]

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24. John Herapath, *Mathematical Physics; or the Mathematical Principles of Natural Philosophy: with a Development of the Causes of Heat, Gaseous Elasticity, Gravitation, and other Great Phenomena of Nature* (Whittaker and Co. and Herapath's Railway Journal Office, London, 1847)

"Newton, in the early and latter part of his life, propounded a cause for the phenomena of gravitation. He supposed all space to be filled with a highly elastic medium, or ether, which, like any other aeriform body, might be the more rarefied the hotter it is. The nearer to the sun, therefore, the hotter this medium would become, and consequently the more rarefied the ether. Hence, if a body was placed in it he considered that the denser parts would press that body

more forcibly than the rarer, and therefore the parts farther from the sun, being more pressed than those nearer, would create a tendency directly towards the sun, ‘with all that force which we call gravity.’

The planets, in the same way, being hotter than the spaces surrounding them, would have an effect on the medium similar to that of the sun, and cause a tendency of other bodies towards them. The same would be the case with all bodies ; and hence all the phenomena of attraction which we see in the world may be explained.

So far Newton’s idea goes of the cause of gravitation, which, as he says, he has given to show that he does not take gravity to be an essential property of matter. He has left us no notion of how the medium is expanded by heat ; nor, if it is so dense as phenomena require it should be, to pervade the pores of all bodies and act on each particle separately, has he shown how bodies can move through such a medium and experience no sensible resistance to their rapid motions. Neither has he explained how the parts of the medium can keep each other in equilibrio, and yet press unequally on the farther and nearer sides of any body within it. These are difficulties in the hypothesis he bequeathed to posterity.

From our views of the nature of airs the phenomena of expansion by heat are obvious. It is also easy to understand how great elasticity, great density, and exceeding activity may be combined and still produce no sensible retardation to bodies in rapid motion. For we have only to suppose the atoms of the medium to be excessively small for them to have exceedingly great velocity, and of course the medium to have a very high degree of activity, and be competent to afford but a very small resistance, though the numeratom of the medium be very great. A medium, therefore, with all the properties Newton required is perfectly reasonable, and it only remains for us to investigate what is the law of the increase of its density from an agitating centre; whether it can keep its parts in equilibrio, and still have an elasticity increasing with the density of the medium; and whether it gives results according with phenomena.”
[24, p.231-233]

“If we regard bodies, this force of agitation corresponds with their temperature, and hence we have this law, namely, that the force of the attraction is directly as the temperature of the body. Therefore the intensity of attraction in any body, at the temperature of waterfreezing, is to the intensity with which it attracts at the temperature of water-boiling, as 29 to 34, or approximately as 6 to 7, for such is the ratio of the true temperatures at those points.
The proof of this influence of heat on attraction is very desirable.” [24, p.253]

“It is much, therefore, to be wished that a new set of experiments were instituted, for the especial purpose of settling the question of temperature. It is a point well worthy the labours of those who have a place fit to make the experiments in. The reward would be the determining of a very important question mooted by our illustrious Newton, namely, whether gravity be or be

not an essential property of matter. If heat has any influence on the intensity of attraction, it is evident that that force which we call gravitation is not a property of matter." [24, p.259]

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25. Vilhelm Friman Koren Bjerknes, *Fields of Force* (The Columbia University Press, New York, 1906)

"*The Dynamics of the Electric or the Magnetic Field* – Our knowledge of the dynamics of the electric or magnetic field is very incomplete, and will presumably remain so as long as the true nature of the fields is unknown to us.

What we know empirically of the dynamics of the electric or magnetic field is this - bodies in the fields are acted upon by forces which may be calculated when we know the geometry of the field. Under the influence of these forces the bodies may take visible motions. But we have not the slightest idea of the hidden dynamics upon which these visible dynamic phenomena depend.

Faraday's idea, for instance, of a tension parallel to, and a pressure perpendicular to the lines of force, as well as Maxwell's mathematical translation of this idea, is merely hypothetical. And even though this idea may contain more or less of the truth, investigators have at all events not yet succeeded in making this dynamical theory a central one, from which all the properties of the fields, the geometric, as well as the dynamic, naturally develop, just as, for example, all properties of hydrodynamic fields, the geometric, as well as the dynamic, develop from the hydrodynamic equations. Maxwell himself was very well aware of this incompleteness of his theory, and he stated it in the following words:

" It must be carefully born in mind that we have only made one step in the theory of the action of the medium. We have supposed it to be in a state of stress but have not in any way accounted for this stress, or explained how it is maintained. …

"I have not been able to make the next step, namely, to account by mechanical considerations for these stresses in the dielectric."

In spite of all formal progress in the domain of Maxwell's theory, these words are as true to-day as they were when Maxwell wrote them. This circumstance makes it so much the more interesting to enter into the dynamic properties of the hydrodynamic fields, which have shown such remarkable analogy in their geometric properties to the electric or magnetic fields, in order to see if with the analogy in the geometric properties there will be associated analogies in their dynamical properties. The question is simply this:

Consider an electric, or magnetic field and the geometrically corresponding hydrodynamic field. Will the bodies which produce the hydrodynamic field, namely, the pulsating or the oscillating bodies or the bodies which modify it, such as bodies of other density than the

surrounding fluid, be subject to forces similar to those acting on the corresponding bodies in the electric or magnetic fields ?" [25, p.29,30]

"Let us consider a body in the current produced by any system of synchronously pulsating and oscillating bodies. It will be continually subject to a kinetic buoyancy proportional to the product of the acceleration of the fluid masses into the mass of water displaced by it. If its volume be constant, so that the displaced mass of water is constant, the force will be strictly periodic, with a mean value zero in the period. It will then be brought only into oscillation, and no progressive motion will result.

But if the body has a variable volume, the mass of water displaced by it will not be constant. If the changes of volume consist in pulsations, synchronous with the pulsations, or oscillations, of the distant bodies which produce the current, the displaced mass of water will have a maximum when the acceleration has its maximum in one direction, and a minimum when the acceleration has its maximum in the opposite direction. As is seen at once, the force can then no longer have the mean value zero in the period. It will have a mean value in the direction of the acceleration at the time when the pulsating body has its maximum volume. We thus find the result:

A pulsating body in a synchronously oscillating current is subject to the action of a resultant force, the direction of which is that of the acceleration in the current at the time when the pulsating body has its maximum volume." [25, p.30,31]

"*Between bodies pulsating in the same phase there is an apparent attraction; between bodies pulsating in the opposite phase there is an apparent repulsion, the force being proportional to the product of the two intensities of pulsation, and proportional to the inverse square of the distance*.

[…] the law enunciated above has exactly the form of Coulomb's law for the action between two electrically charged particles, with one striking difference; the direction of the force in the hydrodynamic field is opposite to that of the corresponding force in the electric or magnetic field. For bodies pulsating in the same phase must be compared with bodies charged with electricity of the same sign; and bodies pulsating in the opposite phase must be compared with bodies charged with opposite electricities. This follows inevitably from the geometrical analogy. For bodies pulsating in the same phase produce a field of the same geometrical configuration as bodies charged with the same electricity (Fig. 5, a and b); and bodies pulsating in opposite phase produce the same field as bodies charged with opposite electricities (Fig. 6, a and b).

[…] Thus, taking the facts as we find them, we arrive at the result that with the geometrical analogy developed in the preceding lecture there is associated an *inverse* dynamical analogy:

Pulsating bodies act upon each other as if they were electrically charged particles or

magnetic poles, but with the difference that charges or poles of the same sign attract, and charges or poles of opposite sign repel each other." [25, p.32,33]

"If the field be produced by only one pulsating or one oscillating body, the result is very simple. For the energy of the field has its maximum at the surface of the pulsating or oscillating body, and will always decrease with increasing distance. Therefore, the light body will be repelled, and the heavy body attracted by the pulsating or the oscillating body." [25, p.44]

"Our knowledge of electromagnetic fields is contained in what is generally called Maxwell's theory. This theory does not tell us what electromagnetic fields are in their true nature. It is a formal theory, bearing upon two aspects of the properties of the fields. What are generally called Maxwell's equations give a very full description of the variation from time to time of the geometric configuration of electromagnetic fields. To this geometric theory is only feebly linked the much less developed theory of the dynamical properties of these fields.

Maxwell's theory has a central core, generally called the equations for the free ether, relating to which there is good agreement among different writers. But this agreement ceases when we pass to the equations for ponderable bodies and for moving media, and, as will be seen, the full discussion of the analogy will depend upon certain details of the theory for this general case." [25, p.57,58]

"We will consider […] the geometric description of electromagnetic fields. To give this description, a series of special electric and special magnetic vectors has been introduced.

We believe that these vectors represent real physical states existing in, or real physical processes going on in the medium which is the seat of the field. But the nature of these states or processes is perfectly unknown to us. What still gives them, relatively speaking, a distinct physical meaning is […] that certain expressions formed by the use of these vectors represent quantities, such as energy, force, activity, etc., in the common dynamical sense of these words. These quantities can be measured in absolute measure." [25, p.59]

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