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XLII. *On a possible means of determining the two characteristic Constants of the Æther of Space.* *By* Sir Oliver Lodge, *F.R.S.**

[This elementary paper has for its object the eliciting of an opinion, not the communication of a result.]

THE two constants which regulate the properties and behaviour of the æther so far as known, whether the phenomenon studied be electric, magnetic, or optical, are simply and fundamentally defined thus, in terms of actual mechanical force:—

$$F=\frac{ee'}{Kr^2} \quad \text{and} \quad F=\frac{mm'}{\mu r^2}.$$

These definitions are independent of any system of units (*i.e.* are true in all), so the dimensions of an electric charge are $e=l\sqrt{(KF)}$ and of a magnetic pole $m=l\sqrt{(\mu F)}$.

We may also write magnetic moment $ml=\mu AI$, A being area and I being de/dt; or we may equally well write $m/e=\mu v$; which happens to be of the same dimensions as the coefficient of electrical resistance.

The dimension of an induction coefficient is μl, and of a capacity is Kl.

In the case of *energy* all unknown dimensions disappear, since all forms of energy are interchangeable; hence $\frac{1}{2}LI^2$ and $\frac{1}{2}SV^2$, or mI and eV, are truly dynamical expressions.

* Communicated by the Author.

There are also some expressions which are really *time*, namely RS, L/R, and $\sqrt{(LS)}$. And there is also the remarkable relation $\sqrt{(1/\mu K)}$ which dominates optics and is really a velocity. It follows that the product *em* is really angular momentum, or of the same dimension as Planck's constant h.

[It is even of interest to reckon the purely numerical relation between $e_1 m_1$ and h, where e_1 is the charge of an electron, and m_1 some corresponding unit magnetic pole which might be called a magneton. When an electron in an atom is revolving so fast that it flies off, these quantities are brought into relation with the *quantum*; and since $4\pi m$ is the total induction from a pole, and $4\pi e$ the total lines of force from a charge, and $h/2\pi$ the angular momentum of a revolving electron ready to escape from an atom so that its energy comes within our range of observation, it is natural to write

$$4\pi m_1 \times 4\pi e_1 = h/2\pi$$

or

$$h = 32\pi^3 e_1 m_1.$$

To see if the order of magnitude here involved is at all right, we can utilize the known relation $m = \mu v e$, and take v as practically the speed of light, c, for an escaping β ray.

Now h has been measured as

$$6{\cdot}547 \times 10^{-27} \text{ c.g.s. } (\mathrm{ML^2T^{-1}}),$$

while Professor Millikan's measure of

$$e \text{ is } 4{\cdot}774 \times 10^{-10} \text{ electrostatic unit.}$$

Hence $e_1 m_1 = \mu c e_1^2 = e_1^2/\mathrm{K}c = 7{\cdot}6 \times 10^{-30}$ c.g.s. $(\mathrm{ML^2T^{-1}})$ *.

It will be seen that $32\pi^3$ times this quantity gives an h of the right order of magnitude, though a little too big, namely $7{\cdot}5 \times 10^{-27}$. But the agreement is sufficiently near to be striking. To make it exact we should have to consider the electronic charge as

$$e_1 = 4{\cdot}36 \times 10^{-10} \text{ electrostatic unit.}$$

Or, if we take h and e, above, as both correctly measured, and $\mu v e_1^2 = h/32\pi^3$, we can reckon the velocity with which an electron is revolving before it escapes, as $v = 2{\cdot}61 \times 10^{10}$ cm. per sec.]

In passing we may note that electromotive force is m/t

* The above $e_1 m_1$ is the angular momentum of a sphere the size of electron and density 10^{-12} revolving on its own axis with an equatorial speed of light.

while magnetomotive force is e/t; so the ratio of the two potentials is the inverse ratio of the charges.

Every electrical expression which can be interpreted dynamically necessarily involves *two* of the electric or magnetic quantities,—one of each except when a mere ratio is involved,—otherwise the ætherial constants could not cancel.

If the constants are omitted and their unknown dimensions not attended to or allowed for, we get impossible equations expressing electric and magnetic quantities in terms of ordinary mechanical units; so that the relation between æther and matter is masked. If they are always retained, the equations are true in all respects, and it is easy to interpret them in any artificial and temporary system of units that may be convenient. The two recognized artificial systems are necessary until the nature of the constants μ and K is known: and even afterwards they will probably still be used for practical purposes.

All that we at present certainly know about these constants is derived from Maxwell's theory, and can be expressed thus:—that if the following operators are applied to any suitable electric vector this relation holds,

$$\nabla^2 + \mu \mathrm{K} \frac{d^2}{dt^2} = 0.$$

Whence it follows that the product μK is the reciprocal of the square of the velocity of wave propagation, or $\mu \mathrm{K} c^2 = 1$.

Well-known facts in electrostatics suggest that K has some kind of elastic significance; while μ, which dominates magnetic phenomena, simulates more the properties of inertia. Yet neither property can belong to ordinary matter: they both belong to vacuum: matter can only modify them, as it can only modify the velocity of light. Hence it becomes natural to suggest that $\frac{4\pi}{\mathrm{K}}$ may be the transverse elasticity or rigidity of the æther; while $4\pi\mu$ may be its density. (See 'Modern Views of Electricity,' Appendix *p*.)

Reasons are given in the Phil. Mag. for April 1907, p. 488, and in my book 'The Ether of Space,' for the probability—assuming æther to be the raw material out of which electrons are made and that it is incompressible—that the density of æther is excessively great: in fact possibly of the order 10^{12} grammes per c.c.

If that were true it would follow that the elasticity effective in radiation must be of the order 10^{33} c.g.s., so that the ratio of the two may be 9×10^{20}, the square of the velocity of light.

The problem before us is to find out if any experimental means can be devised for putting this hypothesis or assumption to an experimental test, so as either to confirm or correct it.

Now we know that magnetic lines of force, unlike electric lines of force, are always closed curves; hence it is possible for something material to flow along them continuously. Round every electric current there is magnetic circulation; is it possible that this may be ætherial circulation?

As I understand Larmor's theory of magnetism (see for instance pages 84 & 336 of his book, Æther and Matter. See also the Phil. Mag. for April 1907, p. 500) it postulates a flow of something along magnetic lines. A magnetic field is a seat of kinetic energy, while an electric field is a seat of potential energy; the interaction of the two fields is responsible for wave propagation.

If any æther is really flowing along the lines of a magnetic field, and if it has a real density, it is natural to attribute the energy of the field to the kinetic energy of this flow; and to identify the self-induction of an electric current with the surrounding ætherial inertia.

That, at any rate, is the working hypothesis which I propose to make; and if we could determine the velocity of the flow in a given field, we should thereby determine the ætherial density. That is an experiment the possibility of which I propose to consider.

The obvious suggestion is to split a beam of light and send each half in opposite directions round a closed optical circuit in such a way that when they meet they shall form interference bands. Examine these bands in a micrometer, then magnetize the circuit in such a way that the lines of force run parallel to or coincident with the beam of light, and watch for a shift of the bands.

A circuit shaped like an equilateral triangle, with mirrors at the corners, would seem the best for this modification of Fizeau's classical experiment on the effect of moving water.

In 1892 & 1893 at Liverpool I performed carefully an experiment of this kind (see Phil. Mag. April 1907, p. 495), using a square not a triangle, (which had some advantages and some disadvantages: neither obvious). I tried filling the magnetic solenoids with water, bisulphide of carbon, and salts of iron, as well as with air: and sometimes I passed the light four times both ways round the square. The maximum drop of magnetic potential applied was nearly 2,000,000 c.g.s., and this did not affect the light by so much as 1/100 of a wave-length. I could have detected an æther-drift of 1 foot per second, or a thousand millionth of the velocity of light; but I did not press the experiment to further extremes such as would have decided against a *very slow* ætherial flow.

We must now examine reasonable laboratory data to see if by any possibility we could hope so to improve the arrangements as to make perceptible a drift of æther in a transparent magnetic field of practicable strength, even if ætherial density is very great.

Take then the simplest form of magnetic circuit, a closed solenoid or anchor-ring of sectional area A and mean periphery l, and let it be wound with n turns of wire; then its coefficient of self-induction is $L = 4\pi\mu n^2 A/l$ and the mass included in the ring is $M = Al\rho$.

A current circulating in the wire has the energy $\frac{1}{2}LI^2$; while the energy of a hypothetical ætherial flow round and round the ring, is $\frac{1}{2}Mv^2$.

Assuming that the two expressions are equal, or that one is the equivalent of the other, we get

$$\frac{v^2}{I^2} = \frac{L}{M} = \frac{4\pi\mu n^2}{\rho l^2},$$

$$\text{or} \qquad v = n_1 I \sqrt{\left(\frac{4\pi\mu}{\rho}\right)}.$$

This is the drift to be observed.

If the current is expressed in electromagnetic units, μ will be 1; and if we *assume* the density ρ as 10^{12}, $\surd(4\pi/\rho)$ will be $3\frac{1}{2} \times 10^{-6}$; so in that case the velocity v will be very slow, and to make it perceptible we must contrive to make $n_1 I$ very large.

Magnetically the *size* of the solenoid does not matter, but we must arrange to crowd on it as many turns of wire to the centimetre as we can, and to send as big a current as possible through the wire without overheating it.

Let us see whether an extreme case can be thought of which shall come within the limits of experimental possibility. Take a closed magnetic circuit of any convenient sectional area and of length to be subsequently settled on optical considerations; wind it with wire so that if possible a thousand turns are piled up on every centimetre of its effective length; keep it so cold, say by liquid air, that it can carry 1000 amperes or 100 c.g.s. units of current; then $n_1 I = 10^5$ c.g.s. units. Wherefore v will be

$\frac{1}{3}$ centimetre per second.

That is to say in a magnetic field excited by a million ampere-turns per centimetre, the rate of æther flow along the lines of force will be only 3 millimetres per second or 7 inches a minute—about a snail's crawl. This is the speed which has to be compared with the velocity of light.

A considerable length of optical circuit becomes clearly necessary. Let each side of the supposed equilateral triangle constituting our magnetic circuit be a helix 10 metres long, and let the optical arrangements be so perfect that a shift of $\frac{1}{1000}$ of an interference band can be detected, then the ratio which we have available for comparing the velocities is the ratio of the total length of the circuit to one-thousandth of a wave-length; that is to say,

$$\frac{30 \text{ metres}}{6 \text{ tenth-metres}} \quad \text{or} \quad 5 \times 10^{10}.$$

The speeds to be compared are

$$\frac{3 \times 10^{10}}{\cdot 3} \quad \text{or} \quad 10^{11}.$$

Hence by taking advantage of the opposite transits of each half of the light beam, and taking advantage also of reversal of the magnetic field, the observation seems just barely feasible.

If the light were sent round a square circuit two or three times, as was done in my Æther experiment (Phil. Trans. vol. 184, A, 1893, page 757), it would seem possible to make a sort of measurement of the speed, and therefore of the ætherial density, even in the extreme case of its being as high as the estimate here suggested as a maximum. The density can hardly be greater: if it is less, the determination is proportionately easier. I expect it to be rather less, but not much: I think the order of magnitude is probably right. If there is no shift at all, and if the absence of drift can thus be certainly established, we shall learn that something is wrong with the hypothesis of ætherial flow along magnetic lines of force; for it is on that hypothesis that the whole suggested experiment has been founded.

If a distinct answer can be gained, the experiment is well worth while.

Perhaps it is not clear why I attach so much importance to a measurement of the ætherial constants and a determination of their dynamical nature. If a positive result could be secured it would be the first positive result which the æther, apart from matter, has yielded, since the fundamental fact of wave propagation and its definite velocity. This determined the product of the two constants, and was the first step in our knowledge of them. If however by some new phenomenon the two constants could be separately known, a second and even more important step would have been taken towards understanding the æther's structure and real nature. Until these constants are known, its relation to and interaction with ordinary matter must be largely guess-work. Radiation once excited obeys known laws, but of the emission and the absorption of radiation very little is really understood; and even the refraction or slowing of speed when passing through dense matter appears to be a subject of some difficulty, at least when anything more has to be apprehended than the bare fact and its elementary exposition.

If the density were known, of course the elasticity would be known too, unless the dynamics of æther is not merely a variation on Newtonian dynamics but something utterly different. The only way to ascertain the truth on this subject is to try how far the æther can be treated as a substance amenable to ordinary laws. The principle of least action holds for light, and it seems possible that a developed turbulent or vortex sponge theory may account for the æther's elastic rigidity (*cf.* Appendix E and p. 124 of Larmor's 'Æther and Matter.' Also Phil. Mag. for April 1907, p. 503). It is essential however that we know the value of this rigidity. If it is kinetically explicable in the way originally suggested by Lord Kelvin (though afterwards abandoned by him) then the amount of energy locked up in the æther is something prodigious. Some day such a fact as this, when ascertained, may be found to have a bearing on really practical problems.