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F. T. Trouton and H. R. Noble

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V. *The Mechanical Forces Acting on a Charged Electric Condenser moving through Space.*

By Professor F. T. TROUTON, *F.R.S., and* H. R. NOBLE, *B.Sc., University College, London.*

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THE experiments described in this paper were designed with the object of investigating the behaviour of a charged electrical condenser moving through space, and to discover, if possible, whether there be a relative motion between the earth and the æther. It was previously suggested by one of us in the 'Proceedings of the Royal Dublin Soc.' (Vol. VII., Part XIV., April, 1902), in connection with an experiment of a similar nature suggested by the late Professor FITZGERALD, and mentioned in his collected papers edited by Professor LARMOR.

The idea underlying the experiments will be understood from the following considerations:—If a charged condenser be placed with its plane in the direction of the æther drift, then, on the assumption that a moving charge develops a magnetic field, there will be associated with the condenser a magnetic field perpendicular to the lines of electric induction and to the direction of the motion. When the plane of the condenser is perpendicular to the æther drift, the effects of the opposite charges will neutralise each other. Thus there is magnetic energy stored in the medium when the plane of the condenser and the direction of the drift coincide; and accordingly it is to be expected that under these circumstances the condenser, when freely suspended, would tend to move so as to take up the position with its plane perpendicular to the drift, in order to transform this energy.*

To realise this, a condenser, with its plane vertical, was suspended by a fine wire and charged. The charges were let into the plates of the condenser by means of the suspending wire, and by a wire which hung from beneath, dipping into a liquid terminal. Observations were made at different times in the day, when the plane of the condenser made various angles with the direction of the drift. If the condenser

* [According to the theory given by LARMOR ('FITZGERALD'S Scientific Papers,' p. 566) the longitudinal direction, being that of maximum kinetic energy, is the direction of equilibrium; the forces due to displacement from it however remain as above, if the form of the system be assumed permanent. The negative electric experimental result reached in this paper is connected with the other negative second-order results of optical experiments relating to motion through the æther, which have been obtained by MICHELSON and by RAYLEIGH. The inferences as regards molecular theory are indicated *loc. cit.*]

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be hung with its plane north and south, then about 12 o'clock in the day there would be no couple tending to turn it, because the æther drift due to the earth's motion in its orbit round the sun is at right angles to the plane of the condenser; on the other hand, at any other hour, say 3 o'clock, there would be a couple making itself felt by a tendency to rotate the plane of the condenser into the position at right angles to the drift.

The effect to be looked for was an extremely small one, being a second-order effect only. In the earlier forms of the apparatus the calculated deflection was found to be entirely obscured by a number of accidental disturbing causes, and, in fact, the course of the experiments consisted mainly in eliminating these disturbances one by one.

The first difficulty arose from the preponderance of the electrostatic attractions between the suspended condenser and the walls of the containing case. To minimise these effects the condenser was protected by a metallic coating which was kept at the same potential as the case, all being earthed.

The suspending wire was made the insulated terminal, so that any electrostatic pull upon this wire could only produce a force acting through the centre of support, and thus the rotational effect would be eliminated, leaving only a translatory pull, which would not affect the result. There were still residual electrostatic actions, which were traced to the point where the suspension was fixed to the condenser. At this point there was necessarily a break in the metallic protecting coating fixed to the condenser, owing to the fact that the earthed terminal could not be brought very close to the insulated terminal without breaking down the insulation. To eliminate this effect, the protecting coating was prolonged up round the support in the form of a cylinder, about 3 centims. wide, and 6 centims. high. The pull being now between the cylinder and the wire, and therefore an internal force, there could be no rotation produced. Finally, it was found necessary, for similar reasons, to shield the wire as it passed through the top of the containing vessel (or case in which the condenser hung) by a thin brass tube 1 centim. wide, passing well into the vessel, and at the same potential as the wire. These precautions practically eliminated all electrostatic disturbances.

As it was necessary to keep the condenser charged for several minutes at a time, condensers insulated with paraffin wax were found quite useless for the high potentials required (3000 volts), any small leak probably increasing itself by melting the wax. Special condensers were then made in the following manner:—

Carefully selected mica plates, ·011 centim. thick, were individually tested to about 5000 volts. A disc of mica, 7·7 centims. diameter, was covered with tinfoil of 4·5 centims. diameter; the uncovered portion was coated with a thin layer of shellac-varnish. The disc was then dried on a hot plate. Two plates prepared in this way were ironed together with a hot iron, and the whole condenser was built up in this manner. We thus had almost perfect insulation, for when charged the

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potential only fell from 3000 to 2000 volts in about 5 minutes, although the outside terminal or protecting coating was wrapped round the condenser to within 1 centim. of the other terminal.

The lower contact was made by a wire dipping into a liquid, which also served the purpose of damper to the oscillations. Water was first tried, but the air in the case soon became saturated with water vapour, to the detriment of the insulation. The water was then replaced by sulphuric acid, but it was found that the acid controlled the motion of the condenser to a large extent, although thin platinum wires were used, and all damping arrangements detached. The acid was then diluted as far as was compatible with good insulation, the thin platinum wire (6 mils.) dipping into it. This has been found satisfactory, even for small controlling couples.

The last difficulty was with convection currents or draughts. Owing to the unsymmetrical shape of the suspended condenser — a flat vertical disc — air currents had powerful disturbing effects. The condenser was then fitted into a smooth spherical celluloid ball, upon which the draughts had less effect. The ball was covered with gilt paint, and earthed by means of the lower contact.

A cylindrical vessel of zinc plate, just wide enough to hold the ball, was made, inside which the condenser was hung. We thus further diminished the possibility of convection currents by limiting the space around the condenser. Around the inner zinc vessel was placed another, concentric with the first, the interspace being packed with cotton-wool. The whole of the apparatus except the suspending wire was earthed.

The final form of the apparatus is as follows (fig. 1) :—PA, the suspension, is a phosphor bronze strip 37 centims. long, the finest that could be obtained. This was soldered at its lower end A to a copper cap, fixed to the condenser protecting the projecting tin-foil tags, and making contact with them by means of fusible metal.

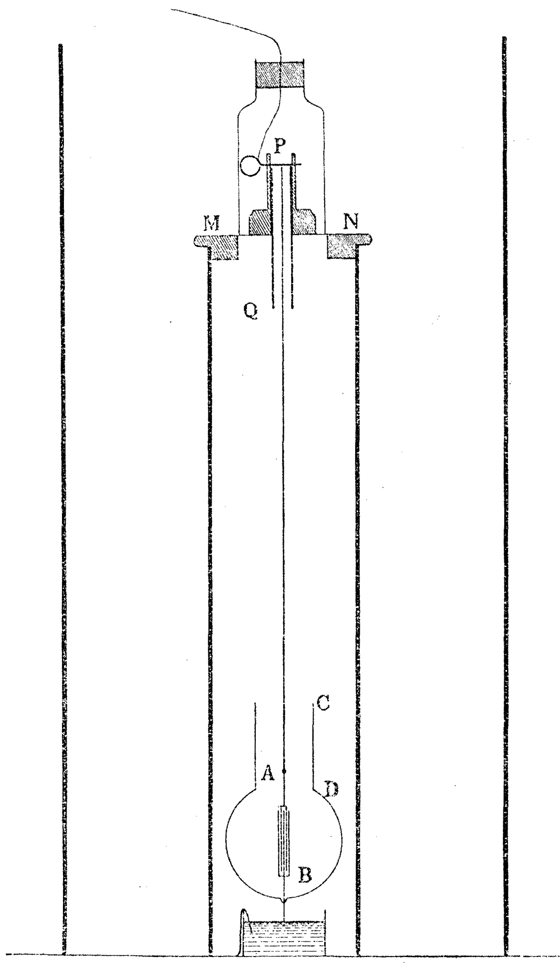

Fig. 1.

The upper end of the suspension, P, was wound on a small windlass, which was insulated by a mica plate fixed to an annular wooden ring MN, forming the lid to the inner zinc vessel.

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To prevent draughts from blowing down into the apparatus, a small glass bell jar covered the windlass, contact being made by a wire passing through the small cork at the top. PQ is the small brass tube shielding the upper part of the suspension. CD is the cylinder protecting the point of support. AB indicates the position of the condenser inside the celluloid ball. Two cylindrical zinc vessels protect the apparatus; these were earthed together with the ball containing the condenser.

A plane mirror was attached to the condenser. This was viewed by means of a telescope and scale, through small mica windows in the zinc coverings.

The potential was maintained by a Wimshurst machine, to the terminals of which was attached a Kelvin-White voltmeter.

Calculation of the Effect.

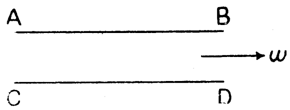

Fig. 2.

Let ABCD (fig. 2) be a given condenser charged to a surface density σ. Let it be moving in the direction AB with velocity w. We have a charge σ per unit area moving with velocity w; this is equivalent to a current σw across unit length of the plane. The opposite charge on the other plate will produce an equal and opposite current; therefore perpendicular to the plane of the paper and parallel to that of the condenser we have a magnetic field equal to $4\pi\sigma w$. The magnetic energy per unit volume is $\frac{\mu H^2}{8\pi}$, where H is the intensity of the magnetic field; this equals $2\mu\pi\sigma^2 w^2$.

The volume of the dielectric is Se, where S is the total area of one armature of the condenser and e the thickness of the dielectric. The total magnetic energy is $2\pi\mu\sigma^2 w^2 Se$. The total charge Q is $\frac{KSV}{4\pi e}$, where V is the potential difference between the plates; hence $\sigma = \frac{Q}{S} = \frac{KV}{4\pi e}$. The total magnetic energy is thus $2\pi\mu w^2 Se \frac{K^2V^2}{(4\pi)^2 e^2}$. If N be the electrostatic energy of the condenser, N is $\frac{1}{2}\left(\frac{KS}{4\pi e}\right)V^2$; so that the total magnetic energy is μKNw^2—or, if v be the velocity of electric propagation, the magnetic energy is $N\left(\frac{w}{v}\right)^2$.

Suppose now that the plane of the condenser makes an angle ψ with the direction of motion. Then magnetic energy of condenser is $N\left(\frac{w}{v}\right)^2 \cos^2\psi$.

The total energy of the system is

$$E = N\left[1 + \left(\frac{w}{v}\right)^2 \cos^2 \psi\right],$$

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the couple tending to increase ψ is $-\frac{dE}{d\psi}$, which is

$$N\left(\frac{w}{v}\right)^2 \sin 2\psi - \left[1 + \left(\frac{w}{v}\right)^2 \cos^2 \psi\right] \frac{dN}{d\psi}.$$

If we assume N independent of ψ, the couple is $N\left(\frac{w}{v}\right)^2 \sin 2\psi$.

If N changes so that couple is always zero, $\frac{dN}{d\psi} = N\left(\frac{w}{v}\right)^2 \sin 2\psi$ (neglecting small quantities of 4th order). Suppose u is the velocity of the earth's way through space, represented by OD (fig. 3). Let plane of condenser be yZ, and OZ the axis of suspension. Let plane ZOD cut plane xy in OH; let λ be the ZOD and μ the angle yOH.

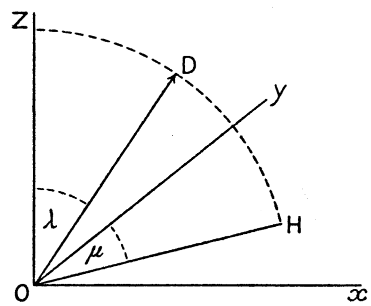

Fig. 3.

Now component of velocity along axis of suspension cannot rotate condenser about OZ, so that effective component is $u \sin \lambda$, and the expression for the couple becomes

$$N\left(\frac{u}{v}\right)^2 \sin^2 \lambda \sin 2\mu.$$

The experiment can be so arranged that $\lambda = 90°$ and $\mu = 45°$, and the couple reduces to $N\left(\frac{u}{v}\right)^2$.

The best Conditions for Experiment.

The following considerations show clearly the best conditions for making the experiment, in respect to time of day, time of year, and azimuth of the plane of the condenser.

(i.) The variation of the direction of drift with time of year.

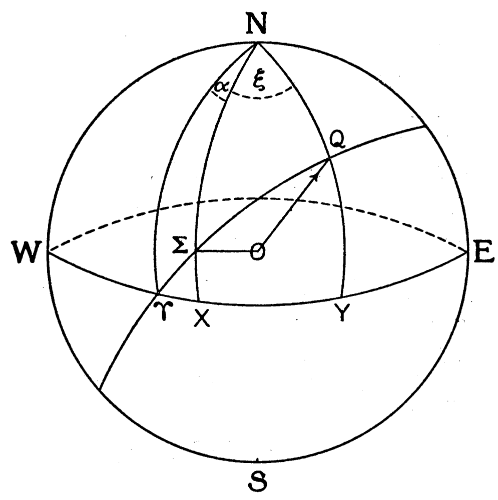

Fig. 4.

Consider the celestial sphere (fig. 4). Let Σ be the position of the sun on the ecliptic ♈Σ. If Q be a point such that $\Sigma Q = \frac{1}{2}\pi$, then OQ will be the direction of the drift past the earth.

Let $\Sigma NQ = \xi$.

Let QY $= \eta$, the declination of the point Q.

If $w =$ obliquity of the ecliptic,

$\alpha =$ right ascension of the sun.

$$\text{Tan } ♈Q \cos w = \tan ♈Y$$

$$\tan ♈Q = -\cot ♈\Sigma, \quad \text{since} \quad \Sigma Q = \tfrac{1}{2}\pi$$

$$= -\cos w/\tan \alpha,$$

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so that $\tan \Upsilon Y = -\cos^2 w/\tan \alpha$

$$\xi = XY = \tan^{-1}\left(-\frac{\cos^2 w}{\tan \alpha}\right) - \alpha \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (i.),$$

$$\operatorname{Sin} \eta = \sin QY = \sin \Upsilon Q \sin w = \cos \Upsilon \Sigma \sin w$$

$$= \frac{\sin w \cos w}{\sqrt{\cos^2 w + \tan^2 \alpha}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (ii.).$$

(ii.) The effective couple due to the drift.

Let sphere (fig. 5) represent the earth turning round its axis NS.

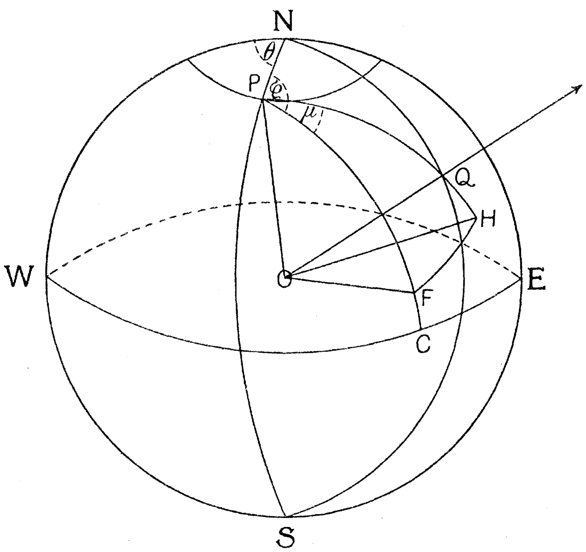

Fig. 5.

Suppose the sun to be somewhere in the plane perpendicular to the paper and passing through the centre.

Let OQ be the direction of the drift.

Then with same meaning as before for ξ and η,

$$QNE = \tfrac{1}{2}\pi - \xi, \quad NQ = \tfrac{1}{2}\pi - \eta.$$

Let P be a particular place on the earth, which for London we take the latitude $51\tfrac{1}{2}°$. Then $NP = 38\tfrac{1}{2}°$.

Let PC be plane of suspended condenser passing through centre of earth, and making angle ϕ with the meridian $CPN = \phi$.

Call WNP, the time after 6 A.M., θ.

Then $PNQ = \pi - \theta - (\tfrac{1}{2}\pi - \xi) = \tfrac{1}{2}\pi - \theta + \xi$.

Let OF be perpendicular to OP in the plane of the condenser.

With P as pole draw a great circle arc FH, meeting PQ produced at H.

Then $FH = \mu$, $PQ = \lambda$. (See fig. 3.)

Let u be the velocity of the drift along OQ.

The component along $OH = u \sin \lambda$.

So we have finally for the couple tending to rotate the condenser the value $N(u/v)^2 \sin^2 \lambda \sin 2\mu$.

If it be possible, let us select the time of day so that $\lambda = 90°$.

Now

$$\cos PQ = \cos NP \cos NQ + \sin NP \sin NQ \cos PNQ$$

$$\cos \lambda = \sin 51\tfrac{1}{2} \sin \eta + \cos 51\tfrac{1}{2} \cos \eta \sin (\theta - \xi) \quad . \quad . \quad . \quad . \quad . \quad (iii.).$$

When $\lambda = 90°$, we have

$$\sin (\xi - \theta) = \tan 51\tfrac{1}{2} \tan \eta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (iv.).$$

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Since η never exceeds $23\frac{1}{2}°$, it is always possible to choose θ so as to satisfy this condition. When θ is so chosen, we can rotate the condenser about its axis of suspension until the angle μ is 45°. The couple then becomes $N(u/v)^2$, which is the greatest possible.

The azimuth of the drift, measured as positive from the meridian easterly, is deduced from the following:—

In triangle NPQ,
$$\frac{\sin NPQ}{\sin PNQ} = \frac{\sin NQ}{\sin PQ};$$

or, since $NPQ = \phi - \mu$, $\sin(\phi - \mu) = \frac{\cos\eta}{\sin\lambda}\cos(\xi - \theta)$.

But $\sin\lambda$ has been chosen as unity, therefore
$$\sin(\phi - \mu) = \cos\eta\cos(\xi - \theta),$$
or
$$\cos(\phi - \mu) = \frac{\sin\eta}{\cos 51\frac{1}{2}} \quad \ldots\ldots\ldots\ldots \quad \text{(v.)}.$$

The angle $(\phi - \mu)$ is the azimuth of the drift.

The dotted curve, fig. 8, shows the time of day when drift is entirely horizontal.

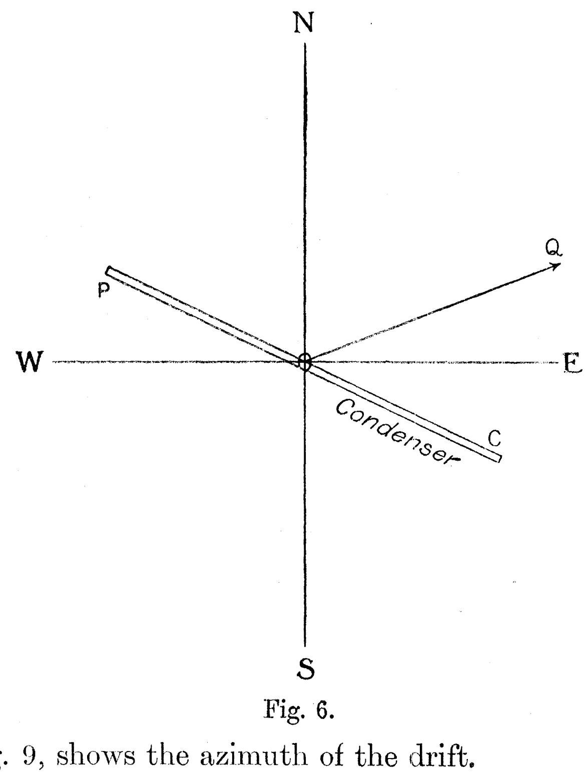

Fig. 6.

The dotted curve, fig. 9, shows the azimuth of the drift.

If the condenser be placed as in the diagram (fig. 6), then it should tend to move so as to increase the angle NOC.* That is, the motion should be in the direction E.S.W. We shall call this the positive direction. $NOC = \phi$, $QOC = \mu$.

* Accepting LARMOR'S Theory, the angle NOC would diminish.

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Influence of the Sun's Proper Motion.

In the above we have only considered the drift due to the motion of the earth round the sun; but it is also necessary to consider the effect when the sun's proper motion is included. The magnitude of this motion has been investigated by NEWCOMB ('Astronomical Journal,' No. 457, pp. 4, 5), KAPTEYN ('Astronomische Nachrichten,' No. 3487, p. 104), CAMPBELL ('Astrophysical Journal,' vol. 13, No. 1). The result of these investigations is, that there is still considerable doubt as to the magnitude and direction of this quantity; no very exact treatment is therefore possible. We have adopted for this calculation the rough value 15 miles/sec., in a direction whose right ascension is 270° and declination $38\frac{1}{2}°$. This corresponds very nearly to the position of α Lyræ (Vega).

In the diagram (fig. 7) let OQ be the component of the drift due to the annual motion. Let V be the position of Vega, which we shall consider as having right ascension $= 270° = \frac{O\pi}{2}$ and decl. $= 38\frac{1}{2}°$; and let OD be the resultant of both components.

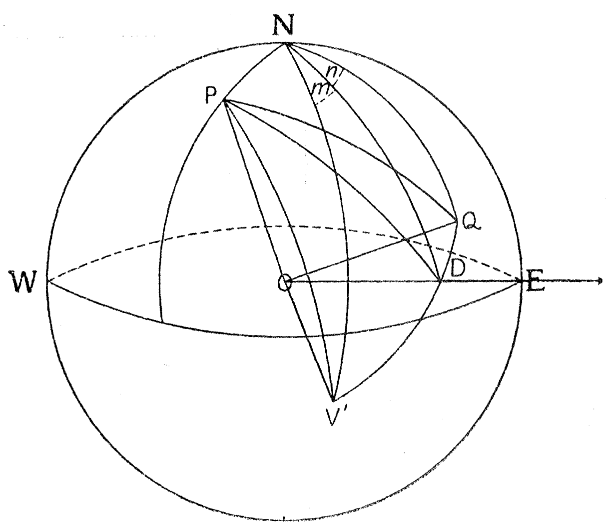

Fig. 7.

Let V′ be a point diametrically opposite Vega (V). Then, if $\theta =$ time after 6 A.M.,

$$\text{PNV} = (\text{RA Vega} - \text{RA Sun}) + (\tfrac{1}{2}\pi - \theta)$$
$$= 18h - \alpha + \tfrac{1}{2}\pi - \theta = 2\pi - \alpha - \theta,$$

$$\text{PNV}' = \text{PNV} - \pi = (\pi - \theta - \alpha) \quad \ldots \ldots \quad \text{(i.)},$$

$$\text{NV} = (\tfrac{1}{2}\pi - 38\tfrac{1}{2}°), \quad \text{NV}' = (\tfrac{1}{2}\pi + 38\tfrac{1}{2}°) \quad \ldots \ldots \quad \text{(ii.)},$$

OV′ is the direction of drift due to the sun's proper motion, which, as we have said,

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we shall take as 15 miles/sec., OQ is the direction of drift due to the sun's annual motion, which we take as 19 miles/sec.

We have, therefore,

$$\frac{\sin \text{V}'\text{D}}{\sin \text{DQ}} = \tfrac{19}{15}.$$

Let V′ND $= m$, DNQ $= n$; then

$$\frac{\sin \text{V}'\text{D}}{\sin \text{NV}'} = \frac{\sin m}{\sin \text{V}'\text{DN}} \quad \text{and} \quad \frac{\sin \text{DQ}}{\sin \text{NQ}} = \frac{\sin n}{\sin \text{NDQ}}.$$

Dividing the first by the second,

$$\tfrac{19}{15}\frac{\cos \eta}{\cos 38\frac{1}{2}} = \frac{\sin m}{\sin n},$$

or

$$\frac{\cos \eta}{\cdot 618} = \frac{\sin m}{\sin n} = \frac{\sin m}{\sin(m + n - m)}.$$

Now $m + n =$ V′NQ $= (\xi + \alpha - \frac{1}{2}\pi)$, therefore

$$\frac{\cos \eta}{\cdot 618} = \frac{\sin m}{\sin(\xi + \alpha - \frac{1}{2}\pi - m)} = -\frac{\sin m}{\sin(\xi + \alpha)\sin m + \cos(\xi + \alpha)\cos m},$$

or

$$\sin(\xi + \alpha) + \cos(\xi + \alpha)\cot m = -\frac{\cdot 618}{\cos \eta},$$

whence

$$\cot m = -\frac{\cdot 618}{\cos \eta \cos(\xi + \alpha)} - \tan(\xi + \alpha) \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(iii.)}.$$

From the triangle NDV′

$$\cos \text{ND} \cos m = -\tan 38\tfrac{1}{2} \sin \text{ND} - \cot \text{NDV}' \sin m.$$

From the triangle NDQ

$$\cos \text{ND} \cos n = \tan \eta \sin \text{ND} - \cot \text{NDQ} \sin n;$$

hence, since $\cot \text{NDV}' = -\cot \text{NDQ}$,

$$\begin{aligned}\cos \text{ND}&(\cos m \sin n + \cos n \sin m) \\ &= -\sin \text{ND}(\tan 38\tfrac{1}{2} \sin n - \tan \eta \sin m),\end{aligned}$$

or

$$\cot \text{ND} = \frac{\sin m\{\tan \eta - \tan 38\frac{1}{2}(\sin n/\sin m)\}}{-\cos(\xi + \alpha)}$$

$$= \frac{\sin m}{\cos(\xi + \alpha)\cos \eta}(\cdot 491 - \sin \eta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(iv.)}.$$

Now PND $=$ PNV′ $+ m = (m + \pi - \theta - \alpha)$.

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Whence, taking PD = 90°,

$$0 = \cos 38\tfrac{1}{2} \cos \text{ND} + \sin 38\tfrac{1}{2} \sin \text{ND} \cos (m + \pi - \theta - a),$$

so that

$$\cos (\theta + a - m) = \cot 38\tfrac{1}{2} \cot \text{ND} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(v.)}.$$

ND is determined by the time of year from equations (iii.) and (iv.), so equation (v.) gives us the value of θ, the hour when the resultant drift is perpendicular to the axis of suspension.

The azimuth of the drift NPD is given by

$$\sin \text{NPD} = \sin (\theta + a - m) \sin \text{ND},$$

which reduces to

$$\cos \text{NPD} = \cos \text{ND} \operatorname{cosec} 38\tfrac{1}{2}^\circ \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(vi.)}.$$

The Best Conditions when the Drift can never be entirely Horizontal in this Latitude.

We have when PD is any angle

$$\cos \text{PD} = \cos 38\tfrac{1}{2} \cos \text{ND} + \sin 38\tfrac{1}{2} \sin \text{ND} \cos (m + \pi - \theta - a).$$

When PD exceeds 90°, we must choose the time of day so that PD is a minimum. By differentiation we obtain the condition

$$\theta = m + \pi - a.$$

In a similar manner the azimuth of this component (viz., the one at right angles to OP) is given by

$$\sin \text{NPD} = \sin (\theta + a - m) \frac{\sin \text{ND}}{\sin \text{PD}} = 0,$$

so that

$$\text{NPD} = 180°.$$

If $\text{ND} = \frac{1}{2}\pi + 38\frac{1}{2} + \epsilon$; then the component utilised is, of course, given by resultant × cos ϵ. In the end table the component is given. It is also shown in fig. 9.

If we call the magnitude of the resultant drift R, then

$$\text{R}^2 = 15^2 + 19^2 + 2 \times 15 \times 19 \cos \text{V}'\text{Q},$$

so that

$$\text{R} = 34 \cos (\tfrac{1}{2}\text{V}'\text{Q}) \text{ approximately.}$$

Now

$$\cos \text{V}'\text{Q} = - \sin 38\tfrac{1}{2} \sin \eta + \cos 38\tfrac{1}{2} \cos \eta \cos \text{V}'\text{NQ},$$

$$\text{V}'\text{NQ} = \text{PNQ} - \text{PNV}' = \xi + \tfrac{1}{2}\pi - \theta - \pi + \theta + a = (\xi + a - \tfrac{1}{2}\pi),$$

$$\cos \text{V}'\text{Q} = - \sin 38\tfrac{1}{2} \sin \eta + \cos 38\tfrac{1}{2} \cos \eta \sin (\xi + a),$$

$$\cos \tfrac{1}{2}\text{V}'\text{Q} = \sqrt{\tfrac{1}{2}(1 + \cos \text{V}'\text{Q})} = \sqrt{\cdot 5 - \cdot 311 \sin \eta + \cdot 391 \cos \eta \sin (\xi + a)}.$$

Therefore

$$\text{R} = 34 \sqrt{\cdot 5 - \cdot 311 \sin \eta + \cdot 391 \cos \eta \sin (\xi + a)} \quad . \quad . \quad . \quad . \quad \text{(vii.)}.$$

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The time of day, when the drift is horizontal, is shown by the full line in fig. 8.

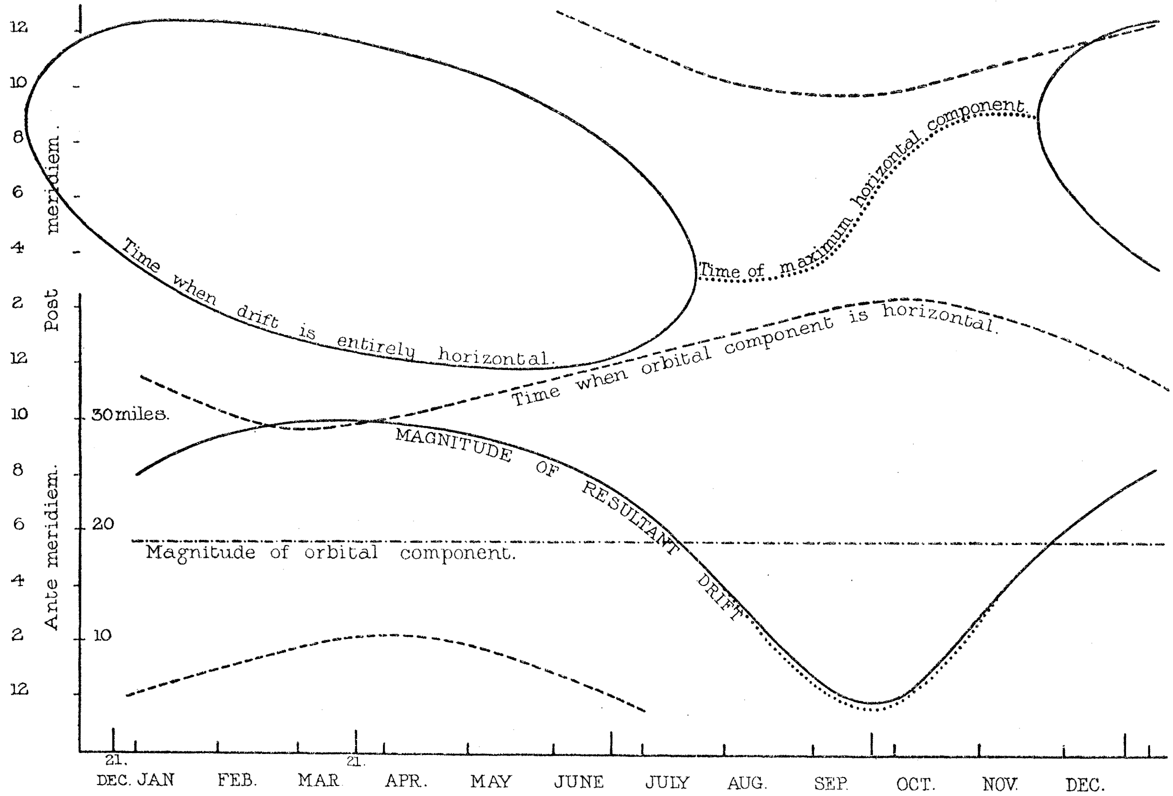

Fig. 8.

The azimuth of the drift is shown by the full line in fig. 9.

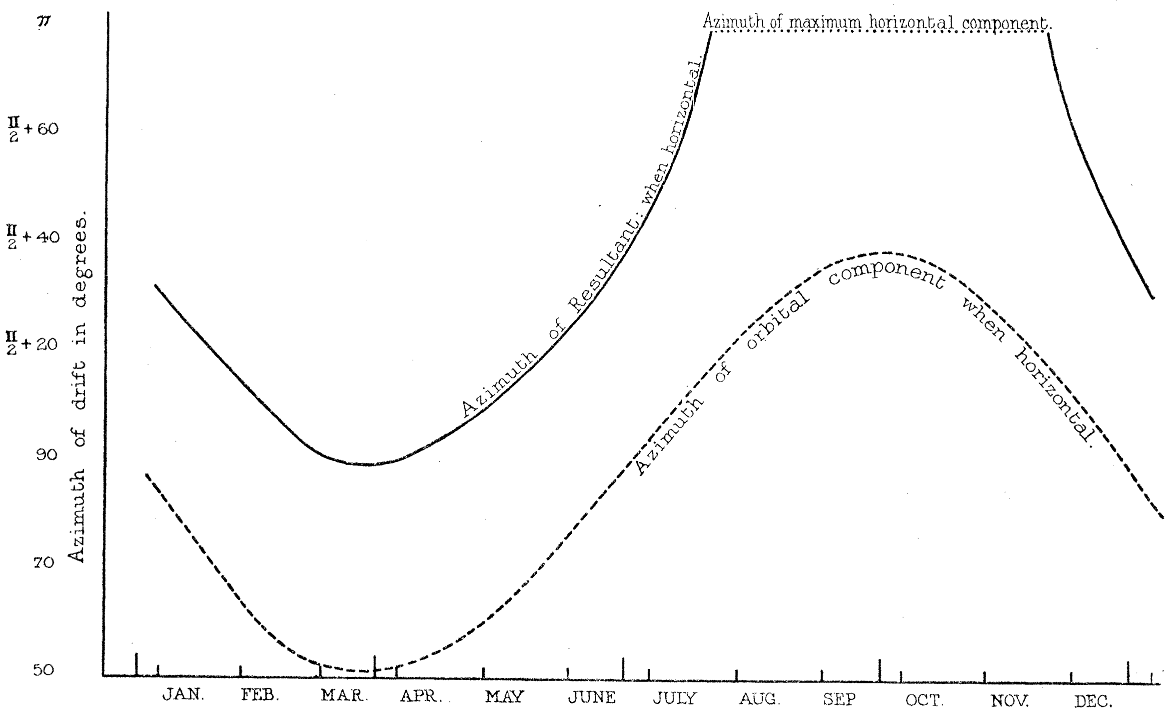

Fig. 9.

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The lower curve with full line in fig. 8 shows the corresponding magnitude of the resultant drift.

The following table shows the time of day when the drift is entirely horizontal, and the azimuth of the drift at that hour, for the first day of every month in the year :—

	Orbital motion alone.		Orbital motion and sun's proper motion.		Magnitude.
	Hour of horizontal drift.	Azimuth of drift.	Hour of horizontal drift.	Azimuth of drift.	miles per sec.
January 1st . .	11.32 A.M. 12.15 ,,	+84° −84	3.31 P.M. 12.21 A.M.	$+(\frac{1}{2}\pi+31^\circ)$ $-(\frac{1}{2}\pi+31)$	24·9
February ,, . .	10.20 ,, 1.0 ,,	+65 −65	1.45 P.M. 12.13 A.M.	$+(\frac{1}{2}\pi+14\frac{1}{2})$ $-(\frac{1}{2}\pi+14\frac{1}{2})$	27·9
March ,, . .	9.46 ,, 1.48 ,,	+53 −53	12.45 P.M. 12.1 A.M.	$+(\frac{1}{2}\pi+1)$ $-(\frac{1}{2}\pi+1)$	29·0
April ,, . .	10.2 ,, 2.12 ,,	+52 −52	12.9 P.M. 11.29 ,,	$+(\frac{1}{2}\pi+\frac{1}{2})$ $-(\frac{1}{2}\pi+\frac{1}{2})$	29·8
May ,, . .	10.44 ,, 1.54 ,,	+61 −61	11.50 A.M. 10.38 ,,	$+(\frac{1}{2}\pi+11\frac{1}{2})$ $-(\frac{1}{2}\pi+11\frac{1}{2})$	27·8
June ,, . .	11.41 ,, 12.45 ,,	+78 −78	11.47 ,, 9.7 ,,	$+(\frac{1}{2}\pi+24\frac{1}{2})$ $-(\frac{1}{2}\pi+24\frac{1}{2})$	26·2
July ,, . .	12.13 P.M. 11.46 ,,	$+(\frac{1}{2}\pi+5)$ $-(\frac{1}{2}\pi+5)$	12.15 P.M. 7.3 ,,	$+(\frac{1}{2}\pi+46)$ $+(\frac{1}{2}\pi+46)$	22·2
			Best time.	Horizontal component.	
August ,, . .	1.1 P.M. 10.16 ,,	$+(\frac{1}{2}\pi+23)$ $-(\frac{1}{2}\pi+23)$	3.2 P.M.	180°	15·3
September ,, . .	1.46 ,, 9.46 ,,	$+(\frac{1}{2}\pi+36)$ $-(\frac{1}{2}\pi+36)$	3.28 ,,	180	6·5
October ,, . .	2.15 ,, 9.54 ,,	$+(\frac{1}{2}\pi+39)$ $-(\frac{1}{2}\pi+39)$	7.6 ,,	180	4·6
November ,, . .	1.57 ,, 10.40 ,,	$+(\frac{1}{2}\pi+30)$ $-(\frac{1}{2}\pi+30)$	8.58 ,,	180	11·8
December ,, . .	12.58 ,, 11.30 ,,	$+(\frac{1}{2}\pi+14)$ $-(\frac{1}{2}\pi+14)$	6.25 P.M. 10.55 ,,	$(\frac{1}{2}\pi+63^\circ)$ $-(\frac{1}{2}\pi+63)$	19·2

From August to November the best time denotes the hour of the day when we obtain the maximum horizontal component. The total resultant can never be entirely horizontal during these months.

Measurement of the Capacity of the Condenser.

The capacity was measured absolutely on the apparatus designed by Dr. FLEMING and Mr. CLINTON ('Phil. Mag.,' vol. 29, 1903), and gave the value ·0037 m.f. This

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value was confirmed by comparison with another known capacity by DE SAUTY's method.

Measurement of the Controlling Couple.

A piece of brass rod, of length 3·35 centims., and diameter ·97 centim., and weight 20·6 grams, was attached by its centre to the suspending strip with its long axis horizontal. The time of oscillation of this was observed, and gave the value 2 mins. 17·8 secs. The value of the couple per unit twist deduced from the above data is equal to ·0426 C.G.S.

Calculation of $\mathrm{N}\left(\frac{u}{v}\right)^2$.

Capacity of condenser ·0037 m.f.

Couple per unit twist of wire ·0426 C.G.S.

Potential difference = 2000 volts = $\frac{20}{3}$ electrostatic units.

Electrostatic energy $= \frac{1}{2}\,\frac{\cdot 0037 \times v^2}{10^{15}}\,\left(\frac{20}{3}\right)^2$.

The distance of the sun from the earth is $1{\cdot}50 \times 10^{13}$ centims., so that

$$u = \frac{2\pi \times 1{\cdot}50 \times 10^{13}}{365 \times 24 \times 60 \times 60}\,\frac{\text{centim.}}{\text{sec.}} = 3 \times 10^{6}\,\frac{\text{centim.}}{\text{sec.}}.$$

Taking v (velocity of propagation) as 3×10^{10}, we have $(u/v)^2 = 10^{-8}$.

The couple due to the drift when the condenser is in its best position is $\mathrm{N} \,.\, 10^{-8}$.

Let d be scale deflection at distance of 1 metre; then angular deflection is $\frac{1}{2} \cdot \frac{d}{100}$.

Equating the balancing couples,

$$\cdot 043 \times \frac{d}{200} = 10^{-8}\,\tfrac{1}{2}\left(\frac{\cdot 0037 \times v^2}{10^{15}}\right)\left(\tfrac{20}{3}\right)^2,$$

so that d is 3·4 centims. That is to say, neglecting the proper motion of the sun, and under the best conditions, when charged to a potential of 2000 volts the deflection of the condenser should amount to 3·4 centims.

Observations.

In order to be sure that the condenser was not held in any position, it was set oscillating uncharged and readings were taken every quarter of a minute; giving the curve (fig. 10).

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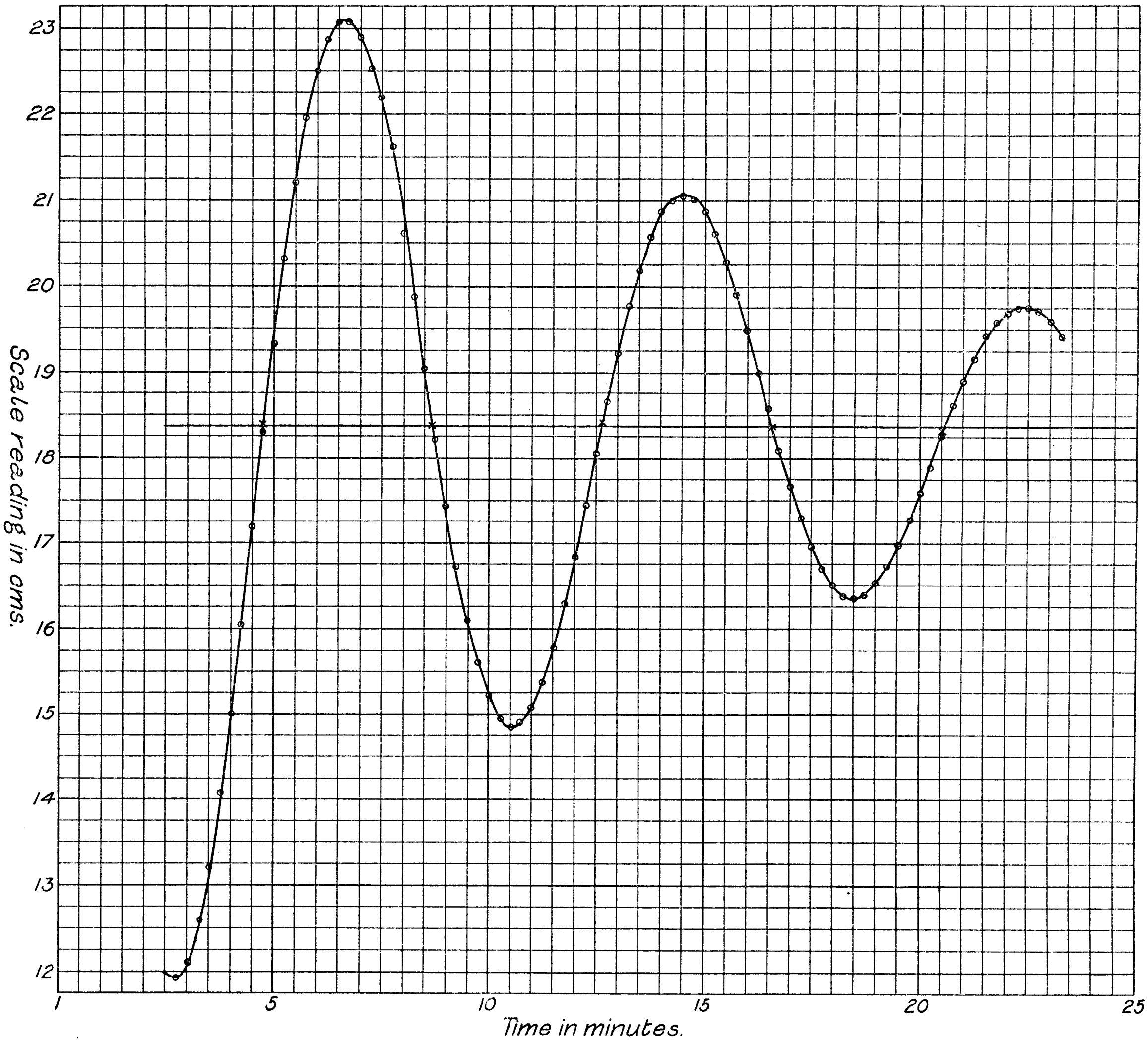

Fig. 10.

Analysis of the Curve.

Readings of extremes { Left . . 23·10 21·05 19·75
Right . 11·99 14·85 16·37

Amplitudes :—	Ratios :—	Amplitude $\times \frac{1\cdot35}{2\cdot35}$:—
11·11		6·38
8·25	1·35	4·74
6·20	1·33	3·56
4·68	1·33	2·69
3·38	1·38	1·94
Mean . . .	1·35	

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11·99 + 6·38 = 18·37 = zero of 1st vibration.
23·10 − 4·74 = 18·36 = „ 2nd „
14·85 + 3·56 = 18·41 = „ 3rd „
21·05 − 2·69 = 18·36 = „ 4th „
16·37 + 1·94 = 18·31 = „ 5th „

Mean . . 18·36, which is mean zero.

Any irregularity would have shown itself in a corresponding change of zero as calculated from the decrement and the amplitude of any particular swing. The variations in zero do not amount to more than ·05 centim.

Observation of the Effect.

The following observation is appended as being typical :—

March 10, 1903. Time 11.45 to 12.15 mid-day.

Before Charging.

Left.	Right.	Mean.	
62·22	62·35	62·29	Zero 62·29.

Charged to 2100 *volts at pt.* 62·30.

Left.	Right.		
61·69	62·09	61·89	
61·79	61·93	61·86	
61·76	61·84	61·80	
	Mean . . .	61·85	Deflected 61·85.

Discharged at pt. 61·84.

61·80	62·35	62·08	
61·98	62·22	62·10	
	Mean . . .	62·09	Final zero.

Initial zero	62·29
Final zero	62·09
Mean zero . . .	62·19
Reading of deflection .	61·85
Deflection . . .	− ·34 centim.

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The following table gives the final results obtained. These were observations taken after many months of experience with the apparatus, and were considered by us as conclusive against there being any such effect as we were seeking.

AZIMUTH of Condenser + 45°.

Date.	Time.	Potential in volts.	Deflection calculated (annual motion).	Deflection calculated (annual + proper).	Deflection observed.
			centims.	centims.	centims.
March 9 . . .	12.15 P.M.	2100	−2·6	−6·8	−0·35
9 . . .	6 P.M.	2100	+0·8	0·0	−0·12
,, 10 . . .	12 (day)	2100	−2·6	−6·8	−0·34
,, 10 . . .	3 P.M.	2100	−1·2	−3·4	−0·23
,, 10 . . .	6 P.M.	2100	+0·8	0·0	−0·26
,, 12 . . .	12 (day)	2100	−2·6	−6·8	−0·36
,, 12 . . .	3 P.M.	2100	−1·2	−3·4	−0·25
,, 12 . . .	6 P.M.	2100	+0·8	0·0	−0·32
,, 13 . . .	5.30 P.M.	2100	+0·8	0·0	−0·34
,, 13 . . .	6.30 P.M.	2100	+0·8	0·0	−0·18
,, 18 . . .	3 P.M.	2000	−1·2	−3·4	−0·02

The largest observed deflection, ·36 centim., barely exceeds 5 per cent. of the calculated deflection, 6·8 centims.

The following observations, taken between March 13 and March 18, illustrate the behaviour of the apparatus as regards electrostatic effects. These justify the conclusion that the effect observed was the result of residual electrostatic action,* and could in no way be attributed to the relative motion of the earth and the æther.

The sign of the charges was reversed at times.

The insulation was good.

Date.	Potential.	Sign of suspension.	Deflection.
March 13	1100	negative	+0·05
	1100	positive	−0·01
,, 18	1100	,,	slight +
	1100	negative	+0·01
	1500	,,	+0·04
	1500	positive	+0·16
	1500	,,	+0·13
	1500	negative	+0·24
	1500	,,	+0·14
	1500	positive	−0·09

* It might be thought, at first sight, that the magnetic field produced by the moving condenser might interact with the earth's magnetic field; that no such action exists has been shown by FITZGERALD ('Scientific Papers,' p. 111). We are therefore justified in concluding that the residual action did not arise from disturbances due to the earth's magnetic field.

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All the above observations were taken during the middle of the day and the afternoon.

There seems to be no change of deflection with change of sign, and by comparison with previous results there seems to be no bias one way or the other.

From experience gained with the apparatus, the deflections observed would appear to be attributable to small sparks or discharges taking place inside or over the condenser, causing slight heating and consequent perturbation of the surrounding air. This is further suggested by the fact that when the condenser employed had become damaged by falls and other vicissitudes, so that audible sparkings occurred, the perturbations became so great as to prevent all possibility of observation.

There is no doubt that the result is a purely negative one. As the energy of the magnetic field, if it exists (and from our present point of view we must suppose it does), must come from somewhere, we are driven to the conclusion that the electrostatic energy of a charged condenser must diminish by the amount N $(u/v)^2$, when moving with a velocity u at right angles to its electrostatic lines of force, where N is the electrostatic energy.

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