THE POLARIZATION OF SOUND.

AN EXAMINATION INTO THE NATURE OF VIBRATIONS IN EXTENDED MEDIA.*

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The phenomena of polarization of light have heretofore presupposed transversal vibrations of particles of the luminiferous ether. Such vibrations have not only been supposed transversal when polarized, but primarily, or when in their primitive condition. It is proposed now to show that no necessity exists for considering the vibrations in light as transversal in front of a polarizer; and furthermore to show that in all probability luminous vibrations are primarily longitudinal.

It is well known that light can be radiated, reflected, refracted, diffracted, diffused, can be made to interfere and can be polarized. All these effects are known to be common to sound, except the last, and it is for the sole purpose of explaining this in light that the convenient theory of transversal vibration has been set up by physicists, for the single case of luminous vibration. It is to be noticed that transversal vibrations are not to be assumed impossible when sufficient cause exists. It is simply assumed that the cause is insufficient when a material particle is made to vibrate from the action of a disturbance at a remote single centre transmitted to the particle considered; the centre, the transmission, and the particle considered, being supposed as belonging to a homogeneous medium of indefinite extent. As regards the nature of the vibratory movements of particles of luminiferous ether may we not justly ask that, if we can go through such a range of density as from platinum to hydrogen without a change in the nature of the vibrations where, as we rise in the scale of etheral tenuity, shall longitudinal end and transversal begin? Why should the luminiferous ether, now considered as a substance, have a peculiar form of vibration? If ether undulations can be polarized, why not undulations generally? These questions are not answered by the highest authorities. The short of it all seems to be that if polarized light had never been discovered probably the device of transversal vibrations never would have been set up. Indeed, the eminent author M. J. Jamin, says in his three volume work on Physics at the outset, in his lesson on polarization, and subsequent to the treatment of interference, diffraction and other phenomena: "What has been said previously of the movement of luminous waves is absolutely independent of the directions of the vibration." This is good authority for limiting the *transversal* theory to polarization, authority with which doubtless all physicists will agree on this point. It is, therefore, only necessary to polarize sound to place all the known effects of luminous waves in common with sound waves, or to make the theory of longitudinal vibrations universal.

Assent to the above notions will be the more readily given after noticing the consideration that, in polarized light it is not necessary to suppose the vibrations transversal till after passing the polarizer, and that the latter probably imparts an effect equivalent to a lateral impulse, as due to its one-sided action upon the ray transmitted, thus giving cause for vibration which are more or less transversal; the same being true for undulations in air, water, iron, platinum, hydrogen, luminiferous ether, etc., without exception.

But independent of all questions of polarization we find powerful evidence of the unity of system, for vibrations in all possible media; evidence which, in one case at least, is employed as the basis of a rigorous mathematical demonstration of the impossibility of existence of perpetual motion. This latter named evidence is the famous principle of Helmholtz regarding the action of natural forces among mutually interacting material points, viz.: that the forces must be central forces and functions of the distance, and hence motions of remote particles can only be longitudinal with reference to the centre of force. This principle, considered aside from luminiferous ether, will be universally accepted as truth. But what is the criterion for making an exception of any homogenous substantial medium; even luminiferous ether? Indeed, if any criterion exists for such an exception, it consists simply in a desired convenient means for explaining polarization: a theory of transverse vibrations, which, though convenient and probable beyond the polarizer, has thoughtlessly and without need, been extended to the front of the polarizer, and to undulations in the primitive conditions, where, as shown above, no necessity exists for transversal vibrations. That the necessity for transversal vibrations in primitive rays of light is entirely wanting, let it be granted for the sake of an argument that the source of light, such as the sun or a gas burner, is capable of exciting vibrations in the adjacent medium, which are in all possible directions immediately at the radiant. At a considerable distance from the radiant, the effect upon a single particle will be the resultant of action of all the particles immediately surrounding the radiant, and transmitted by and through the intervening medium; such a resultant impulse can hardly be admitted to be otherwise than longitudinal. Or again, a particle near the radiant imparts an impulse to the adjacent particle. If the passive particle is in direct line with the active one, the impulse received will be in direct line also, and the direction of motion of the two particles coincides. The similar direct action of a second particle upon a third will also be in the same line, and so on indefinitely. At a distance of several hundred or thousand times the diameter of the radiant the line of vibration indicated will be almost perfectly longitudinal irrespective of where the first particle considered is situated about the radiant. That is to say, a particle at the surface of a radiant vibrating in a line of direction tangential to it or transversal, may be considered as transmitting its vibration from particle to particle in a direct line, and hence to the best advantage; and still, at a distance this direct line becomes nearly a line of longitudinal vibration for a remote particle.

Thus all lines of direction of vibration will pass through the radiant or be tangent to it, so that in sunlight the rays, and the directions of vibration, will all lie within the visual angle of the sun, or within about half a degree of arc, and hence almost perfectly longitudinal.

These considerations all confirm the principle of Helmholtz. And that remarkable principle, together with all considerations presented above, and all which can possibly result from a careful study of the subject of transmitted impulses, go to confirm a universal law of longitudinal vibrations for primitive rays in all possible substantial media, and to antagonize the notion of transversal vibration.

Hence, if light can be polarized, why not undulations generally. The writer, after much study of the subject, became convinced of the possibility of this about eight years ago, and six years ago apparatus was made for putting the matter to an experimental test. Want of time prevented, and further study determined a modification of the apparatus which was made over two years ago. This apparatus was successful in verifying all my preconceived notions in the matter, but owing to extended study and matured views of the principles involved, the experiments simply confirmed, without developing new theories or unanticipated facts. I propose now to describe the apparatus and give the results.

The means adopted for polarizing the undulations is the same as that for polarizing light by reflection. It is well known that when sound passes from one medium into another whose velocity of sound differs, the sound is refracted. Recent investigations of Henry, Tyndall and others have indicated that when sound encounters a change of density of medium, as when passing from clear atmosphere into a wall of fog, there is a reflection of sound. Altogether there seems no doubt but sound acts like light in these respects, that is, on meeting a change of refractive power, it is both reflected and refracted, as light is at the surface of water or of glass. The reflected light is found to be always more or less polarized, perfectly so for the so-called polarizing angle. This polarizing angle of incidence is such that, as discovered by Brewster for light, the reflected and refracted components of a single ray, as they strike away from the point of incidence are at right angles. As reflected light is polarized, reflected sound was supposed to be also.

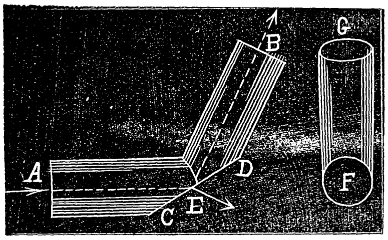

FIG. 1.

Applying the laws of Fresnel and Brewster—1st, that the index of refraction is equal to the ratio of the velocities of the waves in the media; and 2d, that complete polarization is obtained for the particular case of right angled reflected and refracted component rays, we are guided to the proper conditions. We conclude that any two substances having different velocities of propagation of waves may be selected For instance, two gases, like hydrogen and air, any two liquids, any two solids, a solid and a gas, or, generally, any two media whatever. Considerations of convenience would indicate air and illuminating gas, and these were chosen for the present purpose. The velocities of propagation in air and coal gas being as 1125 and 1420, the index of refraction, according to the first law above, is $n = 1{\cdot}26$. The second law gives for the polarizing angle of incidence, tangent $i = n = 1{\cdot}26$, or $i = 51\frac{3}{4}°$, the rays or waves being in the gas. To realize this incidence upon a surface of separation between the gas and air, the cool gas was placed in L-shaped tubes, *AB*, Fig. 1, having a portion cut away at the angle, as shown at *CD*. The branches of the L make equal angles of $51\frac{3}{4}°$ with the normal to *CD*. A delicate membrane was gummed to the tube covering the opening at *CD*, also shown at *F*, the object of which was to retain the gas and maintain a polarizing surface, *CD*. The arrow at *A* indicates a ray which is incident at *E*, and is then in part refracted outward at *E* in a direction perpendicular to the reflected component *EB*. Each tube was about one inch in diameter and three inches long. A number of these were made of tin, each with one end slightly larger than the other, so that they could be joined up, stove-pipe fashion, to any desired extent. Being cylindrical, the plane of one L-piece could be placed at any angle with the plane of the preceding one, according to the desired polarizing test.

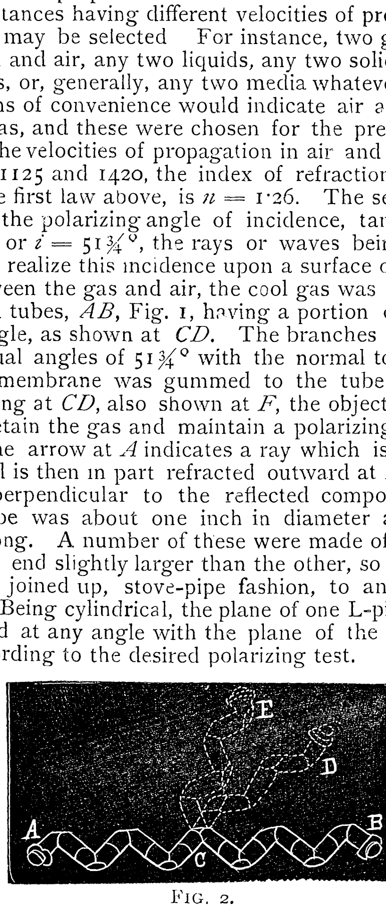

FIG. 2.

Fig. 2 shows the manner of joining the tubes, giving the effect of nine polarizing surfaces, like nine plates of glass in light arranged at the polarizing angle. The nine plates of glass can be used in two parts—one part, 4 for instance, serving as a polarizer and the remaining 5 as analyzer. The ends at *A* and *B* were capped with membranes and the whole filled with illuminating gas. Thus *AC* may serve as a polarizer and *CB*, or *CE*, or *CD* as analyzer. When arranged as in *ACB* or *ACE* all conspire to the same effect of polarization; but when arranged as in *ACD*, the plane of all the L-pieces in *CD* being at right angles to that of those in *AC*, the effect of one part antagonizes that due to the other, and to a maximum degree as regards the angle. Partial effects may be obtained with intermediate angles between 0° and 90°. Again, we observe that the L-pieces of Fig. 2 may be alternately crossed, so that no two contiguous ones will be parallel. It is believed that this arrangement will give the greatest possible antagonistic effect; also while all Ls are in one plane it is not necessary that they be arranged in a zig-zag line, like *AC* and *CE*, but may be indiscriminately connected in that plane. The few experiments made with the above-named arrangements gave very marked results. Of course it need not be confined to nine or any particular number of the L-pieces.

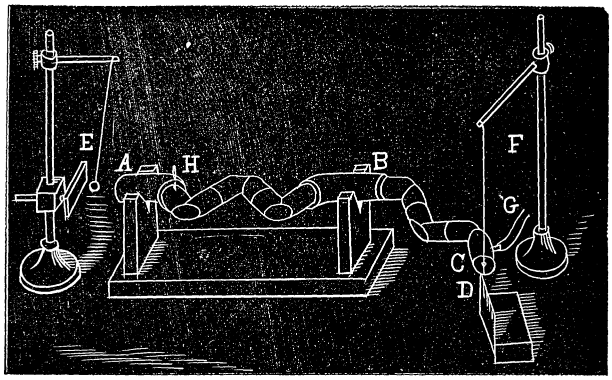

FIG. 3.

It was found, however, wanting in convenience. The apparatus finally adopted is that shown in Fig. 3. A different number of L-pieces were used at different times. The portion *AB* is the polarizer and *BC* the analyzer. The joint at B was kept tight with beeswax; the ends at *A* and *C* were capped square with the same membrane material as were the angles of the Ls, giving, when charged with illuminating gas, a continuous zig-zag column from *A* to *C*. The L-pieces of the polarizer enter half Ls at *A* and *B*, the latter having a common axis and resting in bearings at *A* and *B* in the standards, as shown. The object of this is to enable the experimenter to turn the polarizer readily from cross to parallel, etc. This convenient arrangement of the polarizer is due to my assistant, Mr. Wright. Although applied to the polarizer, it is evidently equally applicable to the analyzer instead. The half L angles were not covered with membranes, but left solid, with gradual inside curvature. Membranes might have been applied here with partial polarizing effect. The half L solid angles are supposed to have detracted in a measure from the percentages of polarization obtained; but this sacrifice is more than compensated for by the greater convenience and constancy of conditions obtained. If this arrangement gives decisive results, of course, more perfect apparatus would. The illuminating gas was admitted by a nipple and rubber hose at *C*, the same flowing the length of tubes and issuing in a small jet at *H*; my assistant kept this ignited, and used the flame length as a pressure indicator, and it served admirably.

The first trials were made by blowing an organ pipe in front of the membrane *A*, to agitate the gas column, A small mirror was attached to the membrane *C*, reflecting a pencil of light upon a screen. The deportment of the image indicated complex and inadmissible vibratory movements of gas column, and besides quantitative indication was found preferable to qualitative; thereupon the quantitative impulse and indicator pendulums were adopted, as shown at *E* and *F* respectively, Fig. 3. An ivory ball, ¼ inch in diameter, suspended by a thread of 8 inches length, was used at *E*, and so placed that when at rest the ball would just touch the membrane at *A*. The impulse was imparted by bringing the ball back against the stop, shown by means of a spatula held in the hand, and then allowing it to swing free against the membrane, each time with a definite, predetermined arc. So much of the impulse as reaches *C* knocks the pendulum *F* through a certain arc, the same being measured on the scale *D*. This pendulum was a small, hollow glass bead, suspended by a silk fibre and trained delicately against the membrane. The bob carried a pointer for the scale *D*.

In the experiments the ball would be dropped against *A* some five or ten times, at intervals of about ten seconds, the corresponding deflections at *D* being noted and recorded; then the polarizer would be turned 90° and like observations noted. Again, 90° would be turned off, etc., etc.; occasionally the length of impulse arc would be changed, or more or less L-pieces applied, and in each case a large number of observations made.

In the experiments the initial pulse seemed to be followed by a series of vibrations in rapidly decreasing amplitudes; but it is believed that the initial pulse is equivalent to a genuine sound wave, or an undulation. Evidence of soundness of this view is found in the fact that the velocity of sound can be satisfactorily determined by similar pulses sent through tubes of 25 or 50 feet length. It was evident that the initial pulse only, was concerned in the first swing of pointer at *D*.

Observations were made with as few as one L in the polarizer, and two in the analyzer. But the results were small, averaging about 4 per cent. But during the noting of 455 individual results of observation the number of Ls in the polarizer ranged from 1 to 3 and in the analyzer 2 to 3. The average of all of these 455 observations gave a percentage of 8.87 hundredths of quenching of the polarized beam. That is to say, where the analyzer, in light, entirely quenches the polarized beam in turning through 90°, in the above 455 experiments only 8.87 hundreths of the polarized ray was quenched.

But as a higher percentage was looked for, the instrument itself was now examined for possible faults. The membranes were all found under considerable tension. whereas, of course, they should be perfectly free from it. After completely slackening, then, as was supposed, the experiments were continued with the following results:

POLARIZATION CONTINUED.

Coal Gas in L-tubes and Air outside.

Individual results.

Polarizer having 4 Ls and Analyzer 5 Ls.

	=	+	=	+	=	+	=	+	=
	6.0	6.0	8.0	5.0	6.5	5.8	6.2	6.0	6.0
	6.0	6.0	7.5	5.5	6.5	5 5	6.0	5.2	6.2
	6.2	6.0	7.0	5.3	6.3	5.6	6.5	5.2	7.2
	6.1	5.8	7.5	5.2	6.5	5.2	6.4	5.1	6.2
	6.0	5.7	7.0	5.0	6.2	5.7	6.3	5.5	6.1
	6.1	5.5	7.2	5.2	6.6	6.0	6.3	5.1	6.1
	6.2	5.8	6.5	5.0	6.8	5.2	6.2	5.2	6.1
	6.0		7.0	4.9	6.2	5.2	6.5	5.4	6.5
			7.0	4.0	6.3	5.3	6.3	5.8	6.8
							6.3	5.2	6.4
Means	6.07	5 83	7.19	5.01	6.43	5.50	6.30	5.37	6.34

In this series each value given in any column is the number of divisions on the scale *D*, Fig. 3, of the deflection of the indicator pendulum bob. After obtaining one column of results the polarizer, *AB*, was turned 90°, and the next column obtained. Thus the several columns were obtained. The = and + signify that the polarizer and analyzer are in parallel or perpendicular planes respectively.

On completing this series of observations air was passed into the L tubes, completely displacing the coal gas, so that the membranes were now suspended in mid air. Other conditions remained the same. The indicator pendulum now responded to the same impulses so slightly as to be barely observable, but not measurable, and they were apparently the same for the polarizer in all positions; that is to say, when air was upon both sides of the reflecting surfaces there was almost no appreciable reflection. This evidently should be the case, as the light membrane itself is now the chief cause of reflection. This, compared with the results obtained with gas in the tubes, shows that a considerable reflection is due to surfaces of separation of gases differing in density.

As regards the polarization, we observe that every mean under "=" is larger than any mean under "+," a fact which cannot be assumed accidental, nor explained on any other ground than polarization. To find the percentage of this in a single result, we have

Means of the above series.

	=	+
	6.07	5.83
	7.19	5.01
	6.43	5.50
	6.30	5.37
	6.34	
Means,	6.47	5.43

$$\text{Per cent.} = \frac{6.47 - 5.43}{6.47} = 16.1.$$

Whole number of observations, 80.

At this point the membranes were again examined and found to have appreciable tension, though supposed to have been entirely slackened at the beginning of the series of observations just cited. It seemed that the dampness in the gum used, expanded the membranes so that they became tight after thoroughly drying as the experiments went on. It was thereupon determined to slacken them with the utmost possible care, and continue the observations The following table of individual results was then obtained in the manner explained above, the membranes being constantly watched for entire slackness.

POLARIZATION CONTINUED.

Coal Gas in tubes and Air outside of tubes.

Polarizer having 4 Ls and Analyzer 5 Ls.

Individual results.

	=	+	=	+	=	+	=	+	=	+	=	+	=	+
	1.2	0 9	2.0	1.0	1.5	1.0	1.6	1.0	1.8	1.4	1.5	0.9	2.0	1.0
	1.5	1.0	2.1	1.2	1.5	1.0	1.4	1.1	1.5	1 2	1.5	1.0	2.1	1.2
	1.5	1.0	1.8	1.1	1.8	1.0	1.8	1.1	1.5	1.4	1.5	1.0	1.8	1.1
	1.5	1.0	2.0	1.0	1.3	1.0	1.9	1.2	1.7	1.2	1.5	1.0	2.0	1.0
	1.5	1.1	2.0	1.0	1.3	1.0	1.9	1.0	1.7	1.1	1.5	1.1	2.0	1.0
		1.0	2.0	0.9	1.2	1.0	1.8	1.0	1.7	1.2	1.5	1.0	2.0	0.9
			2.1	0.9	1.3	1.0	1.6	1.0	1.8	1.0			2.1	0.9
					1.5	1.0		1.1	1.7	1.0				
								1.1	1.7					
								1.1	1.6					
Means	1.44	1.00	2.00	1.01	1.45	1.00	1.71	1.07	1.67	1.19	1.50	1.00	2.00	1.01

Polarizer turned 90° immediately following each column of results.

For gas displaced by air, other conditions the same; deflection, 0.00.

The smallness of these results, compared with those of the previous series, may be explained on the ground of extreme and entire slackness of the membranes; also the slackness is still further evinced by the fact that, when air displaced the gas no deflection of the indicator pendulum was observable in response to the impulses. Tense membranes would have turned the sound waves somewhat, and in the manner of the rebound of a drumstick from its drumhead.

To obtain the percentage of polarization effect, we have:

Mean of the above series.

=	+
1.44	1.00
2.00	1.01
1.45	1.00
1.71	1.07
1.67	1.19
1.50	1.00
2.00	1.01
Means, 1.68	1.04

$$\text{Per cent. } \frac{1.68 - 1.04}{1.68} = 38.1.$$

Thus with the apparatus working most perfectly, the analyzer succeeded in extinguishing or quenching 38 per cent. of the polarized wave, a percentage too great to be mistaken. Considering the analyzer and polarizer as equally efficient, the real percentage of polarization by polarizer would be 62 per cent., and of the analyzer 62 per cent., as is evident from the fact that 62 per cent. of 62 per cent, is 38 per cent. Thus, either part of the apparatus obliterates over half of the wave attempting transmission, a fraction which would be unmistakably visible in polarized light.

These results establish the following facts for sound waves or for undulations, viz.:

1st. A decided reflection occurs at a surface separating two gases of different density, confirming the views of Henry and Tyndall in this regard.

2d. In repeated reflection from such surfaces the intensity of the final component varies with the relative positions of those surfaces, the same following the laws of polarization in light, from which we conclude that longitudinal undulations can be polarized.

With sound polarized, we complete the list of effects for longitudinal undulations which are known to light, viz.: radiation, shadows, reflection, refraction, diffusion, diffraction, interference and polarization; for the laws are common for like conditions, viz.: for intensity of radiation in ambient space, $\frac{I}{d^2}$; in parallel space, $\frac{I}{d^1}$; in prismatic space, like a tube, $\frac{I}{d^\circ}$; for shadows, reflection, refraction and interference as well known; for diffusion, as when a steam whistle is sounded, filling the air with its resounding ring; for diffraction, as sound waves diverging rapidly after passing a narrow space between buildings, like light in passing a narrow slit and diverging; and, finally, for polarization, as above. In studying these comparisons we should recollect the vast difference between the properties of undulations in heavy, and ethereal media. Thus the wave length is very great and the velocity of propagation very small in sound as compared with light. This seems sufficient to account for the greater definition of shadows in light; but when a slit or an obstacle is made as narrow for light as for sound, in comparison to wave length, the diffraction divergence is probably about alike; that is, the divergence at a linear slit in light, or between two buildings in sound; or again the shadow of a silk fibre in light and a sound shadow of Bunker Hill monument, for instance, are about alike considering wave length. With these considerations it may be reasonable to expect incomplete or only partial polarization with such apparatus as employed above.

The conclusions to which we are conducted by the foregoing may be summed up as follows:

1st. That vibrations in extended media, produced from the action of a remote single centre of disturbance, can only be longitudinal, even in light.

2d. That vibrations will be to some extent transversal when due to two or more centres of disturbance not in the same line, as when two or more independent co-existent systems of undulations combine into one, or when a simple system is modified by such lateral disturbance as a reflection or a refraction.

3d. That undulations, to be in a condition called polarized, probably consist of vibrations which are transversal, and that no necessity exists for assuming vibrations transversal in front of a polarizer.

NOTE.—As regards longitudinal, oblique, transversal, etc., in the foregoing, the estimate is to be taken by comparing the direction of the line of vibration of a particle with that of propagation of the wave.

My acknowledgements are due to Mr. Clarence H. Wright, who, while a student in my physical laboratory last Spring, rendered valuable aid in the experimental work.

ASTRONOMY.

COMET (*a*) 1881—SWIFT.

The question of the best method of transmitting telegraphic announcements of astronomical discoveries has just been discussed by the leading European societies, and a system has been devised by which this information may be comprised in a message of sixteen words. Thinking that perhaps a better way existed of doing the same work, the Boston Scientific Society has adapted a telegraphic code to the needs of the occasion, and this system has just received a practical test. The announcements lie within the province of the Smithsonian Institution, and it was accordingly decided to transmit by cable the elements and ephemeris. These here given were computed at Dun Echt Observatory, in Scotland, by Drs. Copeland and Lohse, and have been distributed in this country to astronomers by special circulars of the Boston Scientific Society. That set which was computed at Boston, for the Society, by Mr. S. C. Chandler, Jr., has already been cabled to Europe, and distributed by mail, from the Observatory of Lord Crawford, to astronomers in England and the Continent.

The cablegram received at Boston consisted of sixteen words, and the translation is here appended. According to the same code, the announcement of discovery could be comprised in a message of seven words, which would itself contain check words against possible error in transmission.

The elements and ephemeris computed at Dun Echt, on Monday, May 9, were transmitted by cable to Boston in the following message: "Decimosexto erective contextual bewitchery anticly demonstrative courageously sputter arithmancy stomachical auriferous suety bayou synecdochically bissextile eminently." The translation of this message is as follows, viz:

ELEMENTS OF SWIFT'S COMET, 1881 (*a*).

Per. Passage, 1881, May 20.67, Greenwich Mean Time.

	°	′	
Long. Perihelion,	300	2	Eq. 1881.0.
Long. Node,	124	54	
$\omega = \pi - \Omega$,	175	8	
Inclination,	78	48	
Log. $q = 9.7674$.	$q = 5854$.		
Motion direct.			

EPHEMERIS.

Greenwich, midnight.	A.R. *h.*	*m.*	*s.*	DECL. °	′	Brightness.
May 10,	0	38	32	+26	46	1.69
14,		56	48	21	35	
18,	1	17	32	15	54	
22,		40	48	9	55	2.32

Computed by Dr. R. Copeland and J. G. Lohse, from observations made at Dun Echt Observatory. The light at discovery is taken as unity.

By means of control-words in the message, it is absolutely known that the elements are those computed yesterday in Scotland, and it is proposed to cable in the same way the first elements and ephemerides of future comets, obtainable at either terminus, until the code has been most thoroughly tested.

J. RITCHIE, JR.