XI. *Experimental Demonstration of the Constancy of Velocity of the Light emitted by a Moving Source. By* Q. MAJORANA, *Professor of Physics at the Polytechnic School of Turin* *.

IN a preceding paper† on the second postulate of the theory of relativity I described an experimental arrangement of mine by means of which I was able to demonstrate that light propagates itself with constant velocity, independently of the conditions of movement or rest of the mirror by which the light is reflected. At the end of the above-mentioned paper I hinted at my intention of studying experimentally the eventual influence of the movement of the source on the velocity of the propagation of the light; the object of the present note is to communicate the result of these researches.

As is known, the only studies made with luminous sources in motion are astronomical ones, and those with the canal rays. Particularly with the former it has been possible to deduce the measure of the Doppler effect (and therefore the value of the velocity of displacement) for different sources, such as the fixed stars or planets and the limb of the sun. I am not aware of any attempt to prove the Doppler effect with the artificial movement of a common luminous source; the difficulty of this research consists principally in the necessity for giving a specially high rate of velocity of displacement to the source.

But even if an arrangement of this kind could be realized, its interest does not lie in the verification of the Doppler effect (change of frequency), upon which no doubt any longer exists, so much as in the control of the value of the velocity of the propagation of the light, also in the case of a moving source. This is the reason why the examination of the latter must not be made either with prisms, as in the arrangement of Belopolski, or with diffraction-gratings, as I have before explained. In making my preparations to set up an apparatus with moving source, I resolved, from the first, to examine the latter with the interference method already described by me, which is founded on the use of the

* Communicated by the Author.

† Phil. Mag. Feb. 1918, p. 163; on the same argument see also the papers of Michelson, Astrophysical Journal, xlii. p. 19 (1913), and of Fabry and Buisson, *C. R.* clviii. p. 1438 (1914). These works, of which I heard only lately, arrive in different ways at the same conclusions.

Michelson interferometer, with a great difference in path. Admitting the second postulate of the theory of relativity, or if, in any way, the velocity of propagation of light by earthly sources seems to us unchangeable, supposing such an apparatus were realized, a certain number f of fringes would be seen to cross the wire of the eyepiece, when the source passes from rest to velocity v,

$$f=\frac{lv}{\lambda c},$$

where l is the difference of path of the interfering rays, λ the length of the wave, and c the velocity of light. This is analogous to my affirmation previously made with regard to moving mirrors. Now, the values which it is hoped may be attained in a laboratory for v are rather modest, even with regard to those of astronomical luminous sources; it is therefore necessary to give to l the highest possible value, which is only to be obtained by using a source of light with a very long visibility curve.

This can only be the green line of mercury, which, however, being more complex in its structure than the lines of cadmium, allows the observation of the fringes up to the value of $l=32$ cm.*, using excitation of vapours by means of a voltaic arc in vacuum. Besides, this source is particularly suited for the present researches because of its exceptional intensity. I believe, therefore, that they would hardly be repeated, using a different source.

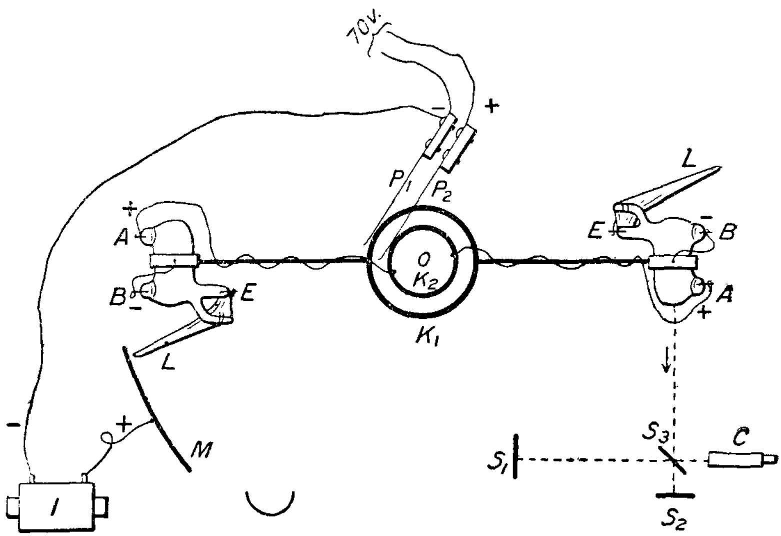
I established a new plan of experiments, intending to endow with swift rotatory movement some mercurial arcs held by airless glass tubes, and to examine by means of the Michelson interferometer the light emitted by them tangentially to the trajectory line. Now in the attaining of a peripheral velocity of nearly 100 m. per second, this being the necessary velocity for a sure appreciation of a displacement in the fringes, two principal mechanical difficulties are found: the enormous centrifugal force, and the very great resistance of air. To diminish the first, it is convenient to enlarge as much as possible the diameter of the trajectory and lessen the number

* It must be noted that Michelson observed fringes up to $l=40$ cm. But that scientist used Geissler tubes with mercury vapour; it seems that the excitation with the voltaic arc in vacuum, used by me, changes the visibility curve.

per second of the revolutions. It is known that the centrifugal velocity increases as the square of that number, and the velocity of displacement grows as the first power. After different attempts I fixed the diameter at 2 m.: because since the small tubes with the mercury weigh 35 gr., the centrifugal force that excites them at a velocity of only 14 revolutions per second (corresponding to nearly 90 m. of peripheral velocity) amounts to 30 kg.

That is nearly the highest point of capacity of charge to which the glass material can be brought. In my experiments the glass tubes still broke very often, although allowing a sufficient interval of time for the observation and measures.

In respect to the resistance of air, it has been reduced to the minimum by using fine steel wires of high mechanical resistance as connexions between the tubes and the rotating axle. Notwithstanding the aforesaid conditions of velocity, the apparatus being provided with only two tubes in diametral position, a power of about 5 kw. was necessary. I give now a short description of it. The figure illustrates schematically



the details, not presenting them on a uniform scale. O is the rotating axle connected with a pulley and strap to a motor with velocity of rotation capable of regulation and inversion, and of the maximum power 10 H.P. Two airless tubes of a particular form (maximum diameter 4 cm.) bear each three electrodes A, B, E, and are joined by means of strong steel wires with the axle O. The latter is encircled by two collector-rings K_1, K_2 communicating with the electrodes A, B. Two brushes P_1, P_2 bring a continuous current at 70 v. A certain quantity of mercury is contained in each tube (28 gr.) and is distributed on A and B when the apparatus is rotating. The electrodes E are provided with light segments of aluminium L, which, when the tubes revolve, pass near a metallic arc M, which has the centrum O. An induction-coil I with its terminals connected as in the figure, placed in action for few seconds, gives discharges, which excite the tubes passing near M. In these the current can be regulated, by interposing the necessary resistance, to between 2 or 3 amperes. I must observe that it is often useless to employ the coil I after having started the rotation. Although in fact the quantity of mercury contained in each tube is absolutely insufficient to establish a continued metallic connexion between A and B, the excitement frequently happens spontaneously by reason of ionization of the remaining gas, caused by the mechanical shaking during rotation. Besides K_1 and K_2, the axle O is surrounded by a series of small metallic blocks (not visible in the figure) across which wipes a third brush. This apparatus, like an electric siren, allows a sound to be heard by means of the necessary connexion with a battery and a telephone, by which it is possible to deduce the value of the velocity of the rotation. The light emitted by the tubes is the highest, for constructive reasons, in the tangential direction of the movement. The Michelson interferometer is disposed as in the figure, and on it the light arrives parallel on the mirror S_2 by means of a lens not shown. With the telescope C it is possible to receive a luminous sensation, sufficiently intense in spite of its discontinuity. (20–30 spots per second.)

Thanks to a sufficient intensity of light, I can use (instead of the above-mentioned experiments with mirrors) a value of $l=232$ mm., by which I have observed a maximum of visibility of fringes. In these conditions, and giving to the apparatus a velocity of from 10 to 14 rotations a second, one perceives a displacement of the fringes when the velocity *passes from one part to the other*. This displacement observed with an eyepiece with micrometer has really the direction that is demanded by the principle of constancy of velocity of propagation of light. Let us foresee its value on this basis. During a long series of observations there is an average :

$v = 79 \cdot 77$ m./sec.; $l = 232$ mm., $\lambda = 0 \cdot 546\ \mu$; so that a displacement is foreseen of

$$f = \frac{232 \, . \, 79 \cdot 77}{546 \cdot 3} 10^{-2} = 0 \cdot 113, \text{ and } 2f = 0 \cdot 226.$$

Experimentally, I have been able to augment considerably the exactitude of observation of the fringes; and this because of the higher luminosity of the phenomena. The circular fringes follow each other as is known, with increasing diameter according to the law:

$$n = \frac{l}{\lambda}\left(1 - \frac{\alpha^2}{2}\right),$$

in which l and λ have the usual meaning, n is the increasing ordinal number of the fringes, beginning at the centre, and α is their radius measured in visual angle from the eye of the observer. So that when a displacement of a fringe is observed, for obtaining a higher precision it is necessary to keep in mind that parabolical law referring to the value of the length of the wave. This is what I have done, studying previously the distribution of the above-mentioned fringes in the field of the telescope. Want of space does not allow me to explain this more at length. I may only say that in the series of observations quoted, I obtained an average of displacement

$$2f = 0 \cdot 238.$$

As we see, this value is somewhat superior to that expected, about 5 per cent. Until now, although I took the greatest care to keep in mind the precision of the different measures which are necessary to arrive at this result, I do not know if any systematic error is the reason for this small difference. Certainly it appears superior to the probable error of the result; and that is why I have mentioned it. But in consideration of the delicacy of the measures I do not register the value of the displacement of the fringes before admitting the above-mentioned discordancy (however slight). For now we may conclude that, under the conditions of the experiment, and within the limits of exactitude of the observations made, *the velocity of light does not change by the movement of the source along the direction of propagation.*

From the researches made by Michelson, Fabry and Buisson, and by myself, it results that the velocity of light is not influenced by reflexion on mirrors, or reflecting surfaces; from those now described by me, it results that the said velocity does not change by the movement of the source. These facts are surely in harmony with the theory of relativity; but really, in spite of their evident interest, they cannot logically be cited as sure experimental proof of this theory. In fact, two experimental circumstances must not be forgotten: first, the presence of materials which are traversed by the interfering rays (air, glass, metals); and second, the gravitation field of our earth. While it is possible to imagine experiments entirely apart from the former, it cannot be foreseen if later experimental results will bring into evidence the eventual influence of the second.

XII. *An Attempt to explain the Michelson Interference-Experiment.* *By* RICHARD BIRKELAND, *Dr. phil., Professor of Mathematics at the Technical High School, Trondhjem* *.

1. THE problem to determine the influence, if any, exercised by the earth's motion on optic phenomena on the earth's surface, is one of great theoretical interest and importance, and a vast amount of speculation and research has been devoted to the subject.

The earth's mean velocity in its orbit is $v=30$ km./sec. Even compared to the velocity of light $c=300,000$ km./sec., v is not a negligible quantity in all circumstances. All attempts to register effects of the $\frac{v}{c}=10^{-4}$ order of magnitude have been in vain. In 1881 Professor A. A. Michelson devised his now famous experiment †, by which it would be possible to discover effects of the $\frac{v^2}{c^2}=10^{-8}$ order of magnitude. The expected effect was not registered. The experiment has afterwards been repeated with still greater accuracy, and at present most physicists feel sure that the effect, which was to be expected, does really not occur.

It had been possible to explain all previous experiments

* Communicated by the Author.

† American Journal of Science, (3) xxii. p. 128 (1881).