EXPERIMENTAL VERIFICATION OF THE PRINCIPLE OF DOPPLER-FIZEAU;

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The relative motion of the source and the observer leads, in optics, to very small variations of wave length because of the very large speed of light. Also, the check on the principle of Doppler-Fizeau is easily accessible only when one is addressing already considerable speeds, such as those posed by the celestial bodies. Astronomical observations have for a long time made it possible to check this principle, either if the source and the observer have a relative movement, or in where it relates to a mobile, broadcasting body. One knows about the broad research field that was opened by the introduction of such measurements in astrophysics.

There is thus no reason to doubt the exactitude of the principle of Doppler-Fizeau. It can be, however, of a certain interest to check it by laboratory experiments, in which speeds are known without any uncertainty. A certain number of experiments have already been made to this end, with means more or less quite suitable. We will list them quickly.

Most these experiments were made by leaving the source and the observer fixed, while making light reflect several times off mobile mirrors. The conditions to fill are the following ones: rates of travel as large as possible; analysis of light by means of a very powerful dispersive apparatus, being able to detect very weak variations of wavelength; use of radiations as perfectly monochromatic as possible, so that the very small variations wavelengths are observable.

In 1901, Bélopolsky ([1]) tried to make a checking while making use of an astronomical spectrograph with three composed prisms provided with a view camera with a 1.75 meter housing. The source of light was the sun, and the observation related to the displacement of the black lines. Before arriving at the slit of the spectrograph, the light underwent a certain number of reflections on mirrors fixed at the periphery of the two rotating discs, of which the

([1]) BÉLOPOLSKY. On an apparatus for the laboratory demonstration of the Doppler-Fizeau principle. *Astrophysical Journal,* t. XIII, p. 15; January 1901.

linear velocity could reach 80 meters a second. The two wheels turn in opposite direction, and the light undergoes six reflections, including three on a mirror which approaches the observer and three on a mirror which moves away from there. They operated, by photograph, in the region of $\lambda = 4{,}400$. Despite of the use of sunlight (very intense but very badly suited to such measurements), the exposure necessary to obtain a photograph of the spectrum was thirty minutes. Measurements seemed to express a displacement of the lines, just perceptible, in the direction envisaged by the theory.

In 1907, Galilzin and Wilip ([1]) took again these measurements, by using the same mobile mirrors, but by using a different dispersive apparatus and another source of light. The dispersive apparatus was of a level of Michelson; the source of light was a mercury vapor lamp. They made measurements on photographic stereotypes, obtained either with the green line ($\lambda =$ 5,461), or with the line violet ($\lambda = 4{,}358$); exposure times up to one hour were necessary, and it was necessary to take meticulous precautions to shelter it from the effect of temperature change during such a long time. The speeds deduced from the displacement of the lines coincide within a few percent near with those given by direct measurement.

As it is seen, these experiments were delicate and required a complicated crew of revolving mirrors. By employing the means available now, we have at the beginning of 1914, demonstrated and measured the phenomenon of Doppler-Fizeau using a rather simple device so that the experiment can now be handled by a student ([2]). It is this device which we will describe.

([1]) Prince B. GALITZIN and J. WILIP. Experimental test of Doppler's principle for light-rays. *Astrophysical Journal*, vol. XXVI, p. 49; July 1907.

([2]) Our device was described in 1914, in a short note published in *Comptes rendus de l'Académie des Sciences*, vol. CLVIII, p. 1498, meeting of 25 May 1914.

In 1917 and 1918, Mr. Majorana, who did not know our experiments, published two notes on the same subject. In the first (*C.R.*, vol. CLXV, p. 424, October 1, 1917), he describes an experiment similar to ours, in which however the Doppler Effect is produced by several reflections on mobile mirrors. The effect is noted by interference, while employing as we did the light of a bare mercury arc and a path difference of 130 millimeters. In the second note (*C.R.*, vol. CLXVII, p. 71, July 8, 1918), he described an experiment in

To avoid the difficulties inherent in using quickly turning sources of light or even mirrors, we took as the mobile object a diffusing body; in which case it is similar to that presented in the study of the rotation of planets. The Fig. 1 represents, in projection, the diagram of the apparatus. The mobile

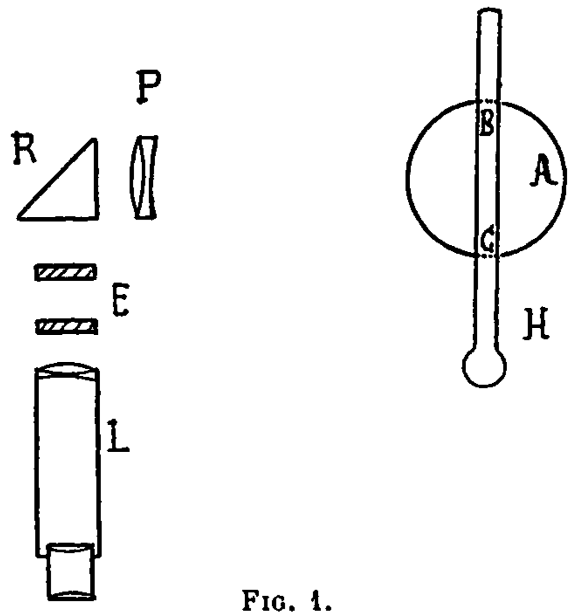

FIG. 1.

object is a horizontal disc of white paper, A, 16 centimeters in diameter, put in fast rotation around its vertical axis; for that, it was assembled on the axis of a centrifugal separator, a small apparatus which is crank driven by hand and by means of a multiplication of movement by gears, gives a speed of approximately 200 revolutions per second. This high speed is obtained without difficulty, thanks to the lightness of the disc. The points on the edge move thus with a speed of 100 meters a second. The source of light is a Cooper Hewitt mercury vapor lamp, consisting of a 60 centimeters long luminous tube, placed horizontally, H, above diameter BC of the disc. Each points B and C receives, from the lamp, the rays of various directions, but all

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which it is the source of light itself which is assembled on the revolving disc.

Mr. Majorana presented his experiments as showing certain results relating to the theory of light or that of relativity. Actually, the exactitude of the principle of Doppler-Fizeau allows us to deduce certain consequences from the standpoint of the theory of light, but the experiments of Mr. Majorana, like those of Bélopolsky, Galitzin and ours, are nothing but a verification of this principle.

perpendicular to its speed; each one of these points behaves like a mobile luminous point, emitting a light identical to that of the lamp; they have equal and opposed speeds, of 100 meters a second. An observer placed at a certain distance in a direction perpendicular to BC and looking at the disc under a very oblique angle of incidence will see it in the shape of a much lengthened ellipse whose end of the main axis moves away from him, while the other comes close. The Doppler-Fizeau Effect must produce a small difference between the wavelengths of radiations coming from these two points, equal to 7×10^{-7} in relative value. To highlight this difference in wavelength, we employed an etalon interferential standard with silver-plated blades of 65 millimeters thickness represented as E in the figure ([1]). The rings are observed by means a telescope, L, focused to infinity. It is important that each point of the field is illuminated by a single point of the disc, and, for that, that the clear image of the disc is seen in the scope at the same time as that of the rings. It is thus necessary to reject the image of the disc by focusing to infinity. This result is obtained using the lens P, having 1 meter of focal distance, and whose focal plane contains diameter BC of the revolving disc. The axis of this lens is slightly inclined, so that the disc is not seen strictly by its edge. The beam resulting from the disc and outgoing of the lens is reflected by the prism, R, with total reflection, then crosses the etalon interferential standard and the spotting scope; by slightly turning the prism one moves the image of the disc in the field of the scope, first one edge, then the other, can be brought to clarify the motionless center of the rings; the movement of the prism is limited by two stops, which makes it possible to pass without groping for one of the positions to the other. If the disc is stationary, this change does not bring any modification in the aspect of the rings; when the disc turns, one sees the rings contracting when one passes from the edge which approaches with that which moves away from the observer.

For the visual observation, we made use of green radiation, isolated by means of absorbing filters. The order of interference, with the difference in hopscotch employed of 130 millimeters, is then about 240,000. While passing from one edge to another, the change is from approximately1/6 of a ring;

([1]) We will describe soon detail of them various etalon interferential standards which we employed in our research.

it is large enough to be noted easily without any measurement.

If one wants to make measurements there is, as usual, great advantage in using photography. We then use the violet line, and replace the scope with a view camera focused to infinity. We made successive photographs by employing the two edges of the animated disc at a known velocity of revolution, and measured the variation in wavelength by measuring on the stereotype the diameters of rings according to the usual method. The exposures necessary to obtain the stereotypes are extremely short; even with the apparatus of very small aperture of which we used (focal length 50 centimeters, opening confined to approximately 2 centimeters and consequently a numerical opening that is 1/25) we obtained a good negative with five seconds of exposure. As the two successive exposures are made without interruption, all the experiment is completed in a time of about ten seconds, and one is safe from all the difficulties arising with the effect of changes of temperature on the interferential apparatus, which were so seriously felt in the experiments of Bélopolsky and Galitzin.

The rotation speed of the disc, deduced from that of the crank driven manually and the step-up ratio, was 214 revolutions per second. The diameter of the revolving disc on which the centers of the rings in the two exposures are located was 15 centimeters; the difference of speeds of the two ends of this diameter results in 201 meters per second. In addition, the path difference produced by the etalon interferential standard being of 130 millimeters, the order of interference for violet radiation is 298,300. We deduced that the variation about interference in the center of the rings should be 0.200. Direct measurement gave 0.206, which constitutes an agreement better than one could not have hoped for, given the conditions under which measurement was made.

By improving the details of measurement, by employing higher, more regular and better known speeds, one could easily arrive at a higher precision. One would thus carry out a good method of measurement speed of light, different from the traditional methods and, in certain connections, simpler.