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CLASSROOM INSTALLATION FOR THE OBSERVATION OF THE DOPPLER PHENOMENON WITH THE AID OF A LASER

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FOLLOWING the work of A. A. Bielopolski[1] and B. B. Golitzin[2], Ch. Fabry and H. Buisson[3,4] performed experiments to verify the validity of the formula describing the longitudinal Doppler effect. These authors used reflection of light from the edges of a rapidly rotating paper disk. The spectral resolution of the light was with the aid of a Fabry-Perot interferometer.

At the present time, using radiation from a helium-neon laser at the wavelength λ = 6328 Å, it is possible to reproduce the experiments of Fabry and Buisson under classroom and laboratory conditions. We have used a universal brush motor (EM) from a vacuum cleaner, designed for 127 volts. At this voltage, the rotor speed is 14000 rpm. By applying 140–150 V for a short time (1 min), it is possible to increase the rotor speed to 17000 rpm. If the radius of the disk on the rotor shaft is R = 10 cm, this corresponds to a linear velocity v = 180 m/sec on the periphery, and to a ratio $v/c = 6 \times 10^{-7}$. The number of disk revolutions was measured with an ST-MĖI strobo-tachometer.

A good result was obtained by using a duraluminum disk of approximate thickness 1 mm, with a paper ring glued to its dulled edge. A central hole is cut in the center of the disk, which is slipped over a nut on the end of the motor shaft. As a precaution, the nut is covered on all sides with a layer of solder, using a soldering iron, to prevent the disk from jumping off the shaft. For better centering, the edge of the rotating disk was polished with emery.

The motor was strapped in a hollow in a wooden block, which was clamped to a heavy table through rubber shock absorbers.

A narrow laser beam, illuminating an area of 1–2 mm^2, was normally incident on the paper ring on the edge of the vertical disk.* The light scattered by the paper at a small angle to the plane of the disk (in this installation φ = 13–12°, corresponding to cos φ = 0.97), was gathered with a short-focus lens (F = 10 cm) into the gap between the plates of the Fabry-Perot interferometer (Fig. 1). A telescope focused at infinity (see Fig. 1) or a photographic camera was placed behind the interferometer. Rather weak interference rings can be seen in the focal plane of the telescope. The employed laser (LG-56) generates simultaneously a series of nearby frequencies, which produce in each order of interference several rings that differ in brightness. However, only the brightest rings can be seen in the scattered light, and by regulating the power level of the laser it is possible to obtain one or two visible rings in each order.

It is desirable, of course, to use a laser operating

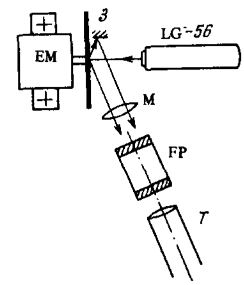

FIG. 1

in the single-frequency regime, something accomplished by the well-known laser-adjustment methods*.

Photography with an exposure of 20–30 seconds on a photographic film with sensitivity 130 units (TAIR-3 telephoto lens with focal length 30 cm, "Zenit-3" camera) yields a picture with a single ring. Figures 2 and 3 show the interference pattern with the disk at rest and with the disk rotating at a normal motor supply voltage 120 V.

To obtain interference patterns produced by the light reflected from diametrally opposite points of the disk, we used the following method. Near the disk, alongside the point illuminated by the laser beam, we placed a surface-coated mirror. Light scattered in a direction away from the interferometer it is possible to superimpose the two light beams bounded by the mount of the lens O and scattered in opposite directions (the two light circles are superimposed on a sheet of paper placed behind the lens). When the disk is at rest, this makes it possible to increase the light flux incident on the interferometer. On the other hand, when the disk rotates, light waves scattered both in the direction of the rotation of the disk and in the opposite direction will be received. This should cause the interference rings to split, in accordance with the two opposite changes of the wavelengths of the scattered light, and obviates the need for obtaining two pictures of the rings—one with the disk rotating and the other with the disk at rest. When an interferometer with a 30 or 50 cm separation between the plates is used, this picture and the dynamic Doppler effect can be observed quite clearly in the telescope. When the speed is varied the sharpness of the observed picture goes successively through maxima and minima, depending on whether the components of the neighboring rings are superimposed (Fig. 4) or not (Fig. 5)†.

*Figure 1 shows the top view of the installation. The laser beam illuminates the area on the upper end of the disk diameter.

*To this end, one of the resonator mirrors is deflected slightly from strict parallelism, and the interference pattern is simultaneously watched.

†The interference pattern on the film measures about 1 mm even when the TAIR-3 telephoto lens is used, owing to the large (30 cm) distance between the plates of the interferometer.

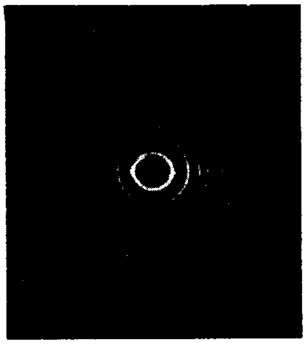

FIG. 2

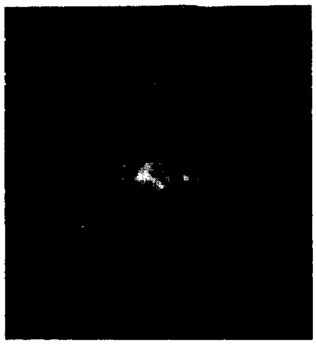

FIG. 3

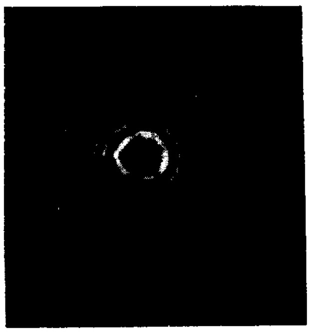

FIG. 4

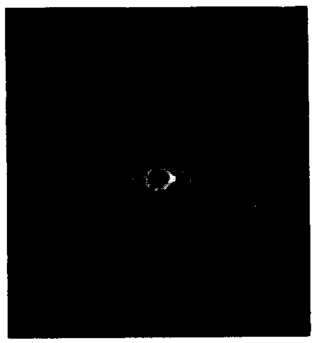

FIG. 5

From the condition that a sharp picture be seen at a certain velocity v, we get the equation $k(\lambda - \Delta\lambda) = (k - 1)(\lambda + \Delta\lambda)$, whence $\Delta\lambda/\lambda = 1/k = \lambda/4t$, where t is the distance between the interferometer plates, so that the verification of the Doppler formula reduces to a comparison of the ratios $(v \cos \varphi)/c$ and $\lambda/4t$. The use of a mirror makes it possible to eliminate also the influence of the variations of the laser frequency on the accuracy of the experiment.

It is possible to replace the mirror with a glass plate located in the path of the direct laser beam and reflecting part of the direct beam to the interferometer. This produces on one negative a system of interference rings with the altered and normal wavelengths.

The reduction of the photographic data consists of measuring the diameters of interference rings of equal order. Since the light is observed after reflection from the moving disk (at an angle φ to the direction of the velocity of the reflecting parts of the disk), the registered wavelength will be altered in accordance with the formula $\Delta\lambda/\lambda = (v \cos \varphi)/c = (R_1^2 - R_0^2)/2F^2$, where R_0 and R_1 are the radii of rings of identical order, and F is the focal length of the photographic lens.

The radii of the interference rings can be measured with a comparator. We used also a projector which gave a strongly magnified image of the negative with rings on a sheet of graph paper.

The Fabry-Perot interferometers constructed by us, with distances 15, 30, and 50 cm between plates, were constructed in the following manner. One of the plates was fixed, and the other was placed between a metallic ring and a cylinder with slots placed at an angle of 120° in several rows, in checkerboard fashion (Fig. 6). The slotted cylinder is deformed somewhat by the pressure of three clamps to which balls from bearings are soldered on the ends. By rotating the glass, it is possible to make the reflecting surfaces of both planes strictly parallel (the plates have a seven-layer dielectric coating for λ = 6328 Å). Approximate parallelism is obtained by aiming the laser beam on the interferometer and placing behind the interferometer a short-focus lens of focal length 8 cm. Looking directly into the interferometer, we see a long and usually curved row of reflections. By turning the regulating screws that control the pressure on the clamps, all the reflected images are made to form a strictly straight line. The subsequent observation is then carried out with the telescope set to infinity. By placing the telescope perpendicular to the interferometer plane, one observes the interference pattern, which should be made, by cautious rotation of the adjusting screws, to form a series of narrow strictly concentric rings. This completes the adjustment.

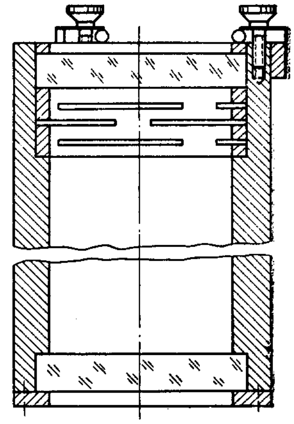

FIG. 6

1. The first method of verifying the result of the experiment consisted of measuring the ring radii with a MIR-12 comparator, on negatives obtained with the disk at rest (radius R_0) and with the disk rotating (R_1), the measurements being made on the ring closest to the central slot (R_1') and on the next ring (R_1''). At a disk peripheral velocity $v \cos \varphi$ = 74 m/sec we obtained $R_0' = 46 \times 10^{-5}$ m and $R_1' = 41 \times 10^{-5}$ m. This yielded $(\Delta\lambda/\lambda)_{exp} = 2.42 \times 10^{-7}$ as against $(\Delta\lambda/\lambda)_{theor} = 2.47 \times 10^{-7}$. The relative error in the comparison of the theoretical calculation with the experimental results is $\epsilon = 2\%$.

For the ring of next order: $R_0'' = 63 \times 10^{-5}$ m, $R_1'' = 59.5 \times 10^{-5}$ m, $(\Delta\lambda/\lambda)_{exp} = 2.43 \times 10^{-7}$, $\epsilon = 1.6\%$.

At a disk peripheral velocity $v \cos \varphi$ = 125 m sec:

$$R_1' = 37 \cdot 10^{-5}\ \text{m}, \qquad \left(\frac{\Delta\lambda}{\lambda}\right)_{exp} = 4{,}15 \cdot 10^{-7}, \qquad \varepsilon = 0{,}5\%;$$

$$R_1'' = 57 \cdot 10^{-5}\ \text{m}, \qquad \left(\frac{\Delta\lambda}{\lambda}\right)_{exp} = 4{,}05 \cdot 10^{-7}, \qquad \varepsilon = 3\%.$$

2. The second method consisted of comparing the velocities obtained directly with those determined by measuring the interference patterns:

$$\frac{v_2}{v_1} = \frac{R_0^2 - R_1'^2}{R_0^2 - R_1''^2}, \quad \text{with} \quad \frac{v_2}{v_1} = \frac{125}{74} = 1{,}69.$$

Measurement of the diameters of the rings closest to the center of the picture yield $v_2/v_1 = 1.72$, $\epsilon = 1.7\%$. Measurement of the diameters of the next rings gave $v_2/v_1 = 1.68$, $\epsilon = 0.6\%$.

Measurement by the method of superposition of the rings: the superposition of the rings is fixed visually in a velocity interval 153–163 m/sec. When the velocity is increased further, the picture loses sharpness.

At a velocity 153 m/sec we got $(\Delta\lambda/\lambda)_{exp} = 5.1 \times 10^{-7}$, and at 163 m/sec we got $(\Delta\lambda/\lambda)_{exp} = (v \cos\varphi)/c = 5.43 \times 10^{-7}$. Hence $(\Delta\lambda/\lambda)_{average} = (5.27 \pm 0.17) \times 10^{-7}$, as against $(\Delta\lambda/\lambda)_{theor} = \lambda/4t = 5.27 \times 10^{-7}$ and $\epsilon = 3.3\%$.

3. The third method consists of comparing the radii of the split rings on one negative. In this case the rings correspond to velocity values $\pm v \cos\varphi$. Therefore $2\Delta\lambda/\lambda = (2v \cos\varphi)/c = (R_0^2 - R_1^2)/2F^2 \cdot \Delta\lambda/\lambda = 3 \times 10^{-7}$ at a velocity $v \cos\varphi = 95$ m/sec. Measurement of the first ring yields $R_0' = 48 \times 10^{-5}$ m, $R_1' = 35.5 \times 10^{-5}$ m, $\Delta\lambda/\lambda = 2.9 \times 10^{-7}$, $\epsilon = 3.3\%$; measurements of the second ring yield $R_0'' = 64 \times 10^{-5}$ m, $R_1'' = 56 \times 10^{-5}$ m, $\Delta\lambda/\lambda = 3.03 \times 10^{-7}$, $\epsilon = 1\%$.

Translated by J. G. Adashko