Aberration of light in a moving medium

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Letters to the Editor

Aberration of light in a moving medium

Abstract. The transverse 'Fresnel ether drag' experienced when light passes through a refracting medium moving at right angles to the original direction of the light, and confirmed indirectly by Airy's water-filled telescope experiment, has been observed directly. A change in rotation speed from 600 to 1800 rpm of a glass disk, of 19·1 mm thickness and refractive index 1·51, produced a transverse displacement of about 1·5 × 10⁻⁶ mm in a light beam passing twice through the disk at a radius of 110 mm from the axis of rotation. This agrees with the Fresnel formula to within the 10% accuracy of the experiment.

Fresnel (1818) concluded that light travelling in a medium of refractive index μ that had a velocity v relative to an observer would appear to him to be carried along by the medium at a velocity of $v(1-1/\mu^2)$ in addition to the velocity c/μ that it would have possessed if the medium had been at rest.

Fresnel's formula for the 'ether drag' was verified by Fizeau (1859) for the case where the light is travelling in a direction the same as or opposite to that of the medium. For the situation where the motion of the medium is perpendicular to that of the light, the formula gives an angle of 'aberration' for the sideways drag of the light $(v/c)(\mu-1/\mu)$. This was indirectly confirmed by Airy (1872), following a suggestion by Boscovitch, in an experiment which involved filling a telescope with water and observing that the angle of aberration as determined by the motion of the Earth relative to the fixed stars remained unchanged.

If light passes through a rotating disk of medium, and the light path is initially parallel to the axis of rotation, it should emerge from the disk parallel to itself but displaced by an amount $(vt/c)(\mu-1/\mu)$ where t is the thickness of the disk and v its tangential speed in the region of passage. This provides the possibility of directly observing the transverse aberration of light, and Lodge (1893) considered performing the experiment. However, with the means of observation then available he estimated that he would have to spin a cylinder one metre in diameter and three metres thick at three thousand rpm to obtain a just detectable displacement of one micrometre.

Developments of optical lever and alignment techniques (Jones 1961) have made it possible to observe much smaller displacements of a light beam, and so render the experiment feasible. For example, a twenty centimetre diameter glass disk, two centimetres thick, and spinning at 2000 rpm should give a displacement of order 10^{-7} cm, which is easily detectable.

The difficulties found in a preliminary experiment on a disk of commercial plate glass are almost entirely due to other sources of deflection of the traversing light beam:

(i) Variations in thickness of the disk

(ii) Variations in local refractive index due to variations in composition

(iii) The axis of the disk may not coincide with that of the shaft on which it is mounted
(iv) Change of axis of the bearings according to direction and speed of rotation
(v) Change in figure of the disk as centrifugal force causes the centre to become thinner than the edge.

The first three sources of error are cyclic, and may be averaged out by observing over several complete rotations. Moreover, the third may be much reduced by making the beam pass twice through the disk in opposite directions, and arranging the optical design so that any displacement due to the 'optical micrometer' effect is cancelled out on the reverse passage, while the genuine aberration effect is doubled. The fourth may be sufficiently reduced by good bearing design, and by observing simultaneously with two light beams at opposite ends of a diameter. The fifth source

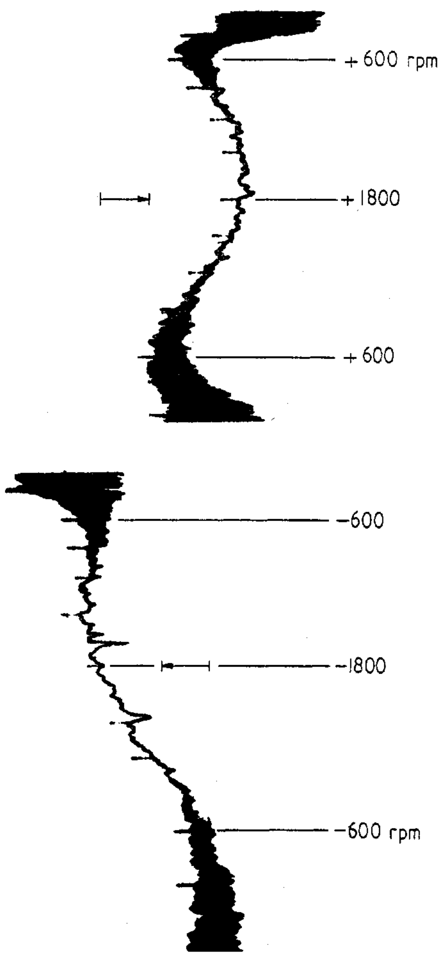

Figure 1. Record of emergent light beam position after passage through a rotating glass disk. The arrows indicate the magnitude and direction of the displacement ($1{\cdot}49 \times 10^{-6}$ mm) expected from Fresnel's ether drag formula when the speed is increased from 600 to 1800 rpm.

gives surprisingly large reflections of the beam, because the disk becomes prismatic in section; fortunately, these deflections occur in a radial direction and can therefore be distinguished from the aberration effect, which is tangential. Moreover, they are independent of the sense of rotation, as are also any effects due to photoelastic polarization by the medium under centrifugal forces.

Figure 1 shows a record of the lateral position of the emergent light beam during a run with the disk rotational speed varying from 0 to +1800 to 0 to −1800 rpm. The broadening effect at low speeds is due to causes (i) to (iii) above; in addition the effect of a slight change of axis is apparent, also some zero drift; but, despite these defects, a general displacement proportional to and in the same sense as the transverse velocity of the disk is present. It can be seen on every run designed to detect a tangential displacement despite intentional changes in items such as the bearings. As for magnitude, with a glass disk of 19·1 mm thickness and refractive index 1·51 with white light passing twice through the disk at 110 mm radius from the axis of rotation, the displacement when the speed is increased from 600 to 1800 rpm should be about $1{\cdot}49\times10^{-6}$ mm from Fresnel's formula; the preliminary experiment gives $1{\cdot}50\times10^{-6}$ mm ± 10%.

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Airy, G. B., 1872, *Proc. R. Soc.*, **20**, 35.
Fizeau, M. H., 1859, *Ann. de Chim. et de Phys.*, **57**, 385.
Fresnel, A., 1818, *Ann. de Chim. et de Phys.*, **9**, 57.
Jones, R. V., 1961, *Proc. R. Soc.* A., **260**, 47.
Lodge, O. J., 1893, *Phil. Trans.* A., **184**, 727.

Numerical calculation of the S-state energy eigenvalues for a local potential

Abstract. A numerical method for calculating the S-state energy eigenvalues for a local potential is given. The method makes use of a first-order differential equation which is easily derived from the Schrödinger equation.

One of the important problems in quantum mechanics is the calculation of the energy eigenvalues for a particular potential in the Schrödinger equation, that is, given the potential V between two particles we wish to solve the equation

$$(T+V)\Psi = E\Psi \tag{1}$$

where T is the kinetic energy, for the negative energy (or energies), $E = -E_B$. For most potentials an algebraic solution of equation (1) cannot be found and numerical methods have to be used. In this letter, a simple method to calculate the S-state