# ON EINSTEIN'S ABERRATION EXPERIMENT

By C. V. RAMAN

ABSTRACT

*Aberration experiment proposed by Einstein to decide between the theories of light.*—According to Einstein, if light from swift canal rays were focused on a slit and the transmitted rays were made parallel and were then focused on cross hairs, the image of the slit would be shifted when a plane-parallel layer of a dispersing medium such as $CS_2$ is placed in the path of the parallel rays, because, due to the motion of the canal rays, the light rays on one side of the beam would have a shorter wave-length than those on the other side and hence, if the ordinary wave theory is correct, the wave front should be rotated. It is here shown, however, that this conclusion is based on a misconception of the behavior of such wave fronts; that the position of the final image is independent of the relative wave-lengths of the different light rays; and that, therefore, no shift is to be expected either according to the wave theory or according to any other theory of light. Hence the experiment cannot help discriminate between the rival theories.

In a recently published communication[1] Einstein has suggested an experiment which according to him furnishes a method for deciding between the two alternative hypotheses regarding the nature of the elementary process of light-emission now holding the field, viz., the classical or undulatory theory in which light-waves are regarded as given out continuously from the luminous atom, and the quantum theory in which light is emitted as the result of an explosive act involving a definite energy-change in the atom and uniquely determining its frequency. It is proposed here briefly to summarize Einstein's paper and then to examine his arguments. It will be shown that his discussion of the phenomena to be expected is at fault and that in reality no effect is indicated by either theory and hence the proposed experiment will not serve to differentiate between them.

The proposed experiment is based upon J. Stark's well-known observation that the light emitted by the luminous atoms in the *Kanalstrahlen* exhibits the Doppler effect, the magnitude of the shift of wave-length depending on the angle between the line of movement of the atoms and the direction of observation. Einstein points out that according to the classical or undulatory theory, light is emitted from the atom simultaneously in different directions

[1] *Sitzung. Preuss., Akad. Wiss.*, 1921, p. 882.

with different frequencies, and proposes to test whether this is actually the case in the following way:

In Figure 1, $K$ represents a stream of canal rays, $L_1$ is a lens which focuses an image of the same on a slit $S$ contained in an opaque screen. The light passing through the slit falls on a collimating lens $L_2$, which renders the beam parallel. The collimated beam then falls upon the object-glass of a telescope focused for infinity (not shown in the figure). An image of the slit $S$ will then be seen in the field of view. Einstein puts forward the proposition that if now a plane-parallel layer of a dispersing medium, e.g., carbon disulphide, be put in between the lens $L_2$ and the observing telescope, a displacement of the image of the slit is

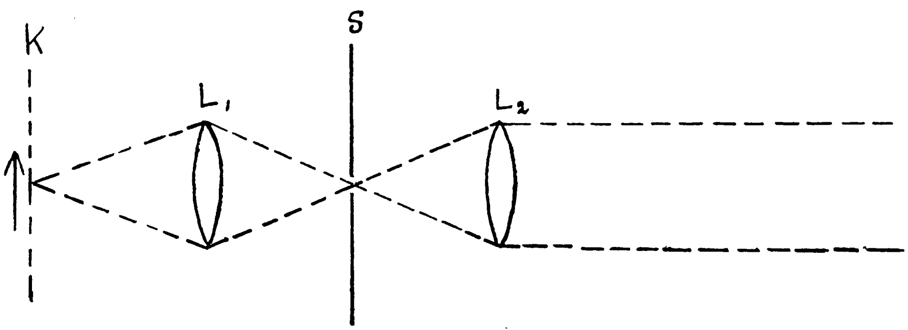


FIG. 1

indicated by the principles of the wave theory, the deviation angle $\alpha$ being given by the formula:

$$\alpha = \frac{l}{\Delta} \cdot \frac{v}{c} \cdot \frac{dn}{\left(\frac{d\nu}{\nu}\right)} \tag{1}$$

where $\frac{v}{c}$ is the ratio of the velocity of the atoms in the *Kanalstrahlen* to the velocity of light, $l$ is the thickness and $n$ the refractive index of the dispersing medium, $\Delta$ is the distance $SL_2$; $KL_1$ and $L_1S$ are assumed to be equal and $\nu$ is the frequency of the light.

We now proceed to indicate the argument on which Einstein bases his derivation of formula (1) which is briefly as follows: The surfaces of constant phase in the light from a luminous atom on emergence from the lens $L_2$ are obviously plane. But since the light falling upon the upper and lower edges of the lens system is according to the Doppler principle of different wave-lengths, the wave fronts after emergence from $L_2$ are not exactly parallel to each other but are slightly inclined in the manner of the leaves of a fan. If no dispersing medium be interposed, the wave fronts after passing through the object-glass of the observing telescope reach foci, which are not coincident but form an image of the slit of finite width in the same position as when the luminous atoms emitting the waves are at rest. If, however, between the lens $L_2$ and the observing telescope a plane layer of a dispersing medium be interposed, the conditions are altered. The upper and lower portions of the wave fronts correspond to different frequencies and therefore move forward with different velocities and hence the wave fronts swing round to a greater and greater extent proportionately with the length of the medium traversed. Einstein then supposes that as the result of this swinging round of the wave fronts, the image of the slit in the observing telescope should suffer a corresponding deflection the magnitude of which is given by formula (1).

The error in Einstein's reasoning enters at the last stage, that is, in his assuming that the swinging round of the wave fronts involves a deflection of the image of the slit in the focal plane of the observing telescope. Referring to Figure 1, we see that as a luminous atom moves along the stream of *Kanalstrahlen*, the waves emitted by it enter the slit $S$ only for a limited period of time depending on its width, that is, the disturbance passing through it forms a wave-group of limited extension. It is perfectly true, as pointed out by Einstein, that when the disturbance enters a dispersing medium, the wave fronts in it swing round steadily as they pass through it. But the position of the image of the slit is determined not by the inclination of any particular wave front to the axis of the optical system, but by the normal to the wave group considered as a whole. It is easily shown that the latter remains fixed and does not turn round. The problem is exactly similar to that which arises in connection with Michelson's determination of the velocity of light in dispersive media by the revolving mirror method, and was very clearly dealt with by Willard Gibbs.[1] The group velocity is given by the relation

$$U=V-\lambda\frac{dV}{d\lambda}\,; \qquad (2)$$

the individual wave planes in the group rotate with an angular velocity

$$\frac{dV}{d\lambda}\cdot\beta$$

where $\beta$ is the angle between successive wave planes; they also move forward through the group with a velocity $(V-U)$, and in the interval of time

$$\frac{\lambda}{(V-U)}$$

in which each wave plane moves into the position of the next in the group, it rotates through an angle

$$\beta\cdot\frac{dV}{d\lambda}\cdot\frac{\lambda}{(V-U)}$$

which by relation (2) is exactly $\beta$. Hence the second wave plane in passing a point moving with the group has exactly the same position which the first one had. Hence as the wave planes move out of the group and disappear and are followed by fresh ones, the inclination of the wave normal to the group considered as a whole remains fixed. In other words, after emerging from the layer of dispersing medium, the group would come to a focus in precisely the same position as when no dispersing medium is introduced.

The matter may also be viewed from another standpoint. Referring to Figure 1, it is clear that what is observed in the field of view of the telescope are not the moving luminous atoms but the fixed slit illuminated by the finite width of the pencil of canal rays. An appropriate method of treating the problem is therefore to regard the slit as a secondary source of light in accordance with the Fresnel-Huyghens principle. If the slit $S$ be very narrow it may be simply regarded as a source of cylindrical waves which diverge

[1] *Nature*, April 1886, p. 582, and *Scientific Papers*, 1, 253.

from it in all directions, and in the disturbance reaching the lens $L_2$, all differences in the frequencies at different points would cease to exist and the image of the slit would be formed in the focal plane of the observing telescope according to the ordinary laws of geometrical optics. No difference would therefore be made by the interposition of a plane-parallel layer of dispersing medium. If the slit $S$ be wider, we may conceive it to be divided up into a large number of very small elements, the image of each of which is formed in a fixed position in the same way as in the case of a very narrow slit, and precisely identical results are reached.

That no displacement of the image in the slit in the observing telescope can occur on the introduction of a dispersing layer can also be shown on purely kinematical reasoning independent of any theory or hypothesis regarding the nature of light. To do this, we have merely to replace the stream of canal rays at $K$ by a stationary source which emits light of different color in different directions, e.g., a small dispersing prism from which a spectrum diverges and falls upon the lens $L_1$ and which after being focused at the slit $S$ and passing through the lens $L_2$ is viewed through the observing telescope. It is clear that the introduction of a dispersing layer bounded by parallel faces will not influence the observed position of the source in the field of view.

CALCUTTA
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