SOME EMISSION THEORIES OF LIGHT.

BY RICHARD C. TOLMAN.

THE Einstein theory of relativity assumes as its second postulate, that the velocity of light is independent of the relative motion of the source of light and the observer. It has been suggested in a number of places that all the apparent paradoxes of the Einstein theory might be avoided and at the same time the principle of the relativity of motion retained, if an alternative postulate were true that the velocity of light and the velocity of the source are additive. Relativity theories based on such a postulate may well be called emission theories.

All emission theories agree in assuming that light from a moving source has a velocity equal to the vector sum of the velocity of light from a stationary source and the velocity of the source itself at the instant of emission. Thus a source in uniform motion would always remain at the center of the spherical disturbances which it emits, these disturbances moving relative to the source itself with the same velocity c as from a stationary source.[1] Emission theories differ, however, in their assumptions as to the velocity of light after its reflection from a mirror.

If an emission theory is accepted, it would seem most natural to assume that the excited portion of a reflecting mirror acts as a new source of light and that reflected light has the same velocity c with respect to the mirror as has original light with respect to its source. The possibility of such an assumption has already been suggested by the writer[2] and apparently disproved by an experiment on the velocity of light from the approaching and receding limbs of the sun. In the present article additional evidence disproving the possibility of the assumption will be presented.

According to an emission theory suggested by Stewart[3] light reflected from a mirror acquires a component of velocity equal to the velocity of the mirror image of the original source. Evidence disproving the possibility of such a principle will also be presented in this article.

[1] Optical theories in which the velocity of light is assumed to change during the path are not considered in this article. It might be very difficult to test theories in which the velocity of light is assumed to change on passing through narrow slits or near large masses in motion, or to suffer permanent change in velocity on passing through a lense.

[2] Tolman, PHYS. REV., *31*, 26 (1910).

[3] Stewart, PHYS. REV., *32*, 418 (1911).

A very complete emission theory of electromagnetism has been presented by Ritz.[1] According to this theory light retains throughout its whole path the component of velocity which it obtained from its original moving source, and after reflection light spreads out in spherical form around a center which moves with the same velocity as the original source. In this article an experiment will be suggested whose performance would permit a decision between the Ritz and Einstein theories of relativity.

The First Emission Theory.

According to the first of the above emission theories, if a source of light is approaching an observer with the velocity v, the emitted light would have the velocity $c + v$ and after reflection from a *stationary* mirror would have the velocity c. We shall now show that measurements of the Doppler effect (in canal rays) do not agree with this theory.[2]

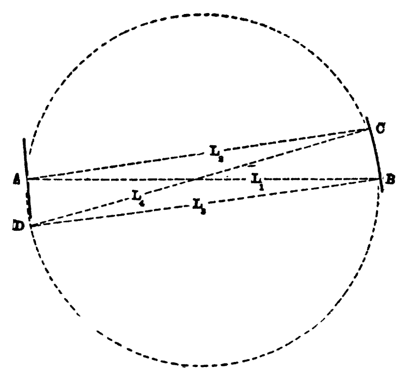

Fig. 1.

Consider measurements of the Doppler effect in light from a moving source made with a concave grating arranged as shown in Fig. 1. Light from the source (canal rays) enters the slit and falls on the grating which is so mounted that its center of curvature coincides with the position of the line of the spectrum to be photographed at D. Hence the paths BD and CD traversed after reflection by the two rays of light ABD and ACD are equal, and

[1] Ritz, Ann. de chim. et phys., *13*, 145 (1908); Arch. de Génève, *26*, 232 (1908); Scientia, *5* (1909). See also Gessamm. Werke. The Ritz electromagnetic theory does not seem to have received the critical attention which it deserves. It was the earliest systematic attempt to explain the Michelson Morley experiment on the basis of an emission theory and is the only emission theory which has been developed with any completeness.

[2] In an earlier article (loc. cit.), the author showed that if an emission theory of light were true, there would be no change in the wave-length of light when the source is set in motion. This undisputed conclusion led the author to believe that with a suitable arrangement of grating no Doppler effect would be detected in light from moving sources if an emission theory should be true. It has been correctly pointed out by Stewart (loc. cit., p. 420), however, that the use of a grating to determine wave-lengths is based on a theory which assumes a stationary medium. Hence grating measurements of the Doppler effect do not afford a general method of testing all emission theories, but such measurements must be subjected to a more complete analysis. As shown in the sequel, however, such an analysis of existing measurements of the Doppler effect is apparently sufficient to disprove the Stewart emission theory. Such measurements are not suitable for deciding between the theories of Ritz and Einstein, however, since in general these two theories would only lead to the expectation of second order differences.

the only difference in length of path occurs, before reflection, *i. e.*, $AB = L_1 > AC = L_2$.

Consider first a *stationary source*, and let τ be the period of the source which produces a bright line at D. For the production of such a line, it is evident that light impulses coming over the two paths ABD and ACD must arrive at D in the same phase. If Δt is the time interval between the departures from the source of two light impulses which arrive simultaneously at D, the condition necessary for their arrival in phase is evidently given by the equation

$$i\tau = \Delta t = \frac{L_1 - L_2}{c}, \tag{1}$$

where i is a whole number. (Note that $L_3 = L_4$ with the apparatus as arranged.)

Consider now a source of light *approaching the slit with the velocity* v. If τ' is the period of the source which now produces a bright line at D and $\Delta t'$ the time interval between departures from the source of two light impulses which now arrive simultaneously at D we evidently have the relation

$$i\tau' = \Delta t'.$$

In order to obtain an expression for $\Delta t'$ in terms of L_1 and L_2, we must note that the source moves toward the slit the distance $v\Delta t'$ during the interval of time between the departures of the two light impulses, and hence the difference in path which was $L_1 - L_2$ for a stationary source has now become $L_1 - L_2 + v\Delta t'$. Furthermore we must remember that according to the theory which we are investigating the light before reflection will have the velocity $c + v$,[1] and hence

$$i\tau' = \Delta t' = \frac{L_1 - L_2 + v\Delta t'}{c + v}, \tag{2}$$

$$i\tau' = \frac{L_1 - L_2}{c},$$

which by comparison with equation (1) gives us $\tau' = \tau$.

In other words if the first of the above emission theories of light is true, both before and after the source of light is set in motion, light produced by the same period of the source gives a bright line at the point D, that is, the expected Doppler effect or shifting of the lines does not occur.

In interpreting actual experimental results, it must be borne in mind that the adjustment of the grating was assumed to be such that the

[1] The slight difference in direction between the rays AB and AC and the motion of the source may be neglected.

reflected light is parallel to the axis of the grating. (Such an adjustment is automatically obtained with the Rowland form of mounting.) If the adjustment of the grating should be such that the difference in path all occurs after reflection it can easily be shown that the first theory *would* lead to a Doppler effect of the expected magnitude, and for intermediate adjustments to an effect of intermediate magnitude.

With regard to actual experimental results obtained with the reflected light parallel to the axis of the grating, the writer quotes from a letter received from Professor Stark.

Professor Stark says: "Sowohl in meinen Beobachtungen mit dem Konkav wie mit dem Plangitter (Ann. d. Phys., 28, 974, 1909) waren die gebeugten Strahlen, welche das beobachtete Spektrogram lieferten nicht parallel oder nahezu parallel der Gitteraxe. Doch has Paschen (Ann. d. Phys., 23, 247, 1907), soviel ich sehen kann, den Doppler Effekt bei Kanalstrahlen in der Nähe der Axe (Normalen) eines Konkavgitters beobachtet; er hat dabei mit Hilfe eines Objektivs paralleles Licht auf das Gitter fallen lassen. Ein Enterschied zwischen Paschens und meinen Reseltaten uber den Doppler-Effekt bei Kanalstrahlen hat sich indes nicht ergeben. Die zwei Methoden (einfallendes Licht parallel der Gitteraxe, gebeugtes Licht parallel dieser) liefern also bei gleicher dispersion ubereinstimmende Doppler-Effekt-Spektrogramme."

We thus see that the first of the above emission theories does not seem to accord with experimental facts.

The Stewart Theory.

By considering the same measurements of Doppler effect just described, it can also be shown that the Stewart theory does not agree with experimental facts.

Suppose a concave grating, Fig. 2, arranged as before with the center of curvature coinciding with the position of the line of the spectrum to be photographed at D.

Consider first a stationary source and let τ be the period of the source which produces a bright line at D. If Δt is the time interval between the departures from the source of two light impulses which after traveling over the two paths ABD and ACD arrive simultaneously at D, it is evident, as in the previous discussion that the condition necessary for their arrival in phase and hence for the production of a bright line is given by the equation

$$i\tau = \Delta t = \frac{L_1 - L_2}{c}, \tag{3}$$

where i is a whole number.

Consider now a source of light approaching the slit with the velocity v. If τ' is the period of the source which now produces a bright line at D and $\Delta t'$ the time interval between departure from the source of two light

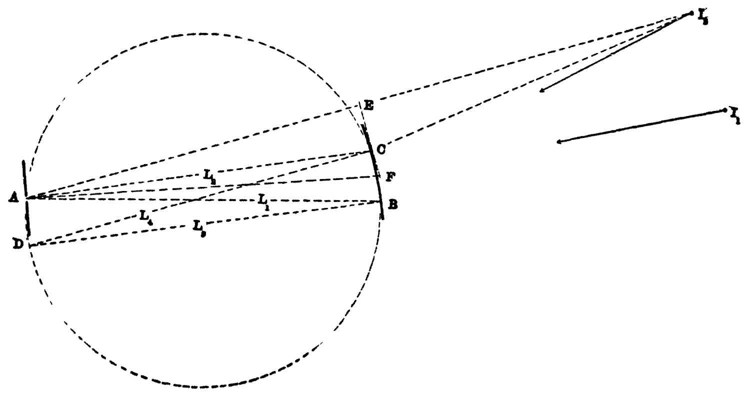

Fig. 2.

impulses which now arrive simultaneously at D, we evidently have the relation

$$i\tau' = \Delta t' = \frac{L' - L_2 + v\Delta t'}{c + v} + \frac{L_3}{c + v_3} - \frac{L_4}{c + v_4}, \qquad (4)$$

where $c + v$[1] in accordance with the Stewart theory is the velocity of the light before reflection and v_3 and v_4 are the components which must be added to c to give the velocity of light along the paths $BD = L_3$ and $CD = L_4$ after its reflection.

According to the Stewart theory v_3 and v_4 will be equal to the components in the direction BD and CD of the velocities of the mirror images of the original source. An idea of the size of these components is most easily obtained graphically. Considering, for example, the point of reflection C as a portion of a plane mirror EF which is tangent to the concave mirror at C, the position of the image I_2 can be found by the usual construction, the line AI_2 connecting source and image being perpendicular to EF and the distances AE and EI_2 equal. Both the original source and the image will evidently be moving towards the point F with the same velocity v. By a similar construction, which has been omitted to avoid confusion, the image I_1 produced by reflection from B is found to be located as shown, and moves also with the velocity v in the direction of the corresponding arrow.

It can be seen from the construction that in the arrangement shown the motion of the image I_1 and the corresponding reflected ray BD are

[1] See note 1, p. 138.

more nearly parallel than the motion of I_2 and the ray CD. Hence from the principle of Stewart the component v_3 is greater than v_4. Referring once more to equation (4), since L_3 and L_4 are equal and v_3 is greater than v_4, we see that the negative term $L_4/(c + v_4)$ is numerically greater than $L_3/(c + v_3)$ and we may write the inequality

$$\Delta t' < \frac{L_1 - L_2 + v\Delta t'}{c + v}.$$

Neglecting second order terms this becomes

$$\Delta t'\left(1 - \frac{v}{c}\right) < \frac{L_1 - L_2}{c} - \frac{L_1 - L_2}{c}\frac{v}{c}$$

and substituting from equation (3),

$$\Delta t'\left(1 - \frac{v}{c}\right) < \Delta t\left(1 - \frac{v}{c}\right),$$

$$\Delta t' < \Delta t,$$

$$\tau' < \tau.$$

Thus on the basis of the Stewart theory, with an approaching source, a shorter period would produce a bright line at the point D than with a stationary source. In other words the actual bright lines would shift towards the red end of the spectrum when the source is set in motion towards the slit, in contradiction to the actually observed shift towards the violet end of the spectrum.

We see that experimental facts do not agree with the Stewart theory.

The Ritz Theory.

According to the Ritz theory of relativity, throughout its whole path, light retains the component of velocity v which it obtained from the original moving source. Thus all the phenomena of optics would occur as though light were propagated by an ether which is stationary with respect to the original source. Light coming from a terrestial source would behave as though propagated by an ether stationary with respect to the earth and light coming from the sun would behave as though propagated by an ether stationary with respect to the sun. Now the Michelson-Morley experiment was devised for detecting the motion of the earth through the ether, and hence if this experiment should be reperformed using light from the sun instead of from a terrestrial source, a positive effect would be expected if the Ritz theory were true. On the other hand if the Einstein theory were true, no effect would be obtained, since according to this theory, all optical phenomena occur as though light were propagated by an ether stationary with respect to the observer.

To show in detail the divergence between the two theories consider the diagrammatic representation of a Michelson-Morley apparatus as shown in Fig. 3.

Light from the sun which is supposed to be moving relative to the apparatus in the direction AB with the velocity v is thrown with the help of suitable reflectors on to the half silvered mirror at A. The divided beams of light travel to the mirrors B and C and after reflection reunite at D to produce a system of interference fringes.

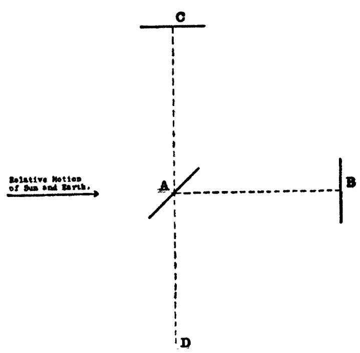

Fig. 3.

According to the Einstein theory of relativity the velocity of light is the same in all directions with respect to all observers, and hence the velocity along the paths AB and CD would be independent of the orientation of the apparatus and on the basis of this theory no change in the position of the interference fringes would be expected on rotation of the apparatus.

According to the Ritz theory, however, the velocity of light in the directions AB and AC would be different and a change in the position of the fringes would be expected on rotating the apparatus through an angle of ninety degrees.

It is easy to see that the Ritz theory would lead us to expect $c + v$ for the velocity of light in the direction AB, $c - v$ for the velocity in the opposite direction, and $\sqrt{c^2 - v^2}$ for the velocity in either direction along AC.

Assuming for simplicity that $AB = AC = l$, we see that the time required for light to travel along the path $ABBAD$ will be longer than that along the path $ACCD$ by the amount

$$\frac{l}{c+v} + \frac{l}{c-v} - \frac{2l}{\sqrt{c^2 - v^2}},$$

which neglecting terms of higher orders reduces to lv^2/c^3.

If the apparatus should be rotated through ninety degrees, it is evident that the longer time would now be required for the light to pass over the path $ACCD$ and we should expect a shift in the position of the fringes corresponding to the time interval

$$\frac{2lv^2}{c^3}.$$

Hence if the Ritz theory should be true, *using the sun as source of light* we should find on rotating the apparatus a shift in the fringes of the same magnitude as originally predicted for the Michelson-Morley apparatus where a terrestial source was used. If the Einstein theory should be true, we should find no shift in the fringes using any source of light.

Summary.

Experimental evidence has been considered in this article which is apparently sufficient to disprove two of the three emission theories of light which have been proposed, and an experiment has also been suggested for testing the truth of the third emission theory, that of Ritz. A definite experimental decision between the relativity theories of Ritz and Einstein is a matter of the highest importance.

The writer wishes to express his gratitude to Dr. P. Ehrenfest for valuable suggestions and criticisms, and to Professor Stark for information concerning the adjustment of his gratings in the measurement of the Stark effect in canal rays.

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