A PROPOSED ASTRONOMICAL TEST OF THE "BALLISTIC" THEORY OF LIGHT EMISSION

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Summary

Ritz's " ballistic " theory of light emission is outlined, and the evidence on which it has been regarded as untenable is re-examined. It is shown that the theory as presented by Ritz is indefinite, and that, when it is amended to a form consistent with the postulate of relativity of motion, it is no longer vulnerable to the earlier criticisms. The question of its admissibility is therefore open. It is pointed out that determinations of the " constant of aberration " from observations of distant nebulae might settle this question, and such determinations are recommended.

It is well known that, according to Einstein's restricted theory of relativity, no material body can move with a greater speed than that of light *in vacuo*, namely, about $3 \cdot 10^{10}$ cm/sec. Recent work in nuclear physics, however, seems to conflict with this*, for, according to the uncertainty principle, the uncertainty in the velocity of a body may approximate to infinity. Independently of this, the internal consistency of the restricted relativity theory seems questionable if the postulate of the constancy of the velocity of light is given its usual interpretation of requiring that all bodies present at the origin of a wave of light, whatever their relative motions, must be regarded as remaining thereafter at the centre of the light-sphere†. These difficulties are removed if the postulate be interpreted merely as requiring that the velocity of light relative to its actual material source shall always be c, and this hypothesis was, in fact, advanced long ago by Ritz‡ and was strongly supported by la Rosa among others: it is usually known as the " ballistic " hypothesis of light emission. Though for a time regarded as a serious rival to Einstein's theory, it was ultimately rejected as being contrary to observation, and has now for many years been held to have been definitely disproved. In view of the new difficulties facing Einstein's theory, however, a revision of the hypothesis and of the grounds for its rejection seems desirable.

Ritz's hypothesis is based on the postulate of relativity of motion, which he expresses in the following way§:— " La seule conclusion qui . . . me semble possible, c'est que *l'éther n'existe pas, ou plus exactement, qu'il faut renoncer à se servir de cette image; que le mouvement de la lumière est un mouvement relatif comme tous les autres, que les vitesses relatives seules jouent un rôle dans les lois de la nature.*"

On this basis he makes the following statements concerning the motion of light||: " les particules lumineuses expulsées en tous sens à l'instant *t se meuvent avec une vitesse radiale constante et remplissent constamment une sphère dont le*

* See, for example, W. Heisenberg, *The Physicist's Conception of Nature*, p. 48, London, 1958

† *Bull. Inst. Phys.* **9**, 314, 1958.

‡ W. Ritz, *Ann. de Chim. et de Phys.*, **13**, 145–275, 1908.

§ *Ibid.*, p. 207.

|| *Ibid.*, pp. 210–1.

centre est animé du mouvement de translation w qu'avait P à l'instant de l'émission; si w est constant, ce centre continuera donc de coïncider avec P .... La vitesse de la lumière dépend donc de celle que possède le corps qui l'émet au moment de l'émission; à partir de cet instant, la vitesse des particules reste invariable, quel que soit le mouvement ultérieur de *P*."

(It should be remarked that, although Ritz speaks of " light particles ", his theory on this point is purely kinematical and implies nothing whatever concerning the nature of light. As Whittaker has pointed out*, a decision on the " ballistic " hypothesis is " without significance one way or the other in the dispute between the wave and corpuscular theories of light ".)

Unfortunately, this statement of the hypothesis is indefinite, since Ritz fails to make clear to what standard of rest the velocities are referred. The ether having been abjured, the phrase, " *mouvement de translation w qu'avait P à l'instant de l'émission* ", leaves us guessing with respect to what *P* (the source of light) has the velocity w; and the phrase, " la vitesse des particules reste invariable, quel que soit le mouvement ultérieur de *P* ", seems to indicate that, whatever the standard may be, *P* may have a varying velocity with respect to it, and therefore with respect to the light particles after the moment of their emission. De Sitter, who has given what is generally considered the most convincing disproof of the " ballistic " hypothesis†, tacitly assumes the standard of rest to be the Earth (or perhaps the Sun). He considers observations of a binary star—for simplicity let us suppose the plane of the orbit to pass through the Earth and one component only to be visible. If the orbital velocity is v, the light issuing while the star is approaching the Earth will have velocity $c+v$, and that issuing while it is receding from the Earth will have velocity $c-v$. If D is the distance of the star from the Earth, the former light will take time $D/(c+v)$, and the latter time $D/(c-v)$, to reach the Earth. The orbit calculated from the observations will therefore be very different from the actual orbit, and if the latter is Keplerian the former will not be so, but, as de Sitter showed, may in a particular case imply that the star has three different velocities at the same time. The actual observations, however, do correspond to a Keplerian orbit. We must therefore, said de Sitter, reject the supposition that the velocity of the light depends on that of its source.

If we are entitled to suppose that a member of the Solar System is acceptable as a unique standard of rest, then de Sitter's evidence against the " ballistic " hypothesis is final. But a different interpretation of Ritz's theory was given by Tolman‡, according to whom the theory requires that " 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." On this view, therefore, the light particles (or wave-front), at a time t after emission, would be at a distance ct from the source, no matter how the source might have moved, between emission and the instant t, with respect to any standard at all.

Ritz regrettably died shortly after his paper appeared, and he therefore had no opportunity of elucidating his meaning. It is clear, however, that the

* E. T. Whittaker, *History of the Theories of Aether and Electricity*, Vol. II, p. 39, London, 1953.
† W. de Sitter, *Proc. Amsterdam Acad.*, **15**, 1297, 1913; *B.A.N.*, No. 64, **2**, 163, 1924.
‡ R. C. Tolman, *Phys. Rev.*, **35**, 136, 1912.

only " ballistic " hypothesis that is consistent with the relativity of motion, the absence of a luminiferous ether, and any plausible form of postulate of constant light velocity, is that contemplated by Tolman. Suppose that a body, alone in space, emits a pulse of light. If there is any meaning at all in calling the velocity of light constant, the pulse must continue to move at velocity c *with respect to the source*. In the absence of a universal stationary medium, there is nothing else with respect to which to express its velocity. It will make no difference to the relative velocity of the light and its source if we place a body some light-years away with respect to which the source moves to and fro; so if, from the point of view of that body, the velocity of the source fluctuates between $+v$ and $-v$, the velocity of its light must fluctuate between $c+v$ and $c-v$, and a beam issuing t seconds after an earlier one will reach a distance D from the source precisely t seconds after that earlier one.

If, then, we interpret the " ballistic " hypothesis in this way, clearly the observations cited by de Sitter afford no evidence against it. With respect to the Earth, each particular light-pulse issuing from the star fluctuates in velocity during its journey, in unison with the fluctuations in velocity of the star, and the observations therefore give precisely the same relation of orbital velocity to time as that characterizing the actual orbit. Such fluctuations seem strange only if the idea of a universal ether remains unrecognized in our minds. If we consider only the Earth and the star, the apparent movement of the star will be indistinguishable in character from that which we attribute to the effect of aberration of light. It is only when we take the rest of the universe into account that we realize the convenience of ascribing the first to the orbital motion of the star and the second to the orbital motion of the Earth. It is tempting, of course, to think that the overwhelming measure of this convenience must make the whole material system of the universe a preferred standard of rest, but however that may be in general mechanics (it is unnecessary to consider that question here), it is an impossible supposition in this case, for we are concerned only with the velocity of light in space. If we suppose that the " universe " provides an absolute reference frame for that, then the Michelson–Morley experiment should have shown the Earth's velocity with respect to this frame, but it did not. Accordingly, " universe " becomes in this connection merely another name for " luminiferous ether ", and the inapprehensibility of that leaves us with the source of light as the only possible reference body with respect to which the velocity of light can be postulated to be constant.

It should be unnecessary to add that, on the " ballistic " theory, the simple addition law of composition of velocities holds, so that the velocity of light with respect to the *receiving* body may exceed c.

Tolman, however, went on to propose a different test of Ritz's hypothesis. He held that the hypothesis would require a positive result in the Michelson–Morley experiment if the light used came from an astronomical source moving with respect to the Earth, for in that case the velocities of the light along the two arms of the apparatus would be different, and a change of fringe system would be expected on rotating the apparatus. Later, the experiment was repeated with celestial light by Tomaschek*, and independently by Miller†,

* R. Tomaschek, *Ann. d. Phys.*, **73**, 105, 1924.
† D. C. Miller, *Proc. Nat. Acad. Sci.*, **11**, 306, 1925.

but with the same result as in the original performance. An experiment by Majorana* with moving terrestrial light also gave a null result. Tolman accordingly concluded that the "ballistic" hypothesis was disproved.

It appears, however, on general grounds that experiments of this kind can afford no evidence on the matter, for, since the only velocity concerned is the relative velocity of the apparatus and the incident light, an experiment which failed to reveal it for one value could hardly do so for another. The equality of the two paths taken by the light in the Michelson–Morley experiment is independent of the velocity of the light when it enters the apparatus. If the velocity should change, the time taken by the light must change equally along both paths, and no differential effect would be expected to be observed. In terms of interference fringes, it should be noted that on the "ballistic" theory the frequency of the (monochromatic) light received is proportional to the velocity of its reception. A change in that velocity would therefore show itself as a change in frequency, and in no other way. But a similar change of frequency would occur with a change in velocity of the radiating body on any theory: it would be observed as a Doppler effect. Consequently, any change in the fringe system arising from a change in the velocity of the radiating body relative to the apparatus would not distinguish between the "ballistic" theory and Einstein's theory of invariability of velocity of light *reception*.

In view of these general considerations, it is necessary to examine Tolman's argument to see where the discrepancy lies. He supposes the experiment performed with light from the Sun when that body is moving along the direction of the arm AB with velocity v with respect to the apparatus, and he writes:— "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." But the theory leads us to expect nothing of the kind. The velocity of the light in the direction AB is certainly supposed to be $c+v$ with respect to the apparatus, but the velocity in the opposite direction depends on the law of reflection of light. On this the Ritz theory says nothing, and the only reasonable assumption is that on this, as on all non-ether theories, light is reflected as a perfectly elastic body, and leaves the mirror at the same velocity with respect to it as that which it had on incidence (but of course with opposite sign). In that case the shift of fringe system assumed by Tolman would not be expected to occur.

This appears to exhaust the evidence on which the "ballistic" theory has been rejected, and we must conclude from these considerations that at present there is no basis at all on which to decide for or against the theory as interpreted by Tolman, namely, that the velocity of light proceeding from a material source remains constant, at a value c, with respect to that source, and is received at velocity $c+v$ (vectorial addition) by a body moving at velocity v with respect to the source at the time of reception. The purpose of this note is to suggest how legitimate evidence might be obtained.

The "constant of aberration" is, to a first approximation, proportional to the ratio, v/V, of the orbital velocity of the Earth to the velocity of the light received from the celestial body concerned, both measured with respect to the Sun as a standard of rest. On the "ballistic" theory this quantity should

* Q. Majorana, *Phil. Mag.*, **37**, 145, 1919.

vary with the radial velocity of the celestial source, while on the view that light is always received at velocity c, it should be constant. Stellar velocities are too small to distinguish between these possibilities, but a distant nebula might move fast enough. The light from a nebula with a velocity of recession of 30 000 km/sec, for instance, should, on the "ballistic" theory, be received at a velocity $0 \cdot 9c$, and the aberrational constant should accordingly be about $23''$ instead of $20'' \cdot 5$—an easily detectable difference. Still larger differences are within range of detection.

Unfortunately, if such a nebula yielded the normal value for the constant the result would not necessarily be conclusive, owing to the uncertainty which still remains as to whether the nebular red-shift is properly attributed to recessional movement. On the other hand, if the larger value were obtained it would be difficult to think of any possible explanation except that the red-shift is due to recession and the "ballistic" theory is correct. Furthermore, a method would become available of finding the recessional velocity of any nebula bright enough to be directly photographed. These possibilities make it very desirable that this observation should be made.

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