Outline of a Kinematic Light Experiment

Christian M. Wackler

Albert-Ludwigs-Universität Freiburg, Philosophisches Seminar, Platz der Universität 3, 79085 Freiburg i. Br., Germany
E-mail: christian.wackler@merkur.uni-freiburg.de

The question whether light moves with constant or variable velocity is indubitably of the utmost importance. Preliminary reflections concerning the nature of that movement contrast the hypotheses of propagation and emission. As a brief historical examination reveals, alleged evidences in favour of the invariance postulate turn out to be erroneous or inconclusive and supposedly decisive tests methodologically invalid. An emission theory based on Michael Faraday's idea of ray vibrations is shown to be in accordance with observation. The question whether the speed of light depends on the velocity of its source has thus not been settled experimentally since only a kinematic test, to date never conducted, can give an unambiguous answer. Juxtaposed to seemingly similar but defective designs Wilhelm Wien put forward in 1904, such an experiment, amending a set-up suggested by Herbert Dingle, is proposed.

1 Introduction

The assumption that the velocity of light with respect to real* space has a constant value is not self-evident at all, as the history of science teaches. Indeed, only in the course of the 19th century the ether or propagation hypothesis of light motion, which this assumption is linked to, succeeded in superseding the ballistic or corpuscular conception of emission, espoused by Isaac Newton. However, at the same time as Christiaan Huygens's interpretation seemed to achieve a late victory, his central idea becoming a general conviction, the problems resulting from it began to accumulate as well. As a consequence, the image of propagating waves has eventually been called into question again [1] – and with very good reason as will be shown. To get a clear picture of the major differences, both views are first juxtaposed in opposition. A generally unheeded emission theory, based on the conceptions of Walter Ritz and amended by Herbert Dingle, is then invoked and demonstrated not to be in conflict with observation [2–7]. Finally, we delineate a kinematic experiment that renders an unequivocal decision between the hypotheses of propagation and emission possible.

2 The nature of light motion – propagation or emission?

To picture the two ways which the motion of light has historically been interpreted in, let us consider the following explanations of Walter Ritz (Figure 1a, b):

> In the theory of the ether, a point mass P, at rest with respect to this medium, will be able to emit waves of a constant radial velocity, which will form at each instant a system of spheres, having P as a centre. If P is animated by a motion of translation, the spheres, on the contrary, will become eccentric, each keeping its centre at P_1 of the ether which coincides with P at the instant of emission. According to the principle of relativity, on the contrary, if the motion of translation is uniform, the spheres will have to stay concentric as at rest, and the centre will always be P. When the motion is no longer uniform, the principle will no longer suffice to determine the movement of the waves.
>
> Two ways of representing the phenomena, two distinct images have successively dominated optics: that of emission (the light *moves*) and that of the ether (the light *propagates*). The second one introduces absolute motion, while the first leads for the movement of light in vacuum exactly to the law that the principle of relativity requires: the luminous particles expelled in all directions at the instant *t move with a constant radial velocity and perpetually fill a sphere whose centre is animated with the motion of translation w that* P *had at the instant of emission; if w is constant, this centre will thus continue to coincide with* P. [8] (The original text is in French.)

The experiment of Michelson and Morley [9] had engulfed the propagation hypothesis and with it electromagnetic theory in a crisis, which most notably H. Poincaré [10] called attention to. Ritz conceived of the ingenious solution to entirely discard the image of propagating waves in favour of a ballistic interpretation. In contrast to other authors, suggesting different emission theories shortly afterwards [11–14], he assumed light to keep the speed it is originally emitted with including after reradiation by a medium [15]. His auspicious but due to his early passing fragmentary work has been the first systematic attempt to revise the notion of emission and turn it into a cornerstone of electromagnetic and optical theory [8, 15, 16]. Not until more than half a century later, that line of thought was keenly continued by R. A. Waldron [17].

*For epistemological reasons, the expression "real" is used instead of the Newtonian term "absolute" throughout this essay.

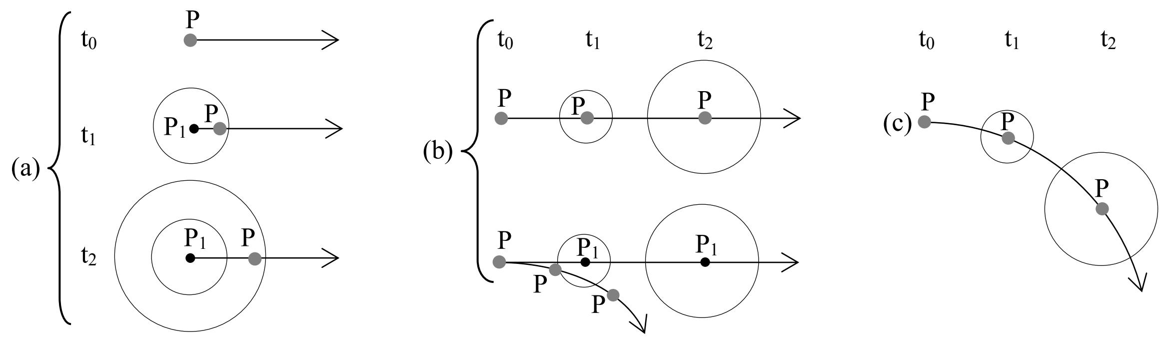

Fig. 1: Movement of a light source P and of a corresponding spherical wave generated at the instant t_0. (a) Propagation (after Maxwell-Lorentz), (b) ballistic emission (after Newton-Ritz), (c) emanation (after Ritz-Dingle).

3 The Ritz theory – criticism and countercriticism

To test Ritz's explanation, M. La Rosa [18, 19] and R. C. Tolman [13] suggested to repeat the Michelson-Morley experiment using light from an extraterrestrial source as the latter moves rapidly with respect to the measuring apparatus. They wrongly presupposed that another null result on such conditions would invalidate his conception. In 1919, an equivalent test, conducted by Q. Majorana [20] with a moving terrestrial light source, showed no shift of the interference pattern. Although F. Michaud [21] demonstrated that Ritz's theory conforms with Majorana's findings – unlike all other emission theories which had been proposed – inferring the fallacy of La Rosa's and Tolman's reasoning from this was omitted. Their view found its way into W. Pauli's [22] influential article on Einstein's theory instead, and after R. Tomaschek [23] and D. C. Miller [24] had finally performed experiments employing sun and star light that again yielded no interference fringes to the calculated extent, Ritz's ideas largely fell into oblivion.

Already previously, an argument adduced by D. F. Comstock [25] and W. de Sitter [26–29] had severely undermined the plausibility of the emission hypothesis. They pointed out that the observed orbits of binary stars are irreconcilable with a ballistic motion of light since particles emitted by a star approaching the observer would overtake the preceding corpuscles and thus distort the image of the system.

Almost half a century had passed until Herbert Dingle [2–4] not only brought the error in La Rosas's and Tolman's reasoning to light but also found a possible explanation considering the seemingly unsurmountable objection that Comstock and de Sitter had raised. In doing so, he seized upon ideas which Michael Faraday had outlined in his *Thoughts on Ray-vibrations*:

> The view which I am so bold as to put forth considers, therefore, radiation as a high species of vibration in the lines of force which are known to connect particles and also masses of matter together. It endeavours to dismiss the æther, but not the vibrations. [30]

Dingle showed that it suffices to extend the classical principle of relativity concerning electromagnetic radiation so that the velocity of light would remain constant with respect to its source even if the radiating body moves non-uniformly and non-rectilinearly (Figure 1c). According to this view, the vibrating rays stay throughout their journey through pure space connected to the source and share the latter's changes of motion. A few years earlier but without building on Faraday's idea, P. Moon and D. E. Spencer had already reasoned along similar lines in response to de Sitters objection [31–35]. However, as H. Bondi aptly remarked, the term "ballistic" does not fit Dingle's conception since the analogy with projectiles no longer characterizes the image [2]. To make a clear distinction, we hence refer to the variation of the emission hypothesis based on vibrating rays as *emanation* and to the correlating principle, governing the motion of electromagnetic radiation, as *classicistic relativity*.

Admitting this principle renders yet another astronomical objection irrelevant H. Thirring [36] propounded against the ballistic concept. He argued that as atoms in the sun are accelerated through thermal collisions, they would emit light particles with different velocities at successive instants. The wave train travelling along a terrestrial observer's line of sight would therefore shrink first, then be stretched, and arrive at the earth as a radio signal.

Finally, a whole class of methodologically interrelated evidences that had been put forward against the emission hypothesis could not withstand Dingle's astute scrutiny either. Over the years, a considerable number of experiments was conducted which seemed to corroborate the postulate of constant light velocity relative to pure space, e.g. [37–43]. But as Dingle correctly remarked:

> The postulate is adopted as part of the basis of a kinematic theory, so that "velocity" must be understood in a kinematic sense, and this requires that the source of light must be an identifiable body, having a definite position in space at each successive instant, the whole sequence of posi-

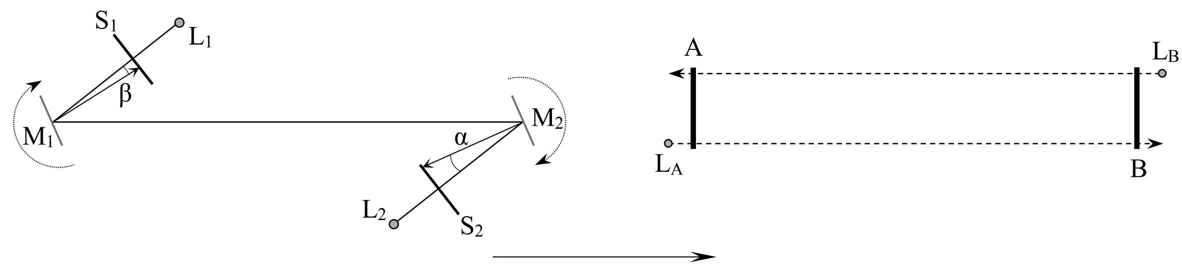

Fig. 2: Schematic of Wien's first and second experimental proposals. A, B: translationally congruent cogwheels; L_1, L_2, L_A, L_B: light sources; M_1, M_2: mirrors in parallel position; S_1, S_2: diaphragms with scales; α, β: deviation angles assuming a stationary ether so that $\alpha > \beta$ as the mirrors rotate, the arrow below indicating the direction of motion of the earth around the sun. Bolometers behind A and B were to record the luminous energy of the incoming beams. When the cogwheels are at rest, the respective values are the same but change as soon as A and B start spinning. An ensuing difference in luminous energy between the rays passing through the notches in opposite directions would have confirmed the hypothesis of a stationary ether.

> tions being consistent with the velocity assigned to the body. [6]

Furthermore, the fact that tests which employ interferometry or use hypothetical particles as sources of light are subject to circular reasoning was generally disregarded.

> In all such experiments, the Maxwell-Lorentz theory, in one respect or another, has been assumed *in the description of the experiment itself*, and since that theory requires that the velocity of light shall be independent of that of its source, the results are of no value at all in relation to this point. [44]

If one visualizes, for instance, the image of the ejected photon string indicated above, it becomes clear at once that a light ray's velocity is not determined by its frequency of vibration. Consequently, a measurement of the frequency of reception, taken by itself, does not allow a conclusion to be drawn about that velocity. Thus, a kinematic question demands a kinematic answer.

For all that and although it was occasionally admitted that Ritz's ideas were discarded prematurely and in part on erroneous grounds [45–49], the theory as amended by Dingle, which no valid evidence exists against, was for decades neglected. Only recently, this conception has finally been resumed and substantially expanded by Luis Bilbao [50], Luis Bernal, and Fernando Minotti [7] under the name of *Vibrating Rays Theory* (VRT). Having adduced further observational data in support of it, they conclude their comprehensive study as follows: "We believe that, given the above evidence, a conscientious experimental research is needed to settle the question of the dependence of the speed of light on that of its source as predicted by Vibrating Rays Theory, and that has been observed during the 1998 NEAR flyby." [7]

4 Towards a kinematic experiment

In 1904, Wilhelm Wien [51–55, pp. 1408-1409] outlined two experiments to determine whether the ether is dragged by the earth or stationary based on the procedures Léon Foucault [56] and Hippolyte Fizeau [57, 58] had devised to measure the speed of light. His first design includes employing two rotating mirrors, his second using two spinning cogwheels which are placed far apart from each other and aligned with the orbital motion of the earth around the sun, respectively (Figure 2). Both experiments demand that the components in rotation have the same angular velocity at any given moment. They therefore depend on the real synchronicity of the instants which the mirrors or cogwheels are set in motion at. However, according to the prevailing theory, this is unattainable through a material connection between them, for example by means of an axle, because within its framework the notion of the rigid body is no longer valid as Wien [59, 60] himself later explained. Nor is utilizing electromagnetic signals to simultaneously start two separate motors feasible due to the supposedly indeterminable times the signals need to reach the different propulsion systems, which count as clocks, so that any possible asymmetry looked for would be offset by the signals' nonsynchronous arrival. These designs being foiled, Wien relinquished further efforts and became a leading proponent of Einstein's theory.

More than half a century later, Herbert Dingle pointed repeatedly to the necessity of a kinematic test for a final answer to the question of the speed of light [4–6, 43, 61–68]. In his book *Science at the Crossroads*, he eventually presented his most sophisticated proposal of an experiment of the kind he hoped for (Figure 3):

> A and B are two sources of light (visible, material sources, not hypothetical particles) of which B is moving rapidly to the left while A is at rest, the paper being the standard of rest. At the instant at which they are adjacent to one another they emit pulses of light towards C and D, which are photographic films whose distances from A are constant and which are moving rapidly downwards through the paper. The relative motion

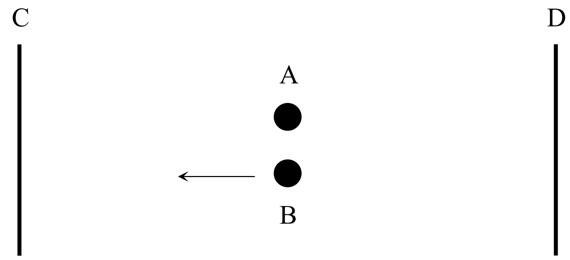

Fig. 3: Light sources A and B, photographic films C and D.

> of A and B continues unchanged throughout the passage of the light. If Einstein's second postulate is true the traces on both films will be symmetrically side by side, while if Ritz's hypothesis is true, that of the light from A will be above that of the light from B on one film and below it on the other. [69]

This proposal undoubtedly implicates considerable and probably still insurmountable technical challenges. However, it at least indicates that the one-way speeds of different beams can indeed be compared without clocks in the usual sense and therefore without the issue of synchronization being relevant at all. That a measurement of the one-way speed of light is possible in principle has also been expressly acknowledged, for example, by Eddington [70], Waldron [17], and Ohanian [71].

Dingle's appeals may have gone unheard for factual reasons at that time. Nowadays, technical infeasibility can certainly no longer hold as a valid argument as will be shown in the following chapter. The matter appears all the more exigent as the invariance postulate in its strict sense has recently been refuted experimentally by slowing down light in vacuum so that c may at best represent a maximum value. Giovannini at al. sum up their findings as follows: "That the speed of light in free space is constant is a cornerstone of modern physics. [...] Our work highlights that, even in free space, the invariance of the speed of light only applies to plane waves." [72] But plane waves are ideal constructs and therefore do not exist as natural phenomena. Considering these facts and especially in view of the work of Bilbao, Bernal, and Minotti, a kinematic test to conclusively answer the question whether the speed of light depends on the velocity of the source is more urgent than ever.

5 Principle and set-up of the experiment

To remove the main difficulties inherent in Dingle's proposal, it is crucial to again follow Michelson's example and to take advantage of the motion of the earth around the sun since the planet's orbital speed of about 30 km/s is great enough to render a potential difference in the travel times of distinct beams observable. Further, employing only one light source will ensure that the emitted rays originate from the same point with respect to the earth.

Thus, the experimental set-up is as follows: aligned with the orbital motion of the earth around the sun, a light source L is positioned far apart from a disk D, the latter's rotational axis being perpendicular to the ground. While the disk is spinning uniformly, L generates short pulses. The emitted beams move towards D and impinge on its photosensitive lateral surface at point A at right angles to the tangent (Figure 4). According to the propagation hypothesis, the velocity of a ray with respect to the ground travelling along the direction of orbital motion of the earth around the sun is $c - V$, with c signifying the speed of light relative to pure space and V the orbital speed of the earth. The travel time of the light referred to $LA = s$ is hence

$$t_A = \frac{s\sqrt{1 - \frac{V^2}{c^2}}}{c - V} \tag{1}$$

whereas in the case of a constant speed of light with respect to the source one has

$$t = \frac{s}{c}\,, \tag{2}$$

the difference between these times being

$$\delta t_A = t_A - t. \tag{3}$$

From the disk radius r and the number of revolutions per second f follows the speed

$$w = fU \tag{4}$$

of the uniformly rotating circumference U. If λ denotes the light spot diameter and the pulse duration p is set according to

$$\delta t_A \leqslant p \ll \frac{U - \lambda}{w}\,, \tag{5}$$

the circular arc length

$$d = \lambda + wp \tag{6}$$

marks the trace the first pulse generates on D's lateral surface. As the disk is spinning constantly and the pulse interval equates to

$$P = \frac{i}{f} - t, \tag{7}$$

where $i \in \mathbb{N}$ denotes the number of revolutions per pulse, any additional pulse must lengthen the trace in the amount of $w\delta t_A$, leaving a solid line on the photosensitive film. Let $n \in \mathbb{N}$ be the number of successively generated pulses, then the trace length a will after n pulses add up to

$$a = d + (n-1)\, w\,\delta t_A\,. \tag{8}$$

Consequentially, the light trace will cover D's entire circumference as soon as

$$n = \frac{U - d}{w\,\delta t_A} + 1. \tag{9}$$

Fig. 4: Schematic of the experimental set-up: A_1 and A_2 denote the points where the rays generated by the first and the second light pulse hit the disk D at the instants t_1 and t_2. The circular arc length $A_1B_1 = d$ represents the trace on D's photosensitive lateral surface the very first pulse causes. $B_1B_2 = w\delta t_A$ depicts the trace's length increment produced by the second and any additional pulse according to the propagation hypothesis. The arrow at the bottom indicates the direction of motion of the earth around the sun.

By contrast, if the emission hypothesis is correct, the rays must always impinge on the same spot so that the trace on the disk retains the length d no matter how much the value of n increases, δt_A having to be substituted with δt in equation (8), where $\delta t = t - t = 0$.

Provided that the propagation hypothesis applies, the exact value of a cannot be predicted. For the conventional value of c would be an average that resulted from two-way measurements and thus deviates from the real one-way speed of light. In case the first test indeed gave $a > d$ for $n > 1$, the result should be crosschecked. Rotating the set-up and repeating the experiment would be expected to yield a different value of a at each angle for a given n. Perpendicular to the direction of orbital motion of the earth around the sun, the trace length would then be

$$a_{90^\circ} = d + (n-1)\, w \left(\frac{\sqrt{s^2 + V^2 t^2}}{c} - t \right) \tag{10}$$

and at 180°

$$a_{180^\circ} = d + (n-1)\, w \left(t - \frac{s\sqrt{1 - \frac{V^2}{c^2}}}{c + V} \right), \tag{11}$$

where $a \approx a_{180^\circ}$. Equations (1) and (11), taking the supposed Lorentz contraction into account, are applicable if the distance LA is measured by means of an etalon. However, considering the necessary magnitude of LA, a travel time measurement using electromagnetic radiation will be conducted in practice. The determined distance

$$s = \frac{cT}{2} = \frac{(c - V + c + V)\, T}{4} \tag{12}$$

then arises from the signal's two-way speed, with T signifying the total time elapsed between emission and return, the respective instants being measured by one and the same clock. Although the square root factor within equations (1) and (11) must under these premises be omitted, the choice between the two methods of establishing LA is evidently of no significance regarding the validity of the experiment.

Due to the motion of the solar system, the propagation hypothesis involves the assumption that t_A varies seasonally. Therefore, if the first experimental run yields $a = d$ for $n > 1$, a conclusive confirmation of the emission hypothesis will not only demand repetitions of the test at different angles but also reperforming it over an extended period to exclude a misleading result because of V being possibly offset by an unknown velocity component just at the time of the initial measurements.

The outlined experiment avoids the theoretical obstacles which defeated Wilhelm Wien's proposals as merely one uniformly spinning mechanical component is required and attuning a pulsing light source to it does not pose a conceptual problem. The test itself implies no two-way measurement and is neither dependent on assumptions of the Maxwell-Lorentz electromagnetic theory, nor are hypothetical particles used as a radiation source. Thus, Dingle's criteria for a kinematic light experiment are met, and objections against procedures based on a closed light path do not apply [73].

6 Conclusion

We may summarize the proposed *experimentum lucis et crucis* in the following way: since any "in itself determined periodic process realized by a system of sufficiently small spatial extension" [74] is considered to be a timepiece, the described set-up consisting of a uniformly spinning disk featuring a photosensitive lateral surface and of a light source pulsing at equal intervals embodies two clocks, their "hands" being successively emitted rays. These "light clocks" run synchronously and thus display real simultaneity. The outcome of the experiment is therefore identical for any observer in any system of reference.

Since the assumption that an ether is dragged by the earth was experimentally refuted [75, 76], no theory reposing on the postulate of constant light velocity relative to pure space or a luminiferous medium in it can explain successive beams impinging on the disk at the same spot. Instead, the emission hypothesis will be fully confirmed. Electromagnetic radiation will have to be understood as a form of energy which is emitted with a real velocity $c + v$, that is the vector sum of a component being invariant relative to the light source and a variable component, the real velocity of this very source. However, according to K. Brecher's [77] analysis of regularly pulsating x-ray sources in binary star systems, a ballistic interpretation even if it allows for the extinction theorem of dispersion theory, as considered by J. G. Fox [45, 46], seems to be untenable (cf. also [48]). Thus, the *Ritz-Dingle Emanation* or *Vibrating Rays Theory* will remain the only explanation consistent with observation [2–7]. In addition to *classical relativity* holding true for matter in uniform translation, a *classicistic principle* will apply stating that the speed of light stays constant relative to its source even if the latter moves non-rectilinearly and non-uniformly.

Should, on the contrary, successive beams mark a solid line on the disk, the propagation hypothesis would bear the palm. Light would have the characteristics of a wave that propagates in a medium with constant velocity relatively to that medium. The recently renewed question whether there is a resting frame in space [78] would be answered in the affirmative.

Submitted on May 11, 2018

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