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Velocity of Light in a Moving Medium According to the Absolute Space-Time Theory

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Abstract

Proceeding from our absolute space-time conceptions and applying the 'hitch-hiker' model (so-called by us) for the propagation of light in a medium, we obtain the general formula for the light velocity in a moving medium including terms of second order in v/c. This formula is identified with that one obtained by proceeding from the Lorentz transformation.

What is light? What is the mechanism of propagation of light?—Despite the high level to which science has been developed in the last century, there has not been a firm and clear answer to these questions.

Now two substantially different models of light are common in physics and, although excluding each other, many phenomena are explained by the one model, many by the other and many by both. These models are:

(1) The corpuscular (Newton's) model.
(2) The wave (Huyghens') model.

In our absolute space-time theory we use only the corpuscular model. We introduce the notion of the 'period' of a photon (i.e., of any light corpuscle) as follows: The period T is the time for which a given photon is emitted or absorbed, or the time for which we can assert with certainty that a photon propagating with velocity c in vacuum (with respect to the reference frame used) and crossing a given surface has indeed crossed this surface. The quality ν inverse to the period is called the frequency.

Since there is a certain time T during which the photon is emitted, we can imagine it as an 'arrow' or as a 'machine-gun burst' with length $\lambda = cT$, called the wavelength. Now the following question arises: When the source moves with a certain velocity v in the reference frame used, would the 'arrow' (or the single bullets of the 'burst') move with a velocity different from c? According to the answer given to this question there are possibly two different models:

(a) The 'arrow' (Ritz') model, according to which the photon moves with a velocity representing the vector sum of $\mathbf{v}$ and $\mathbf{c}$, while the wavelength remains constant.
(b) The 'burst' (Marinov's) model, according to which the photon moves always with velocity c and only the wavelength (i.e., the distances between the single bullets of the 'burst') change.

For the mechanism of propagation of light in a medium we use the 'hitch-hiker' model (so-called by us). According to this model the photon is a hitch-hiker walking with velocity c and the molecules (the atoms) of the medium are cars driving with velocity v ($c > v$). Since the walker would be tired if he walked all the time (then his velocity will be the highest!), he takes any mth car on the road (we suppose that the distance between the cars are the same) and rests there a definite time (if he drove all the time his velocity will be the lowest!). If $v \ll c$, then the mean velocity of the hitch-hiker will be $c_m = c/n$, where $1/n$ is that part of the time during which, on average, the hitch-hiker walks and $1-(1/n)$ is that part of the time which the hitch-hiker spends in the cars.

Now using this model for the propagation of the photons in a medium, we shall calculate their velocity when the medium moves with respect to the observer. The factor n is called the refractive index of the medium; c is the velocity of light in vacuum and $c_m = c/n$ is the velocity of light in the medium when it is at rest with respect to the observer. In the same manner as the hitch-hiker takes a rest in any mth car, so the photon is 'absorbed' by any mth molecule which it meets on its way and there is a definite time after which the photon is again 're-emitted'.

Let us suppose first that the medium rests in the frame of reference used and that the light propagating with velocity c/n makes an angle θ' with the x-axis (Fig. 1). As supposed previously, any photon, on average, moves $1/n$th part of the time and $[1-(1/n)]$th part of the time rests absorbed by the molecules.

Let us then suppose that the medium moves with velocity v along the x-axis only during this time when the photon is absorbed by some molecule and let us suppose that during the time between the re-emission and next absorption the medium is at rest. If we consider the path of the photon between two successive absorptions, then this path could be presented by the broken line ABC in Fig. 1. Supposing that the time between two successive absorptions is chosen for a unit of time, i.e., that

$$\frac{AB}{v} + \frac{BC}{c} = 1 \tag{1}$$

we shall have

$$AB = \left(1 - \frac{1}{n}\right).v, \qquad BC = c/n \tag{2}$$

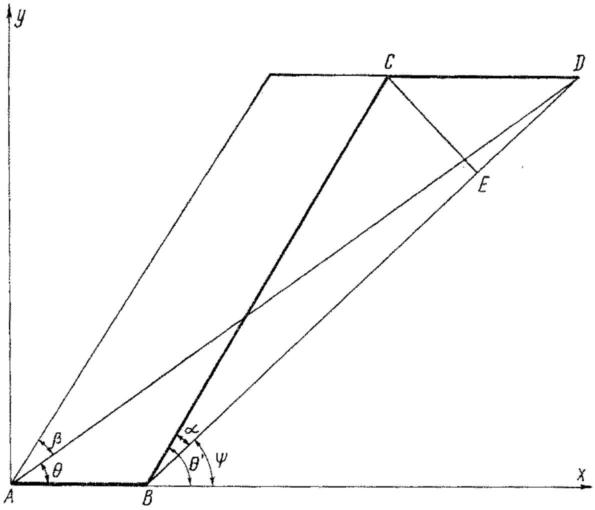

Figure 1.—The paths of a photon moving in a medium with respect to the rest and moving frames.

If now we suppose that the medium moves with velocity v during the whole time, then the next (mth) molecule will be caught not at point C but at point D, where the distance CD is covered by this molecule in the time in which the photon covers distance BD, i.e.,

$$CD = v/n \tag{3}$$

Thus now the distance covered by the photon between two successive re-emission and absorption will be not BC but

$$BD = BE + ED = \sqrt{\left(\frac{c^2}{n^2} - \frac{v^2}{n^2}\,.\sin^2\psi\right)} + \frac{v}{n}\,.\cos\psi \tag{4}$$

where

$$\psi = \theta' - \alpha \tag{5}$$

is the angle between the 'free path' of the photon and the x-axis with respect to the observer, while θ' is the angle between the 'free path' of the photon and the x-axis with respect to the medium, and

$$\alpha = \arcsin\frac{CE}{BC} \cong \frac{v/n}{c/n}\,.\sin\psi \cong \frac{v}{c}\,.\sin\theta' \tag{6}$$

is the difference between these two angles which is small and, as we shall see further, it is enough to consider it with an accuracy of first order in v/c.

Within the same accuracy of first order in v/c we can write, having in mind (5) and (6),

$$\cos\psi = \cos\theta' + \frac{v}{c}\,.\sin^2\theta' \tag{7}$$

The distance covered by the photon between two successive absorptions with respect to the observer will be

$$AD^2 = AB^2 + BD^2 + 2.AB.BD.\cos\psi \tag{8}$$

Substituting here (2), (4) and (7) and working with an accuracy of second order in v/c (obviously in such a case it is enough to take $\cos\psi$—and thus also α—with an accuracy of first order in v/c), we obtain

$$AD = \sqrt{\left(\frac{c^2}{n^2} + 2.\frac{v.c}{n}.\cos\theta' + v^2\right)} = \frac{c}{n} + v.\cos\theta' + \frac{1}{2}.\frac{v^2}{c^2}.n.\sin^2\theta' \tag{9}$$

To obtain the mean velocity of the photon with respect to the observer we have to divide the distance AD by the time for which the broken line ABD is covered. This time, taken with an accuracy of second order in v/c, is

$$\begin{aligned} t_m &= \frac{AB}{v} + \frac{BD}{c} = \frac{AB}{v} + \frac{\sqrt{(BC^2 - CE^2)} + DE}{c} \\ &= \frac{AB}{v} + \frac{BC}{c} - \frac{1}{2}.\frac{CD^2}{BC^2}.\frac{\sin^2\psi}{c} + \frac{CD}{c}.\cos\psi \\ &= 1 + \frac{v}{c.n}.\cos\theta' + \frac{1}{2}.\frac{v^2}{c.n}.\sin^2\theta' \end{aligned} \tag{10}$$

where we have used (1), (2), (3) and (7).

Thus for the mean velocity of the photon in the moving medium measured by the observer at rest we get, with an accuracy of second order in v/c,

$$\begin{aligned} c_m = \frac{AD}{t_m} &= \frac{c}{n} + v.\left(1 - \frac{1}{n^2}\right).\cos\theta' \\ &- \frac{v^2}{c.n}.\left(1 - \frac{1}{n^2}\right).\cos^2\theta' + \frac{1}{2}.\frac{v^2.n}{c}.\left(1 - \frac{1}{n^2}\right).\sin^2\theta' \end{aligned} \tag{11}$$

The factor

$$\kappa = 1 - \frac{1}{n^2} \tag{12}$$

is called the Fresnel's drag coefficient.

If we want to introduce the angle θ between the x-axis and the average velocity of the photon which is measured by the observer at rest, we shall have

$$\theta = \theta' - \beta \tag{13}$$

where

$$\beta \cong \frac{v.\sin\theta}{c/n} = \frac{v.n}{c}.\sin\theta \tag{14}$$

is the difference between angles θ' and θ which is small and it is enough to consider it only with an accuracy of first order in v/c.

Within the same accuracy of first order in v/c we can write, having in mind (13) and (14),

$$\cos\theta' = \cos\theta - \frac{v.n}{c}.\sin^2\theta \tag{15}$$

Substituting this into (11), we find

$$c_m = \frac{c}{n} + v.\left(1 - \frac{1}{n^2}\right).\cos\theta$$
$$- \frac{v^2}{c.n}.\left(1 - \frac{1}{n^2}\right).\cos^2\theta - \frac{1}{2}.\frac{v^2}{c}.n.\left(1 - \frac{1}{n^2}\right).\sin^2\theta \tag{16}$$

For $\theta = \theta' = 0$ formulaes (11) and (16) give

$$c_m = \frac{c}{n} + v.\left(1 - \frac{1}{n^2}\right) - \frac{v^2}{c.n}.\left(1 - \frac{1}{n^2}\right) \tag{17}$$

For $\theta = \pi/2$, $\theta' = (\pi/2) + [(v.n)/c]$ formulae (11) and (16) give

$$c_m = \frac{c}{n} - \frac{1}{2}.\frac{v^2}{c}.n.\left(1 - \frac{1}{n^2}\right) \tag{18}$$

Exactly the same results can be obtained when proceeding from the Lorentz transformation formulae for velocity which run (see, for example, Møller (1955))

$$v_x = \frac{v'_x + V}{1 + \frac{v'_x.V}{c^2}}, \qquad v_y = \frac{v'_y.1 - V^2/c^2}{1 + \frac{v'_x.V}{c^2}} \tag{19}$$

where v'_x, v'_y are the velocity components of a material point in the moving frame of reference and v_x, v_y are the velocity components of the same point in the rest frame, supposing that the moving frame proceeds with velocity V along the x-axis of the rest frame and their axes are respectively parallel.

Putting in (19)

$$v'_x = \frac{c}{n}.\cos\theta', \qquad v'_y = \frac{c}{n}.\sin\theta', \qquad V = v \tag{20}$$

and working with an accuracy of second order in v/c, we obtain for $\sqrt{(v_x^2 + v_y^2)}$ exactly formula (11).

For the components of the velocity the identity is only within the first order in v/c. Indeed, if we use in the equations

$$c_m . \cos\theta = v_x, \qquad c_m . \sin\theta = v_y \tag{21}$$

formulae (11), (15), (19) and (20), then we see that only the terms of zero and first order in v/c are identical on both sides of these equations.

Formula (17) was proved experimentally within an accuracy of first order in v/c first by Fizeau (1851). An experimental proof of this formula within an accuracy of second order in v/c is still not made and at the present state of technique such an experiment is to be considered only as a challenge to the experimentors.

This experiment, sketched briefly, will appear as follows: Let us use the Michelson interferometer and let us put a liquid with refractive index n in one of its arms whose length is L. We should observe a certain interference picture. Let us then set the liquid in motion with velocity v along the arm L. Now if we use formula (17), we should easily obtain, when the liquid is in motion, the light beam proceeding along arm L, there and back, and returning to the semi-transparent mirror of the interferometer with a time delay

$$t = \frac{L}{c_m^+} + \frac{L}{c_m^-} - \frac{2.L}{c/n} = \frac{2.L.v^2}{c^3} .n.(n^2 - 1) \tag{22}$$

However, even before performing this experiment, we can make the following conclusion: Since the Lorentz transformation formulae have shown their validity in many different experiments, then the identity of the results obtained, on the one hand, proceeding from our absolute space-time conceptions and from the 'hitch-hiker' model for the propagation of light in a medium and, on the other hand, from the Lorentz transformation formulae, is very strong support for

(a) our absolute space-time theory, which defends the assertion that the non-relativistic and relativistic mathematical apparatus (i.e., the Galilean and Lorentz transformations) are not contradictory (at least within an accuracy of second order in v/c), thus an absolute space-time does exist, and
(b) our 'hitch-hiker' model for the propagation of light in material media.

References

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