Flaws in the ether-drift experiments, nature of light and hydrodynamic features of the ether: possible role of a dilatant vacuum.

Marco Fedi *
Ministero dell'Istruzione, dell'Università e della Ricerca (MIUR), Rome, Italy
(Dated: April 21, 2019)

By now, it has become clear that space cannot be treated as mere geometry if we want to achieve a theory of quantum gravity. Evidences from cosmology, dark sector, quantum vacuum, Higgs field and, recently, also dilatant vacuum, suggest that physical vacuum may be endowed with hydrodynamic properties but this contrasts with the null result of the Michelson-Morley experiment and of subsequent tests, which have excluded any dark fluid permeating all space. This is the reason for this new review of the ether-drift experiments, starting from the Michelson-Morley. This analysis shows major flaws in these experiments. The velocity of an apparatus with respect to the stationary ether is more complex to define; apparent ether wind has been confused with ether wind; the transverse path observed in the frame of the ether has not been correctly thought of and invalidates the length-contraction solution to the null result of the Michelson-Morley experiment, which is rather due to the unchanged delta after rotation. The investigation continues by pointing out that thinking of a generic ether can be misleading and specific hydrodynamic properties of the vacuum, as for instance its dilatancy, have to be defined and might explain at the same time both the nature of light and the null results of the ether-drift experiments after the Michelson-Morley, eventually giving a quantum basis to special relativity.
Preprint doi:10.5281/zenodo.2648090

PACS numbers: 95.75.Kk; 03.30.+p; 41.20.Jb
Keywords: Michelson-Morley experiment, ether, electromagnetic wave propagation, photon, dilatant vacuum, special relativity.

I. INTRODUCTION

The reasons for this reanalysis of the Michelson-Morley experiment (MME) [1, 2], as well as of the various subsequent ether-drift tests ([3–5] etc.), are in the developments of modern physics and in the effort to achieve a correct theory of quantum gravity. I am convinced that continuing to treat space as a mere geometrical entity is impeding a quantum theory of gravity and, overall, of relativity. Hydrodynamic forces in a fluid space can mimic curved space-time, as shown for instance in an alternative solution to the perihelion precession of Mercury [6], previously solved only in general relativity. Einstein's theory accurately works *quantitatively* but is probably still far from the correct qualitative view of what space really is [7]. Einstein himself declared in 1920 [8]: "according to the general theory of relativity space is endowed with physical qualities; in this sense, therefore, there exists an aether. According to the general theory of relativity space without aether is unthinkable". Previously, Einstein was indeed influenced by the null result of the MME [1, 2], which suggested a merely mathematical treatment of space and time: a wall erected in front of quantum physics for over a century. The present analysis summarize the MME and its theoretical premise (Sect. II) and points out that since the MME considers a stationary ether, the ether wind it refers to is actually an *apparent* ether wind (Sect. III), therefore valid only for massive bodies traveling through the ether, not for waves, which propagate in a stationary medium at unchanged speed (for waves apparent wind does not exist). Even observing the relative motion photons-apparatus in a real vacuum (no ether), for instance from the Sun, the laws of kinematics indicate that we cannot anyway obtain a null result: it should take longer for light to travel a longer path. If ether-drift tests yield null result, the problem has still to be solved, irrespective of the ether wind. Postulating the problem as a given is actually not helpful. This analysis shows minor and major flaws in the MME, which also concern the subsequent ether-drift tests, for instance the above-mentioned ether-wind issue. The calculation of the actual velocity of the interferometer (and of other devices contrived for other tests) in the stationary ether is not immediate (Fig. 2) and we can notice that the transverse path in the Michelson interferometer is interpreted in a wrong way (Sect. IV), since a laser beam which is normal to the direction of motion of its source, rather leans backward (Fig. 5) and the paths of single photons are orthogonal to the direction of the source. Correcting the transverse path however invalidates the generally accepted length-contraction solution to the null result. As far as the MME is concerned, its solution seems to emerge from a logical error in the equations (Sect. V), rather than from length contraction, while for the other subsequent, different ether-drift experiments, once excluded the ether-wind issue due to the fact that they actually consider *apparent* ether wind, the solution can arise from the possible specific features of the ether, i.e. from its dilatancy (Sect. VI). This could reconcile the ether and special relativity, making it a quantum theory, where the Lorentz factor appears as the rheogram of the vacuum. After this new analysis, the attempt to detect the ether via historical ether-drift experiments based on the concept of an ether wind which should modify the speed of light appears meaningless and the problem rather

* E-mail: marco.fedi@istruzione.it

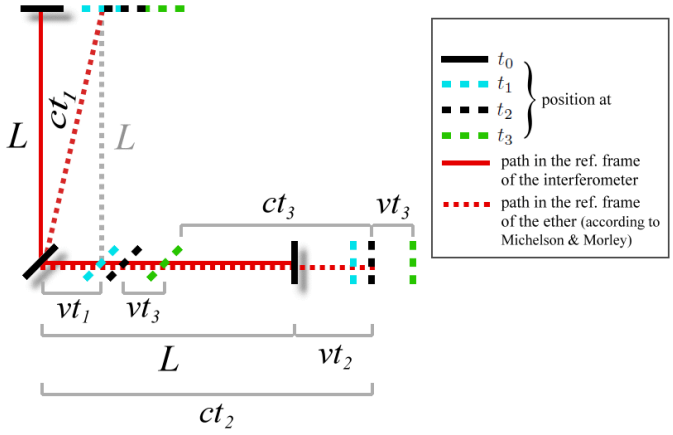

FIG. 1. Longitudinal and transverse paths in the Michelson-Morley experiment. The return transverse path has been omitted for reasons of simplification.

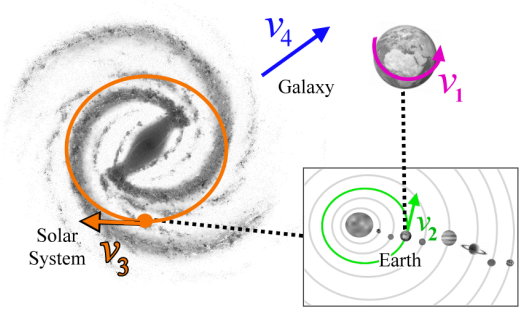

FIG. 2. The speed of the interferometer through the stationary ether (detected by an observer resting in the ether) should be the sum of the velocity of Earth's rotation, Earth's orbital velocity, the velocity of the solar system around the center of the Via Lactea and of the galaxy in the universe (we know for example that our galaxy will collide with Andromeda), making it not immediate to know what value for the fringe shift to expect in the MME.

reduces to the relative motion light-apparatus, even in a real vacuum. Resorting to a dilatant vacuum seems to be a valid solution both to this relative-motion issue and to a quantum justification of length contraction and time dilation.

II. THE MICHELSON-MORLEY EXPERIMENT AND ITS PREMISE

First of all, let us summarize the framework of the MME, including its theoretical premise. A splitted light beam travels in orthogonal directions in a Michelson interferometer. It is reflected and recombines yielding interference. Since it was hypothesized that the Earth and the solar system traveled in a stationary ether, it was expected to detect the effect of an ether wind via the modification of the speed of light, by noticing a fringe shift while rotating the apparatus: specifically, $c-v$, when light travels against the ether wind and $c+v$, when it propagates in the same direction of it, where v is the speed of the ether wind, also corresponding to the velocity of the interferometer with respect to the stationary ether. The exact magnitude, direction and sense of v, from the point of view of an observer resting in the ether, may however be not immediate to calculate, as Fig. 2 shows. In addition, the velocities to be considered are not translational. Since in the frame of the ether the longitudinal path is different from the vertical one (observed as a transverse path, according to Michelson and Morley), after a 90° rotation some fringe shift should be observed but the result of such an experiment is null: no shift observed. According to the MME, a simplification of which is depicted in Fig. 1, we see that the transverse path (ct_1) and the transverse time (t_1) are

$$ct_1 = \sqrt{L^2 + (vt_1)^2} \Rightarrow t_1 = \frac{L}{\sqrt{c^2 - v^2}} \tag{1}$$

and the total transverse time is

$$t_t = 2t_1 = \frac{2L}{\sqrt{c^2 - v^2}} = \frac{2L}{c}\gamma. \tag{2}$$

where

$$\gamma \equiv \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \tag{3}$$

simply arises after some algebra and has no relativistic meaning in this case. Here c might even refer to the speed of acoustic waves: the relative-speed issue would be still valid and according to Sect. V one would obtain even then a null result. The length of the longitudinal path during the outward journey of light and the corresponding travel time are

$$ct_2 = L + vt_2 \Rightarrow t_2 = \frac{L}{c - v} \tag{4}$$

and for the return journey

$$ct_3 = L - vt_3 \Rightarrow t_3 = \frac{L}{c + v}, \tag{5}$$

so we also obtain the total longitudinal time

$$t_l = t_2 + t_3 = \frac{L}{c - v} + \frac{L}{c + v} = \frac{2L}{c}\gamma^2. \tag{6}$$

We see that the transverse 2 and longitudinal 6 travel times therefore differ by a factor γ (according to Michelson & Morley [2]). By rotating the interferometer, the longitudinal and the transverse paths exchange their place (observing from the stationary ether) every 90° : this should cause a fringe shift when observing the recombined beam. On contrary, a null result is obtained.

III. APPARENT ETHER WIND CONFUSED WITH ETHER WIND

The addition and subtraction of the velocity v to/from the speed of light, encountered from (1) to (6), is not simply

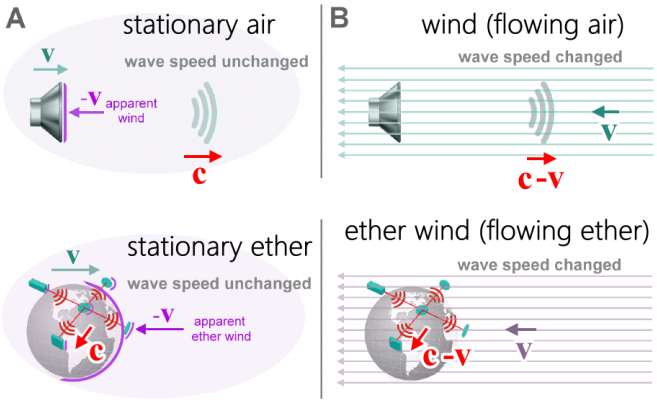

FIG. 3. Difference between wind and apparent wind as regards their action on waves and on massive bodies. In A) only massive bodies traveling through a stationary medium are subject to apparent wind (purple lines indicate the surface of the traveling body which is subject to localized apparent wind), whereas waves (and their velocity, **c** in the figure) are not affected by apparent wind. Only when the medium is flowing (not stationary), real wind (case B) can change the speed of a wave. Since the MME postulates a stationary ether, apparent wind must be considered instead of real wind, so it emerges that in the MME apparent wind has been erroneously equated to real wind. That's why in the expressions $c+v$ and $c-v$ used to explain the experiment, v has actually to refer only to the speed of the interferometer, not of the ether wind. In this figure c and v refer to velocities not to speeds, so $c-v$ is valid for waves propagating in any direction.

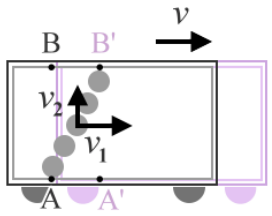

FIG. 4. Transverse path of a massive object, here a ball, thrown up in a traveling wagon, seen by a resting observer. Before being thrown in the air, the ball already exists and has a mass, so it already moves with the longitudinal velocity of the train (v_1). This would not happen for a laser pointed upward in the wagon, since a photon is massless and does not exist before being emitted, so it does not possess the longitudinal velocity of the train. A light beam rather behaves obeying the equivalence principle and leans in the opposite direction with respect to the motion of the reference system in which it is emitted (see Fig. 5).

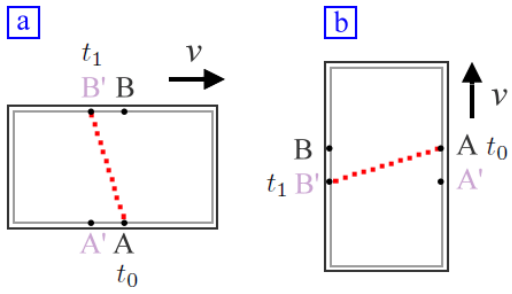

FIG. 5. After rotating 90° (a) Einstein's elevator (b) (let us consider the case in which the elevator travels at constant velocity) we discover what happens to the light beam which is traveling along the vertical arm of the Michelson interferometer, when observed while resting in the ether: the transverse path leans backwards, not in the direction of motion of the system, as usually depicted illustrating the MME. For this reason, in Fig. 1, I specify *path in the ref. frame of the ether according to Michelson & Morley* [2].

justified in the MME as relative speed (photons-apparatus) but is interpreted as the speed of the ether wind which, if an ether exists, should change the speed of light in the way indicated by the equations above. Here is a first error in the theorization of the MME because the authors confused real wind with apparent wind. The difference is of paramount importance because – considering a *stationary* propagation medium – apparent wind acts only on massive bodies traveling in the medium (air, ether etc.), not on waves, which propagate in a stationary medium, with no real wind changing their speed. On the contrary, real wind (a flowing, not stationary, propagation medium) also affects wave speed (Fig. 3). The use of the expressions $v-c$ and $v+c$ in the mathematical interpretation of the MME has actually nothing to do with the *ether wind* and cannot therefore evidence or confute its existence: it has rather to do with kinematics, since a photon traveling toward a mirror should reach it sooner if the mirror is traveling toward the photon. And, vice versa, the photon should reach the mirror later if the mirror is traveling in the same direction and sense of light. Indeed, we could imaginarily stand on the Sun and observe the relative motion photons-mirrors, while both travel in a real vacuum (no ether). Thus, even without an ether, the laws of kinematics are enough to say that we cannot get a null result. Postulating that no ether exists (as in special relativity) is not an answer to the null result. The reason for this unexpected result is on the contrary explained in Sect. V.

IV. CORRECTLY INTERPRETING THE TRANSVERSE PATH

Observing from the frame of the stationary ether, the transverse path is not as actually depicted in the schematization of the MME, as in Fig. 1, in which it is indeed specified *according to Michelson & Morley* [2]. Such a path is valid only for massive objects. For instance, by throwing up a ball inside a running train (Fig. 4), we know that the ball is already endowed with horizontal velocity (that of the train) before being thrown up. As regards light, it is however different: photons do not exist before being emitted and are massless, so they cannot acquire any horizontal velocity component from the system. What actually occurs with the transverse path of light is rather inferable from Einstein's elevator (for the case of constant velocity), as in Fig. 5: the beam leans backward with respect to the direction of motion of the source. However, by decomposing the beam into single photons and imaging to observe their individual paths (Fig. 6), we realize that they travel along orthogonal directions with respect to that of the source. Thus, considering a single photon, there is no transverse path and the generally accepted

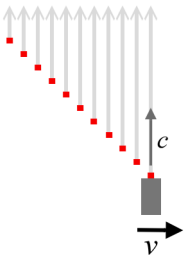

FIG. 6. By decomposing the transverse path of the laser beam into those of single photons, we realize that they actually travel along orthogonal paths with respect to the direction of motion of the source. This fact should cause a slight collimation error in the recombined beam, as shown in Fig. 7

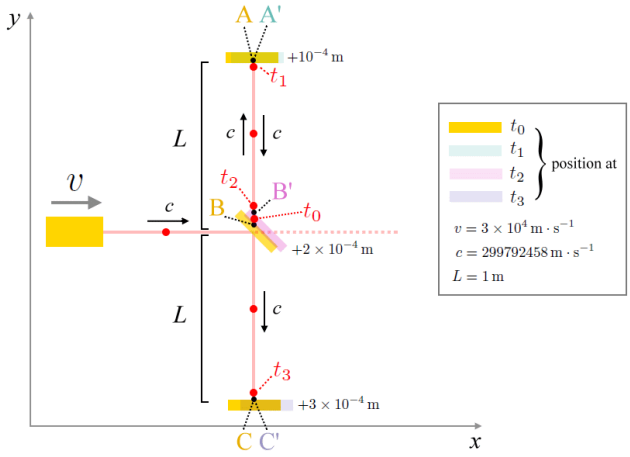

FIG. 7. For the reasons illustrated in Fig. 5, a photon traveling from the splitter hits the mirror in A', it is reflected and passes through the splitter hitting it in B' and finally hits the detector in C'. The collimation discrepancies illustrated in this figure are just exemplifying, because they should be calculated in relation to the real velocity of the interferometer with respect to the stationary ether (see Fig. 2). Here the simple orbital speed of the Earth has been considered as exemplification and the arrow above the light source refers to the velocity of the whole interferometer.

length-contraction solution [9–11] to the null result fails. In fact, after applying the length contraction to the longitudinal path and correcting the transversal path, the total time in the longitudinal direction is $t_l = 2L\gamma/c$ but the time along the vertical arm is now $t_t = 2L/c$ and the null result actually remains unexplained by resorting to length contraction. The transverse-path issue also affects other experiments, such as the Kennedy-Thorndike test.

V. FAILURE OF THE LENGTH-CONTRACTION SOLUTION AND REASON FOR THE NULL RESULT IN THE MICHELSON-MORLEY EXPERIMENT

The accepted solution to the MME's null result is length contraction [9–11]. It would work if a transverse path were there: in this way $t_l = t_t = (2L/c)\gamma$ and the fringe shift is zero. Though, photons do not travel any transverse path (Sect. IV), so this solution is not acceptable. Along with the ether-wind issue, this is another major flaw in the ether-drift tests. As Einstein postulated the invariance of the speed of light in his theory of special relativity, length contraction ceased to be an *ad hoc* hypothesis. This fact, however, does not save the length-contraction solution to the MME's null result from being wrong, since no transverse path of single photons exists for an observer resting in the ether, so a γ^2 discrepancy remains unsolved. Moreover, postulating is not an explanation and today the invariance of the speed of light is still an odd given. But at least for the MME, the solution seems to arise from a logical error in the equations. After each 90° rotation, the horizontal and the vertical arms do not actually exchange their place: the one *becomes* the other, as illustrated in Fig. 8. Since this exchange does not occur, it must not occur even in the equations: the factor γ^2 refers always to the *current* horizontal arm and the factor γ to the vertical arm (if still considering the nonexistent transverse path, just to resort to the familiar equations of the MME). Let us see the error in the equations of the MME, by considering the difference (Δ_1) between (6) and (2), each divided by c to obtain lengths, i.e.

$$\Delta_1 = 2\left(L\gamma^2 - L\gamma\right). \tag{7}$$

The equations of the MME say that after a 90° rotation, we must consider a different delta, that is

$$\Delta_2 = 2\left(L\gamma - L\gamma^2\right). \tag{8}$$

However this would be correct by only considering an exchange between the horizontal and the vertical arm. This cannot happen because, once rotated, the horizontal arm becomes the vertical arm and vice versa: we cannot have the horizontal arm lying on the vertical line! The error is illustrated in Fig. 8 . After this new analysis we can therefore realize that $\Delta_2 = \Delta_1$ and that the null result is therefore obvious, even if the ether exists, indeed

$$\Delta_1 = \Delta_2 \Longrightarrow n = \frac{\Delta_1 - \Delta_2}{\lambda} = 0. \tag{9}$$

Now, by replacing the wrong transverse path (Sect. IV) with the orthogonal path of a single photon, we have $\Delta_1 = \Delta_2 = 2\left(L\gamma^2 - L\right)$ and the null result is still justified.

VI. NULL RESULT IN SUBSEQUENT ETHER-DRIFT EXPERIMENTS AND POSSIBLE ROLE OF A DILATANT VACUUM

The increased accuracy achieved in the subsequent tests based on the same hypothesis of the MME does not cancel the objections presented in this study. Especially that concerning the *apparent* ether wind (Sect. III) can be applied also to other ether-drift experiments, such as the Kennedy-Thorndike experiment, the Trouton-Noble experiment and the Ives-Stillwell experiment. In several cases also the transverse-path issue (IV) applies.

The problem can be again reduced to simple relative motion photons-apparatus (also in a real vacuum, observing from the Sun etc.), irrespective of the existence of an ether, since apparent ether wind does not act on waves in any frame of

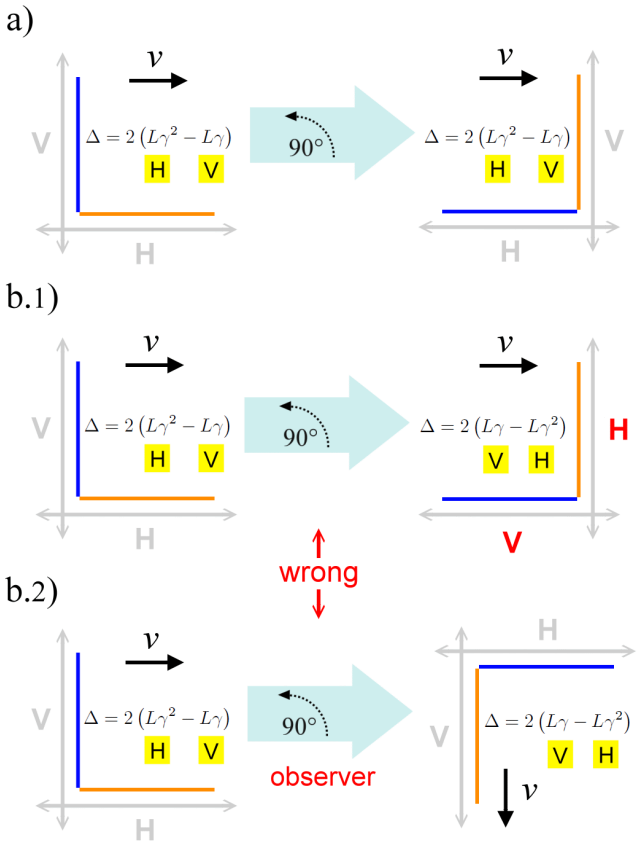

FIG. 8. Once the system is rotated 90°, the horizontal arm cannot be called horizontal anymore (a), it becomes the vertical arm, and the same applies by rotating the vertical arm: in short, horizontal and vertical do not exchange their place at all and this must not happen even in the equations. The factor γ^2 continues to refer to the horizontal line after any 90° rotation. In (b.1) the erroneous exchange is represented and in (b.2) we see that the exchange would rather occur by rotating the observer at rest in the ether, because in this case the vertical arm would lie on the line along which the Earth is traveling: this would be a mistake as well.

reference, as mentioned above: it only acts on the surface of massive objects traveling in a fluid medium. Special relativity merely postulates the constance of the speed of light, without explaining the (quantum) reasons of that. Moreover, this constance itself is the problem, since it implies that light does not obey the normal laws of kinematics and once the matter of apparent wind has released this odd behavior of light from the existence or non-existence of an ether, the problem of the null results in the various ether-drift experiments is still there. A solution might be obtained considering the very characteristics of the ether. Recent evidences suggest that physical vacuum is a dilatant fluid [6]: the equations of dilatant vacuum have solved with unprecedented precision the Pioneer anomaly, are compatible with the stability of planetary orbits and also explain the anomalous perihelion precession of Mercury. It is interesting to consider that dilatant fluids allow transverse acoustic propagation. By considering a photon as a transverse phonon propagating through dilatant vacuum's quasi-lattice (a transient lattice forming due to the applied shear stress, as in other dilatants), not only the nature of light as a transverse wave would be explained but also the possibility for light to propagate with very high frequencies. The issue about light frequency is generally one of the objections to the existence of a luminiferous ether, because the stiffness of the ether should be much higher than that of steel but this is however possible considering a dilatant vacuum, the perfect medium for light propagation. A special quantum fluid, which probably consists of superfluid dark energy and diffused dark matter particles which form clumps as the applied shear stress increases. This would be the cause of vacuum's dilatancy which could also coincide with a possible shear-increasing viscosity of the Higgs field, able to interact also with macroscopic bodies, as probes and planets [6]. The issue of the existence of a dilatant vacuum as the medium for the propagation of photons (described as transverse phonons) is also supported by a full photon-phonon analogy. Indeed, both photons and phonons are bosons [12]; identical excitations can be created by repeatedly applying the creation operator, $b^\dagger$; both possess wave-particle duality [13, 14], indeed in a lattice, or quasi-lattice we expect that waves appear that behave like particles; they obey the doppler effect, $z = (f_{emit} - f_{obs})/f_{obs}$; they are symmetric under exchange, $|\alpha,\beta\rangle = |\beta,\alpha\rangle$; they possess a pseudo-momentum, for a phonon $p_{ph} \equiv \hbar k = h/\lambda$, with $k = 2\pi/\lambda$ (hence the parallelism: radiation pressure $\Leftrightarrow$ sound pressure); they are involved in the photoelectric effect and the Compton scattering thanks to their pseudo-momentum; they can spin [15, 16]. As far as spin is concerned, it would be realistic that the higher degree of freedom of a phonon in the quasi-lattice of a fluid medium, allows it to possess spin 1. For this reason, photons are here treated as special spin-1 phonons. Rotating phonons have been described also as regards the physics of nanotubes [17]). Moreover, we know that photon spin can actually have three different values (-1, 0, 1). Photon and phonon can form squeezed coherent states [18] and can interact via parametric down conversion [19]. For both, $\hbar\omega/2$ is vacuum's energy contribution, since the harmonic oscillator eigenvalues for the mode ω_k (k is the wave number) are $E_n = (n+1/2)\hbar\omega_k$, with $n = 1,2,3,...$ and (to confirm the presence of a *false* vacuum) also for $n = 0$ the energy is not zero. This means that what we think to be a real vacuum (zero mass-energy) actually contains energy and, according to $E = mc^2$, a certain mass density, expressed also in Einstein field equations, that is in Λ and in $T^{\mu\nu}$, as ρ_0. There is a dilatant, dark medium throughout the universe owning mass-energy density $\rho \neq 0$ and through its quasi-lattice light propagates as transverse phonons. This dark, dilatant fluid probably coincides with the viscous Higgs field or with dark matter particles diffused in dark energy (what I call *doped vacuum*, in analogy with doped superfluid helium used in laboratories). Still thinking of light propagation in a true vacuum is then an incorrect view. The Nobel laureate R. B. Laughlin states [20]: "Studies with large particle accelerators have now led us to understand that space is more like a piece of window glass than ideal Newtonian emptiness. It is filled with *stuff* that is normally transparent but can be made visible by hitting it sufficiently hard to knock out a part". This *stuff* is

the dilatant vacuum, in favor of which several evidences have been presented [6, 21], and Laughlin's expression *by hitting it sufficiently hard* corresponds indeed to vacuum solidification under sufficient shear stress.

As we know, Maxwell forged his equations by considering a fluid ether, which was then replaced by a vacuum, still owning however intrinsic physical features such as magnetic permeability and permittivity (initially thought of as density and elasticity of the ether). With the eyes of modern condensed matter physics, Gremaud's work has to be cited [22, 23], because the author translates Maxwell equations into special solid-lattice deformations in Euler's coordinates. Here I am stating that Maxwell equations actually describe the behavior of vacuum's quasi-lattice under acoustic perturbation (photon-phonon analogy in dilatant vacuum): if shear stress is sufficient, physical vacuum transiently becomes solidlike, impeding the passage of any massive body through its lattice (even of a tiny electron) and only allowing transverse-phonons propagation (light). This would be the reason for the existence of an asymptote at the speed of light in the Lorentz factor. No solid object can pass through a wall (without boring it) but sound (phonons) can. Indeed, Lorentz factor, in the form $\gamma - 1$ has been introduced as a term of vacuum dilatancy [6] and its asymptote implies transient vacuum solidification under shear stress. Einstein produced equations which quantitatively work, starting from a postulate. Now we need a quantum explanation to his equations: we need also a correct *qualitative* (quantum) model of space and a more convincing model for the photon, beyond the phenomenological wave-particle description. In my opinion, this can be obtained by introducing a dilatant vacuum, which can support transverse waves propagation even at very high frequencies and whose apparent viscosity increases obeying the Lorentz factor and justifies, in this way, the slowing down of clocks, relativistic kinetic energy [21] and probably, as discussed below, also the null results of the ether-drift experiments which followed the MME.

In a dilatant vacuum, the speed of a shear wave can be expressed by the equation $c = \sqrt{G_0/\rho_0}$, where $G_0 = \tau_{xy}/\gamma_{xy}$ is the shear modulus of the shear-thickening vacuum, τ_{xy} the shear stress and γ_{xy} the shear strain. Being $J_0 = G_0^{-1}$ the shear compliance of dilatant vacuum, the speed of light, within the photon-phonon analogy, can be then defined as

$$c = \frac{1}{\sqrt{\rho_0 J_0}} \tag{10}$$

A variation of J could account for a corresponding variation in the speed of light, producing a compensation in the relative-velocity issue applied to light propagation. According to Han and collegues [24], the propagation speed of a wave front in dilatants depends on the speed of the impactor

$$v_f = \frac{\phi_J}{\phi_J - \phi_0} v_p, \tag{11}$$

where v_f is the front propagation speed and v_p the speed of the impactor: we can analogously think of the impactor speed as the translational speed of the particle emitting the photon (of the particle which produces the transverse phonon in the dilatant vacuum via acoustic perturbation of the vacuum). While ϕ is the packing fraction, with initial fraction ϕ_0 and a jamming fraction ϕ_J: the author suggests jamming instead of densification to explain the shear-thickening behavior of dilatant fluids and I share here such an interpretation. As far as the dilatant vacuum is concerned, jamming could refer to the formation of dark-matter clumps in the vacuum, i.e. in superfluid dark energy doped with diffused dark matter particles, similarly to cornstarch granules in water (oobleck) [7]. Han and collegues also investigate how the front speed, v_f, changes relative to v_p, which is in our case the velocity of the particle emitting the photon and they do that by defining two normalized speed factors, transverse and longitudinal. If the value of the longitudinal factor

$$k_L = \frac{v_{fL}}{v_p} - 1 \tag{12}$$

(where -1 acts in [24] as a compensation for the motion of the impactor) were $k_L = 1$, the null result of the ether-drift experiments would be justified. Interestingly, in [24] it is experimentally found that k – which depends on the speed of the impactor (v_p), on the packing fraction (ϕ) and on the fluid's viscosity (η_0, without considering the dopant, i.e. dark matter particles, in our case) – tends to an asymptotic value k^*. Assuming that $k^* = 1$, the null results are justified: for instance, we would have $v_A = v_B$ in the Kennedy-Thorndike experiment, due to the compensation. Indeed, when light covers a longer distance it means that it's propagating in the direction of motion of the apparatus and in this case the speed of the emitting particle causes greater jamming in the vacuum, permitting a higher speed for the phonon (=photon): a compensation occurs. Vice versa, when the phonon is emitted in the opposite direction to that of the apparatus, the shorter distance is covered by the phonon at a lower speed: a compensation occurs again. Paradoxically, this would mean that the null results have been obtained thanks to the existence of the ether and, specifically, to the fact that it is a dilatant fluid. Special relativity offers length contraction and time dilation as solutions to the null results. This would not contradict the dilatant-vacuum solution. Indeed, in [6], $D = \gamma - 1$ is the term of vacuum dilatancy and is related to the Lorentz factor (reinterpreted as the rheogram of the vacuum). This means that the length difference in length contraction is expressed as $\Delta L = -L_0 D$, which contains the term of vacuum dilatancy and means that as the vacuum solidifies, bodies traveling through it are like sponge balls pressing against a wall. As regards time dilation, it would be due to the fact that a dilated (more viscous) vacuum is able to slow down the clocks: we have indeed $\Delta t = t_0 D$.

VII. CONCLUSION

As far as the reanalysis of the MME is concerned, it clearly emerges that:

a) It is not immediate to define the correct velocity of the interferometer with respect to the stationary ether (Fig. 2) and to consequently define the value of the γ factor in the

equations of relative-motion.
b) The ether wind considered in the MME and in all the subsequent ether-drift experiments is actually *apparent* ether wind, since it is assumed that the ether is stationary, but apparent ether wind cannot change the speed of waves and cannot be therefore referred to the expressions $c-v$ and $c+v$ used in the equations [10]. It is rather a matter of mere relative velocity (photons-apparatus) which could be observed even in a real vacuum from the Sun, for example, while the Earth orbits. In short, the *ether wind* has nothing to do with the MME and with the subsequent tests which aimed at demonstrating (or rejecting) the existence of the ether by trying to detect the effect of the ether wind on the speed of light.
c) The transverse path is different from the one usually depicted to illustrate the experiment: light behaves differently than massive bodies (Sect. IV). Also this problem affects other ether-drift experiments.
d) The equations describing the test are wrong, because $\Delta_2 = \Delta_1$ and the null result is therefore obvious independently from the ether issue. The MME cannot prove or disprove the existence of an ether: that experiment is wrongly thought out in many respects.
The same consideration expressed above in b) and in Sect. III should be considered also for the Kennedy-Thorndike experiment, for Trouton-Noble experiment and for any other ether-drift test. Thus, Einstein's 1920 reconsideration of the necessity of an ether to justify his theory was probably correct. This kind of experiments, irrespective of their later greater accuracy ([3–5] and subsequent tests) have actually not disproven the existence of an ether because, at a deeper analysis, they show crucial flaws. Recent evidences in favor of a dilatant behavior of physical vacuum have been taken into account and it has been shown that such a vacuum can actually support any characteristic of photons and of their specific behavior and might compensate for the velocity of the apparatus. Shedding more light on the features of the vacuum (of the ether) may also help justify the null results of the ether-drift experiments and may explain what physical vacuum and photons really are. One should notice that length contraction and time dilation, which have been proposed as solutions for the null result of the ether-drift experiments, are fully justifiable via a dilatant vacuum. This is a very important point in this study. Indeed, both in the relativistic formula for length contraction and in that of time dilation, the term of vacuum dilatancy, that is $D = \gamma - 1$, is present

$$\Delta L = -L_0 D, \quad \Delta t = t_0 D. \tag{13}$$

A role of dilatant vacuum (of the ether, now endowed with more specific hydrodynamic characteristics) both in the outcome of the ether-drift tests and in special relativity is therefore strongly suggested, confirming the validity of Einstein's statement [8] about the necessity of an ether in his theory, since space must be endowed with physical properties: most likely, these properties seem to be those of a dilatant fluid[6, 7, 21]. *Talking of a generic ether is therefore misleading*: specific features of the ether can make a difference, even in reconciling the existence of the ether with the null results of many different tests and with the theory of special relativity. A correct hydrodynamic definition of the ether might therefore pave the way to a quantum reformulation of relativity.

ACKNOLEDGEMENTS

The author thanks Lorenzo Brandi and Gorm G. Jensen for interesting discussions about the Michelson-Morley experiment.

[1] MICHELSON, Albert A., MORLEY, Edward W. (1886), American Journal of Science, Ser. 3, **31** (185): 377-386
[2] MICHELSON, Albert A., MORLEY, Edward W. (1887), American Journal of Science. **34** (203): 333–345.
[3] MORLEY, Edward W., MILLER, Dayton C. (1905), Proceedings of the American Academy of Arts and Sciences. **41** (12): 321–8.
[4] MICHELSON, A. A., PEASE, F. G., PEARSON, F. (1929), Journal of the Optical Society of America, **18** (3): 181.
[5] JOOS, G. (1930), Annalen der Physik, **399** (4): 385–407.
[6] FEDI, M. (2019), Physical vacuum as a dilatant fluid yields exact solutions to the Pioneer anomaly and Mercury's perihelion precession, Can. J. Phys., **97**(4):417-420, doi:10.1139/cjp-2018-0744
[7] KLIEVER, J. (2019), Describing space as oobleck solves decades-old physics mystery, Canadian Science Publishing's Blog, URL: http://blog.cdnsciencepub.com/describing-space-as-oobleck-solves-decades-old-physics-mystery/
[8] EINSTEIN, A. (1920), Ether and the theory of relativity. In: Sidelights on Relativity. Methuen, London (1922)
[9] LORENTZ, Hendrik A. (1895), Attempt of a Theory of Electrical and Optical Phenomena in Moving Bodies, E.J. Brill, Leiden
[10] LORENTZ, Hendrik A. (1904), "Electromagnetic phenomena in a system moving with any velocity smaller than that of light", Proceedings of the Royal Netherlands Academy of Arts and Sciences, **6**: 809–831
[11] POINCARÉ, Henri (1905), "On the Dynamics of the Electron", Comptes Rendus, **140**: 1504–1508
[12] FEYNMAN, R.P. (1982), Statistical Mechanics, A Set of Lectures. Reading, Massachusetts, The Benjamin/Cummings Publishing Company
[13] EINSTEIN, A. (1909), Über die Entwicklung unserer Anschauungen über das Wesen und die Konstitution der Strahlung. Physikalische Zeitschrift, **10**: 817–825
[14] SALEH, B.E.A., TEICH, M.C. (2007), Fundamentals of Photonics. Wiley
[15] SANTILLÁN, A.O., VOLKE-SEPÚLVEDA, K. (2009), A demonstration of rotating sound waves in free space and the transfer of their angular momentum to matter, Am. J. Phys. **77**, 209

[16] JIANG, X., LIANG, B. *et al.* (2014) Broadband field rotator based on acoustic metamaterials, Appl. Phys. Lett. **104**, 083510

[17] NEGRI, C. (2009), Phonon-Induced Nonadiabatic Rotating Currents around Nonchiral Carbon Nanotubes, graduate dissertation, Università di Milano (from private communications).

[18] REITER, D.E. *et al.,* (2009), Generation of squeezed phonon states by optical excitation of a quantum dot, J.Phys.: Conf. Ser. **193** 012121, Institute of Physics

[19] MARQUET, C., SCHMIDT-KALER, F., JAMES, D.F.V. (2003), Phonon–phonon interactions due to non-linear effects in a linear ion trap, Appl. Phys. B **76**: 199–208

[20] LAUGHLIN, R.B. (2005), A Different Universe: Reinventing Physics from the Bottom Down. NY, NY: Basic Books

[21] FEDI, M. (2019), Relativistic mass due to a dilatant vacuum leads to a quantum reformulation of the relativistic kinetic energy. Preprint at: hal.archives-ouvertes.fr/hal-01898011

[22] GREMAUD, G., Maxwell's equations as a special case of deformation of a solid lattice in Euler's coordinates, Preprint at: arxiv.org/abs/1610.00753v1

[23] GREMAUD, G.: "(2013), Théorie eulérienne des milieux déformables, charges de dislocation et de désinclinaison dans les solides, Presses polytechniques et universitaires romandes, Lausanne, Suisse, 750 pages, ISBN 978-2-88074-964-4

[24] HAN, E., PETERS, Ivo R., JAEGER, Heinrich M. (2016), High-speed ultrasound imaging in dense suspensions reveals impact-activated solidification due to dynamic shear jamming, Nat. Commun. 2016; **7**: 12243.