

Is There an Absolute Scale for Speed?

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Abstract

Except for the speed of photons in vacuum, all speeds are relative. Could we develop an absolute scale for speed in which relative values for speed may be arbitrarily positioned and compared in absolute terms? The currently accepted definition for the meter as the distance covered by photons in vacuum during $1/299,792,458$ s, and the view that the greater a material particle is accelerated towards c , the greater time dilation and length contraction will be, suggest that anything disturbing one of the four spacetime dimensions may affect the other three as well. One hypothetical experiment, one real experiment performed in the 1970s, and one experiment from a different field of science are discussed to propose that both time and velocity are only partially relative. In the first experiment, person A is standing still on the Earth's surface, and person B is onboard a train passing by person A at the constant speed of 60 km/h (as measured by person B on the train's speedometer). Persons A and B define two distinct inertial frames of reference, which correspond to two different spacetime conditions and which are therefore characterized by comparatively different lengths of the meter and durations of the second, as predicted by the Lorentz factor. Therefore, if person B onboard the train measures the train's speed relative to person A as 60 km/h, a simple calculation will show that person A will perceive the train passing by at 59.9999999999981455834 km/h. If we consider the speed of photons in vacuum ($c = 299,792,458$ m/s) as a universal reference, and if we consider that the greater a material particle is accelerated towards c , the greater time dilation and length contraction will be, then person C, occupying an independent, distinct inertial frame of reference, will be unable to determine persons A and B's absolute speeds, but may infer which one is moving at a speed closer to c by comparing, with his own meter and second, the durations of the second and the lengths of the meter experienced by persons A and B. The relativity of time may not be complete due to the bias that derives from the limit imposed on spacetime by c and the Lorentz factor, causing relativity to be

partial. The second and third experiments further help understand this partiality.

Keywords

Spacetime, Relativity, Speed of Light, Space, Time

1. Introduction

Except for the speed of photons in vacuum, all speeds are relative. However, could we develop an absolute scale for speed in which relative values for speed may be arbitrarily positioned and compared?

Suppose we successively accelerate a spacecraft to the constant speeds of $0.1c$, $0.2c$, $0.3c$, ..., and $0.9c$ (speeds adjusted at the spacecraft velocimeter) relative to an inertial frame of reference A (or the surface of the Earth, if we discard any effects due to the atmosphere, to gravity and to non-inertial motion). At each constant speed, the spacecraft passes near the Earth, making it possible, from the Earth's surface, to compare the duration of each second and the length of each meter in the moving spacecraft with those measured on the surface of the Earth. It seems reasonable to assume that the faster the speed in relation to the Earth's surface, the comparatively longer the duration of each second will be, and the comparatively shorter the length of the meter will be.

Let us now imagine that two spacecraft, one moving at the constant speed of $0.1c$ and the other at the constant speed of $0.5c$ (speeds adjusted at each spacecraft velocimeters), pass near the Earth. If, from the Earth's surface (or any other place), we succeed in comparing the duration of each second and the length of each meter in the two moving spacecraft, the one with a comparatively longer duration of the second and comparatively shorter length of the meter will be the one moving faster in absolute terms relative to the Earth.

In relation to time alone, this effect has been widely demonstrated. For example, the Global Positioning System (GPS), a United States of America (USA) global satellite-based radio navigation system, may be regarded as a continuous operating experiment since the clocks onboard the satellites are corrected for both gravity-dependent and non-gravity-dependent time dilation to pass time at the same rate as clocks on the surface of the Earth.

The debate about the symmetry or asymmetry of time dilation has been going on for over 100 years. Time dilation symmetry arose as a logical deduction of Einstein's 1905 postulates: if two clocks occupying two distinct inertial frames of reference are in relative motion, each one is expected to run slower than the other [1]. Abramson [2] proposed an alternative view, in which the symmetry would break if the two inertial frames of reference are defined by two widely different masses (e.g., one GPS satellite and the Earth). It is difficult to accept the existence of an absolute reference without breaking the symmetry of time dila-

tion. Nevertheless, as a counterpart of the special theory of relativity, Burde reconciled the existence of a preferred frame with the relativity principle and the universality of the speed of light [3]. However, in the same article [1], Einstein discussed the relative rates of time ticking in one clock located at one Earth pole and in another clock located at the Equator and concluded that "...a balance wheel clock that is located at the Earth's equator must be very slightly slower than an absolutely identical clock, subjected to otherwise identical conditions, that is located at one of the Earth's poles." In the subsequent years, many experiments were performed to test these two theories (including the continuous experiment conducted at the GPS satellites), and the results seem to confirm that time dilation is an asymmetric phenomenon [4].

In 1908, Hermann Minkowski merged the three dimensions of space with time to conceptualize a four-dimensional continuum known as Minkowski space, Minkowski spacetime, or simply spacetime. It seems increasingly evident that space and time do not exist as separate features of our universe and that a change in speed and/or gravitational acceleration of a material object (e.g., a spacecraft) will not only comparatively alter the duration of the second but will also affect the length of the meter in one or in the three dimensions of space. Therefore, as predicted by the Lorentz factor and for a clock at rest on the Earth's surface and another moving at a relativistic speed, the moving clock is expected to dilate time and contract length (or the three dimensions of space) comparatively to the clock at rest. In contrast, the stationary clock will compress time and expand length (or the three dimensions of space) comparatively to the moving clock.

Albert Einstein's special and general theories of relativity have clearly established the basis for understanding the relative nature of spacetime. However, the speed of light in vacuum ($c = 299,792,458$ m/s) and the Lorentz factor (γ) seem to impose a limit on spacetime. This has implications for observers looking at each other from distinct spacetime conditions, and may ultimately require a third, independent observer. We propose analyzing three experiments to further comprehend this idea.

2. Experiment 1

It is generally accepted that velocities are relative. Imagine two people: person A, standing still on the Earth's surface, and person B, onboard a train passing by person A at the constant speed of 60 km/h (as measured by person B on the speed meter of the train). Both speeds considered (0 and 60 km/h) are relative. Indeed, discarding any effects due to the atmosphere, to gravity and to non-inertial motion, two inertial frames of reference are considered, corresponding to two objects moving at constant velocities relative to one another. Therefore A and B occupy inertial frames of reference, meaning that they are both at rest within each one's frame of reference. The common explanation is as follows: from person B's point of view, person B is inside the train sitting still as he/she

looks through the window at person A passing by at 60 km/h. However, from person A's point of view, person A is standing still outside the train, and it is person B the one who is moving at 60 km/h.

Which one of them (*i.e.*, person A or person B) is truly moving and which one is truly stationary? At first sight, person A seems to be stationary, and person B is moving. However, recall that both person A and the train moving at 60 km/h are standing on Earth, which is rotating and moving around the Solar System's barycenter, which in turn is moving within the Milky Way. In addition, our galaxy is rotating and moving in space. The most obvious explanation would be that there is no absolute rest, *i.e.*, there is no universal stationary reference frame against which all other reference frames may be referenced. Consequently, there is no universal velocity, meaning that only relative velocities exist. Going back to persons A and B, the only relevant conclusion is that the relative velocity between person A and person B is 60 km/h, with neither of them being more or less stationary than the other. This reasoning would be "absolutely" correct if it were not for length contraction, time dilation and the speed limit imposed by the speed of photons in vacuum. Indeed, there seems to exist a universal velocity: c . For now, let us ignore rotational and translational movements of the Earth, Solar System and Milky Way, gravitational fields of the Earth and of any other astronomical bodies, and any effects due to the atmosphere. Under these conditions, person A and person B have two points of view which correspond to two different inertial frames of reference, which are characterized by comparatively different lengths of the meter and durations of the second, as predicted by the Lorentz factor, *i.e.*, they are experiencing distinct spacetime conditions. Nevertheless, each one will obviously perceive the meter and the second as normal in their own frame of reference.

If person A and person B experience comparatively different lengths of the meter and durations of the second, and if person B measures the speed of the train as 60 km/h relative to person A, then person A cannot see person B passing by at 60 km/h. If person B onboard the train measures the speed of the train relative to person A as 60 km/h, then person A will look at the moving train and will see each train meter slightly shorter and each train second slightly longer than person A's own meters and seconds (at this non-relativistic speed, such effects are so small that it is not possible to measure them experimentally), as given by the Lorentz factor.¹

As expected, in what concerns the comparative length of 1 meter and duration of 1 second in the two inertial frames of reference, person A will measure

- m_A in A's own frame of reference, and from A's own frame of reference, $1 m_B = 0.99999999999999845465 m_A$ in the moving train;

¹It is important to note that for such low speeds an assumption must be made here, as highlighted below by the results shown in **Table 1**, obtained in the experiments conducted during October 1971 by Hafele and Keating [5] [6]: for the commercial jet flying westwards, time contracted, *i.e.* shorter seconds were recorded, in comparison with the surface of the Earth seconds, and specially in comparison with the duration of the seconds in the commercial jet flying eastwards. Most probably, this derives from all movements and gravitational accelerations persons A and B are subject to.

- s_A in A's own frame of reference, and from A's own frame of reference, $1 s_B = 1.0000000000000154535 s_A$ in the moving train;

And therefore, from A's own frame of reference, person A will see the train moving at $60 \text{ km}_B/\text{h}_B = 59.9999999999981455834 \text{ km}_A/\text{h}_A$.

The main conclusion of this hypothetical experiment is that person B onboard the train will see person A passing by at $60.00000000000000000000 \text{ km}_B/\text{h}_B$, whereas person A, standing still on the Earth surface, will see the train moving at $59.9999999999981455834 \text{ km}_A/\text{h}_A$.

One other prevailing view is that each one, A and B, will see the other moving at a speed slower than 60 km/h, and therefore each one will perceive a shorter meter and a longer second when observing the other, something which somewhat contradicts the Lorentz factor. This view derives directly from relativity, considering that all speeds are relative. If time dilation were symmetric, we would expect both time dilation values to be identical relative to an external observer (person C).

3. Experiment 2

Of course, several factors other than relative speed will affect length contraction and time dilation. Indeed, if we could consider the movements and gravitational fields of the Earth and beyond, we would obtain different values for the relative speeds between A and B, meaning that the result could be different from that obtained above. The experiment conducted during October 1971 by Hafele and Keating [5] [6] to test Einstein's theory of relativity with macroscopic clocks provides a good example of this situation. Their working hypothesis was to test whether the time recorded (relative to a clock at rest on the Earth surface) by four caesium atomic clocks onboard two regularly scheduled commercial jets flown twice around the world (at typical jet aircraft speeds), one eastward, the other westward, would run faster or slower, depending on the direction and ground speed, after circumnavigation of the Earth. The variables under consideration were the speed (relative to a reference atomic clock maintained at the United States of America Naval Observatory), the altitude, the direction of the circumnavigation and the rotational speed of the Earth.

Special relativity [1] predicts that a moving standard clock will record less time compared with coordinate clocks distributed at rest in an inertial reference space (assuming the Earth surface as an inertial frame of reference). However, since the Earth rotates, coordinate clocks distributed at rest on its surface are not suitable to test Hafele and Keating's working hypothesis [6].

The Earth's rotation is computed by comparison to the "fixed stars", stars that move very slowly relative to the Earth and are therefore considered as a good reference frame. The sidereal period, the time taken by a celestial body within the solar system (the Earth, in the present case) to complete one revolution with respect to the "fixed stars", equals 23 h, 56 min and 4.09053 s. With a circumference of ca. 40,075 km at the equator, an object at the equator on the surface of

the Earth moves, relative to the “fixed stars”, with a speed of 460 m/s.² As the Earth rotates, everything on the ground, in the water, and in the air (e.g., the atmosphere or airplanes flying inside it) also rotates at the same angular speed because of gravity. Therefore, the rotation of the Earth should have no direct differential influence on how long airplanes take to fly eastward or westward when comparing the airplane clocks with that on the surface of the Earth (considering here the atomic timescale of the USA Naval Observatory as the external, independent observer), but they have a differential influence if the “fixed stars” (in this case considered as the external, independent observer) are taken into account. In addition, there is an indirect influence on the travel time taken by airplanes eastward or westward: as a result of the Earth’s rotation, the Coriolis effect is responsible for the high-speed, high-altitude winds of the jet stream, winds prevailing westward at some latitudes and eastward at others. This means that flight times are sometimes shorter eastward and sometimes shorter westward.

The experimental design was based on the predicted assumption that an asymmetry would be found in the time difference between the flying clocks and the ground reference clock, depending on the direction of the circumnavigation [7] [8]. The time elapsed in each case (*i.e.*, eastward, and westward) was compared to that of a reference atomic clock maintained at the USA Naval Observatory (**Table 1**). Consequently, for the flying clocks, and relative to the corotating Earth surface reference clock, circumnavigation in the direction of the Earth’s rotation (eastward, comparatively longer seconds, increased speed) should originate a shorter time recording (*i.e.*, time dilation), whereas circumnavigation in the opposite direction (westward, comparatively shorter seconds, decreased speed) should originate a longer time recording (*i.e.*, time contraction). As predicted by general relativity [9], one other factor considered in **Table 1** that also affected time dilation was the difference in gravitational acceleration between the flying and ground reference clocks.

The results recorded, presented in **Table 1**, show direction-dependent time differences which are in good agreement with the predictions of conventional relativity theory. Relative to the atomic timescale of the USA Naval Observatory, the flying clocks measured less 59 ns \pm 10 ns during the eastward trip and measured more 273 ns + 7 ns during the westward trip [5]. Obviously, both the atmosphere and the jets are corotating with the Earth surface at the same angular speed (unlike the linear speed relative to the “fixed stars”, which increases with the flight altitude). If the speed relativity between both jets and the USA Naval Observatory were 100%, we would expect both time differences (eastward or

²Let us assume that an imaginary observer located at one of the “fixed stars” is monitoring the angular velocity of a fixed point on the Earth equator. Ideally, the observer must view the Earth from a position perpendicular to the rotation axis of the Earth. If only the rotation of the Earth is taken into account, the angular velocity, but not the speed, will be zero after successive periods of Earth 23 h, 56 min and 4.09053 s. The only possibility he would have to assess the angular velocity of the equator, albeit impossible to achieve at present, would be to compare the relative duration of each second at the equator with its own.

Table 1. Recorded versus predicted relativistic time differences observed during the experiment performed in October 1971 by Hafele and Keating [5] [6]. Data are presented as the mean \pm standard deviation of the results obtained from four different caesium atomic clocks.

Effect	Time difference (ns)	
	Direction: East*	Direction: West
Total (predicted)	-40 ± 23	$+275 \pm 21$
Gravity-dependent (predicted)	$+144 \pm 14$	$+179 \pm 18$
Non-gravity-dependent (predicted)	-184 ± 18	$+96 \pm 10$
Clock 120 (measured)	-57	$+277$
Clock 361 (measured)	-74	$+284$
Clock 408 (measured)	-55	$+266$
Clock 447 (measured)	-51	$+266$
Total (mean) (measured)	-59 ± 10	$+273 \pm 7$

*Negative signs indicate that upon return the flying clocks showed an earlier time (comparatively longer seconds, increased speed) than the time indicated on the reference atomic clock maintained at the USA Naval Observatory. Positive signs indicate that upon return the flying clocks showed a later time (comparatively shorter seconds, decreased speed) than the time indicated on the reference atomic clock maintained at the USA Naval Observatory.

westward) to be identical relative to an external observer (person C, in the present case the USA Naval Observatory).

If we consider a single airplane in the Hafele-Keating experiment, then we have an experiment similar to that in our Experiment 1. Hafele and Keating could not measure length contraction, but they recorded time dilation/contraction, meaning that time adjustments had to be made.

The results of the Hafele-Keating experiment, presented in **Table 1**, show the gravity-dependent time dilation predicted values of $+144 \text{ ns} \pm 14 \text{ ns}$ (eastward flight; shorter seconds) and $+179 \text{ ns} \pm 18 \text{ ns}$ (westward flight; shorter seconds). This result was expected, as the airplanes were both subjected to a lower gravitational acceleration, resulting in shorter seconds in both flights (implying time dilation asymmetry).

However, different predicted time dilation values were found between the eastward and westward flights for the non-gravity-dependent time dilation: $-184 \text{ ns} \pm 18 \text{ ns}$ (eastward flight; longer seconds) and $+96 \text{ ns} \pm 10 \text{ ns}$ (westward flight; shorter seconds). This could be interpreted to mean that, in absolute terms, one plane moved faster (the eastward flight), the other slower (the westward flight) than the clock standing still at the Earth's surface.

A comparison of the relative length of the second in two frames of reference (such as the two airplanes that occupied distinct spacetime conditions) may be

established from any other frame of reference (e.g., the USA Naval Observatory, standing still on the Earth surface).

4. Experiment 3

An interesting analogy may be established with spectrophotometry, used routinely throughout the world in most analytical laboratories (**Experiment 3** in **Table 2**). If we fill a glass cuvette with an aqueous solution of betanin (betanidin 5-*O*- β -D-glucopyranoside; $\lambda_{\max} = 535$ nm), the pigment responsible for the red colour of beetroot (*Beta vulgaris*), and measure its absorbance at 535 nm, we get an absorbance value (A''_{535}), a dimensionless number that does not allow us to know the absolute amount or concentration of pigment present in the cuvette. But if we use a blank control, consisting of an identical glass cuvette filled with water, and measure its absorbance also at 535 nm, we get a different absorbance value (A'_{535}), another dimensionless number which is completely unrelated to betanin. However, if we subtract A'_{535} from A''_{535} , we obtain an absolute, dimensionless number which allows us to indirectly determine the absolute concentration of betanin present in the first cuvette.

Table 2. The three experiments selected to obtain absolute values from relative measurements.

	Experiment 1	Experiment 2	Experiment 3
	Person A standing still on the Earth surface (person B's perspective), and person B onboard a train moving at 60 km/h (person B's perspective)	Caesium clocks onboard two jets, one flying eastward, the other westward	Spectrophotometric measurement of betanin absolute concentration
Relative measurement 1 (person A's perspective)	Person A standing still on the Earth surface	Jet flying eastward	Sample: betanin solution of unknown concentration
Relative measurement 2 (person A's perspective)	Person B onboard a train moving at 60 km/h	Jet flying westward	Blank control
Common reference	Person C occupying any independent spacetime condition, different from those occupied by A and B	Reference atomic clock maintained at the USA Naval Observatory (at rest, on the Earth surface), occupying an independent spacetime condition, different from those occupied by the jets	Anything filling the cuvette holder (e.g., air) against which both A_{535} values are measured
Relative readings to be compared	Comparative time dilation or comparative duration of each second experienced by persons A and B, as measured by person C	Comparative time dilation relative to Earth, or comparative duration of each second in both jets, as measured from a fixed point on the Earth surface	A_{535} readings of sample and blank control
Absolute value obtained	Which person is moving faster in absolute terms	Which jet is moving faster in absolute terms	Betanin absolute concentration

USA: United States of America.

In the 60 km/h-moving train hypothetical experiment, how would it be possible to obtain an absolute value starting from two relative speed measurements? It could be achieved by employing the same reasoning used in the spectrophotometric **Experiment 3 (Table 2)**. The absolute concentration of betanin may be obtained from two relative absorbance measurements (A'_{535} and A''_{535}), each made against a common reference (which may or may not contain an unknown amount of betanin; this reference is the analogous equivalent to person C in **Experiment 1**, and to the USA Naval Observatory clock in **Experiment 2 (Table 2)**). In the betanin spectrophotometric experiment, two relative A_{535} readings are made at first. These readings are relative because they are made with reference to a common medium. Most frequently, the spectrophotometric cuvette holder is empty (*i.e.*, filled with air) so that the A'_{535} and A''_{535} values represent the differences in absorbance at $\lambda = 535$ nm between each one of the liquid-containing cuvettes and air. However, the common reference may be any, as long as the same is used for both readings. In this experiment, we do not know how much 535 nm radiation is absorbed by the air molecules that fill the cuvette holder. What is really important is that both readings, A'_{535} and A''_{535} , are made against the same reference. Instead of air, we could as well use a cuvette filled with an unknown (or known) amount of betanin, even if this is larger than that present in the blank control or even in the betanin solution, the end result will be the same.

The difference between the two spectrophotometric readings obtained (*i.e.*, A'_{535} and A''_{535}) do not provide directly the amount or concentration of betanin present in each sample. However, they tell us about their relative positions in an imaginable absolute scale, *i.e.*, which sample contains more betanin and which sample contains less. To determine the amounts/concentrations of betanin present in absolute terms, we need to construct the corresponding “imaginable absolute scale”, which under laboratory routine conditions is provided by a standard curve, for which a series of pure betanin concentrations are used to relate, under precisely identical conditions, betanin content/concentration with A_{535} . Therefore, within reasonable limits and regardless of the absorbance of the blank control (*i.e.*, A'_{535}), an absolute value for betanin amount/concentration can be obtained from the difference between two relative values, A''_{535} and A'_{535} using a standard curve.

Let us consider that the cuvette holder (most often filled with air) contains a cuvette filled with a residual yet unknown amount of betanin dissolved in water that produces a given A_{535} value (x_{ref} ; *i.e.*, analogous to the unknown absolute speed of the Earth in **Experiment 2, Table 2**). As an example, we will consider this betanin concentration as intermediate between that of the blank control and the betanin sample under analysis. If we now measure the absorbance at $\lambda = 535$ nm of both blank control (A'_{535}) and betanin solution (A''_{535}), readings will give one value higher ($A''_{535} > x_{\text{ref}}$) and one value lower ($A'_{535} < x_{\text{ref}}$) than that contained in the cuvette holder. By calculating $A''_{535} - A'_{535}$ and using the standard

curve, we will be able to determine the absolute concentration of residual betanin in the cuvette holder.

$$(A''_{535} - x_{\text{ref}}) - (A'_{535} - x_{\text{ref}}) = A''_{535} - A'_{535}$$

In addition, we may also conclude that the residual betanin concentration in the cuvette holder is between those of the blank and the betanin sample under analysis.

5. Discussion

A similar reasoning could be applied to the Hafele-Keating experiment [5] [6], which starts with the Earth moving at an unknown absolute speed. The airplanes lift from the Earth's surface, one moving eastward, the other westward. In absolute terms, it is possible to conclude, from the results presented in **Table 1**, that one is moving slower than the Earth's surface reference (*i.e.*, the USA Naval Observatory), the other faster. Which one is moving faster? It takes far more than the rotational movement of the Earth to tackle our planet's absolute speed. It is also necessary to consider its movement in the solar system, that of the solar system within the Milky Way, and so forth. Then, as predicted by the theory of relativity, the complex and constantly changing gravitational field acts differentially on every single particle of our planet. How can we go around it?

By analogy, regardless of the unknown absolute speed of the Earth, a comparison between the relative duration of each second (persons A and B in **Experiment 1**, and jets flying eastward and westward in **Experiment 2**), made from an external, independent spacetime condition (person C in **Experiment 1**, and USA Naval Observatory on the Earth surface in **Experiment 2**), will indicate which one is moving faster in absolute terms. Note that the spacetime condition of the external, independent reference may be unknown, but it must be the one used to compare the two spacetime conditions under analysis. The absolute reference is therefore the speed of light in vacuum, $c = 299,792,458$ m/s.

Going back to persons A and B and the train moving at 60 km/h (as measured by person B relative to the Earth's surface), if person B were to increase his/her speed gradually towards c , B would obviously experience, at each speed, B's length of the meter and B's duration of the second as unchanging. However, to person A or to any other person occupying a distinct but constant spacetime condition, B's length of the meter and B's duration of the second would comparatively and endlessly decrease and increase, respectively, as predicted by the Lorentz factor. Therefore, the relativity between persons A and B in what speed is concerned is not total, since an external observer, person C, occupying a third, distinct inertial frame of reference, will be able to tell which one, A or B, is moving faster in absolute (*i.e.*, not relative) terms: the one for which person C perceives the length of the meter to be comparatively shorter and the duration of the second comparatively longer. This will be the person moving closer to c .

Let us flip the reasoning followed by Hafele and Keating [5] [6] to analyse the results they obtained in October 1971. The Earth is moving at an absolute speed

which is not known. However, when perceived from a reference point, the greater the speed (towards c), the comparatively greater time dilation is.

Although person C cannot look at A and B individually and measure their absolute speeds, C will be able to establish an absolute comparison of their speeds as (with the exception of the intrinsic 60 km/h speed of person B relative to A) each one of them is (almost exactly) identically affected by all possible movements and gravitational fields they may be subjected to. Due to the limit imposed by c on spacetime, A and B's measurements are asymmetrical and C is needed to "break the tie".

In summary, from the 1971 Hafele-Keating experiment [5] [6] we may infer that, in absolute terms, the jet flying eastward (time dilation $-59 \text{ ns} \pm 10 \text{ ns}$; comparatively longer seconds, shorter meters and increased speed) moved faster than the jet flying westward (time dilation $+273 \text{ ns} \pm 7 \text{ ns}$; comparatively shorter seconds, longer meters and decreased speed). The reasoning is as follows: when seen from the Earth's surface, the faster jet is the one in which seconds are perceived to be longer, therefore a lower number of seconds will elapse when compared to the Earth's surface, meaning that less time will pass compared to the Earth, meaning that the jet crew will be slightly younger than the people that remained at the USA Naval Observatory when the jet lands.

One other conclusion may be drawn from the experimental data obtained under the conditions selected for the study performed by Hafele and Keating [5] [6], which used the surface of the Earth as the common reference for both jet flights. In absolute terms, it seems that the jet flying eastward is moving faster than the USA Naval Observatory, whereas the jet flying westward is moving slower.

For any significant degree of accuracy, this analysis should go beyond the speed of the train/jets since, as predicted by general relativity, other factors affect spacetime.

This type of experiment does not depend on the spacetime condition of the common reference (in this case, the Earth's surface). Changing the spacetime condition of the reference would alter the time dilation values of the jet flying eastward ($-59 \text{ ns} \pm 10 \text{ ns}$) and of the jet flying westward ($+273 \text{ ns} \pm 7 \text{ ns}$). In any case, the relative positions of the westward flying jet, the eastward flying jet and c would be unaltered in an absolute speed scale.

Finally, in what spacetime is concerned, a special mention to the absolute universal reference against which all other reference frames may be referenced: the speed of photons in vacuum, c .

6. Conclusions

It is assumed that time and the three dimensions of space do not exist as separate features of our universe, but form a four-dimensional continuum known as spacetime. These observations suggest that space is also relative and that anything disturbing one of the four spacetime dimensions will affect the other three

as well. In support of this is the currently accepted definition for the meter as the distance covered by light in vacuum during $1/299,792,458$ s, as well as the view that the greater a material particle is accelerated in the direction of c , the greater the time dilation and length contraction will be.

In this article, one hypothetical experiment, one real experiment performed in the 1970s, and one experiment from a different field of science are discussed to denote that both time and velocity are relative but subject to an upper limit imposed by the speed of photons in vacuum. In the first experiment, person A is standing still on the Earth surface, and person B is onboard a train passing by person A at the constant speed of 60 km/h (as measured by person B on the train's speedometer). Because we do not know the absolute speed of planet Earth, and since there is no universal, stationary frame of reference against which all other frames of reference may be referenced, we come to conclude that neither person A nor person B is more or less stationary than the other, and both speeds are thusly relative. This reasoning would be "absolutely" correct if it were not for length contraction, time dilation and the speed limit imposed by the speed of photons in vacuum.

Indeed, persons A and B define two distinct inertial frames of reference, which correspond to two different spacetime conditions and which are therefore characterized by comparatively different lengths of the meter and durations of the second, as predicted by the Lorentz factor. Therefore, if person B onboard the train measures the train's speed relative to person A as 60 km/h, then person A cannot see person B passing by at 60 km/h, as person A will look at the moving train and perceive each meter in the train's frame of reference slightly shorter and each second in the train's frame of reference slightly longer than person A's own meters and seconds (at this non-relativistic speed, such effects are so small that it is not possible to measure them experimentally), as given by the Lorentz factor. A simple calculation shows that person A will perceive the train passing by at 59.9999999999981455834 km/h.

If we consider the speed of photons in vacuum ($c = 299,792,458$ m/s) as a universal reference, and if we consider that the greater a material particle is accelerated in the direction of c , the greater time dilation and length contraction will be, then we will have a way to position any two particles' velocity directly and absolutely in relation to c , which means we can tell which particle is moving closer to c .

If, in addition to persons A and B, there is person C occupying an independent, distinct inertial frame of reference, and considering that such person C is capable of comparatively measuring the duration of 1 second experienced by person A and by person B, person C will be unable to determine persons A and B's absolute speeds, but may infer which one is moving at a speed closer to c . How can this inference be reconciled with the understanding that regardless the speed (or more accurately, the spacetime condition) of the observer, he/she will always perceive the speed of photons in vacuum as $c = 299,792,458$ m/s? The

answer may be provided by the observation that we are not dealing with time or space considered individually, but with spacetime instead.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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