Velocity and absurdity in modern physics

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Abstract: When physicists write the variable *v*, they usually mean the velocity of an object in an inertial coordinate system, otherwise known as a reference frame. This is the most common velocity concept in modern physics. The velocity of an object in this sense depends on which inertial coordinate system one is working with. For example, an airplane in flight has a velocity of about 500 miles per hour in a coordinate system anchored in a nearby mountain, a velocity of more than 60 000 miles per hour in a coordinate system anchored in the sun, and a velocity of 0 in a coordinate system anchored in the airplane itself. The widely accepted idea that the ticking rate of a clock is a function of this type of clock velocity is absurd. It implies that a human analyst can control the ticking rates of physical clocks through the mental act of selecting a coordinate system. This is a nonsensical mingling of imagination with reality that is akin to believing that a movie character can jump out of your television set and take a seat in your living room. Despite this absurdity, the idea that a clock's ticking rate depends on its velocity in an inertial coordinate system is a staple of modern physics. It is a pillar of Einstein's special theory of relativity. It is central to the standard analysis of the so-called twin paradox. It underlies the predictions of Hafele and Keating concerning the ticking rates of clocks that travel in airplanes. Velocity absurdity of this sort flourishes today, and it may well continue to flourish for many years to come. © *2020 Physics Essays Publication*. [http://dx.doi.org/10.4006/0836-1398-33.2.118]

Résumé: Lorsque les physiciens écrivent la variable *v*, ils désignent généralement la vitesse d'un objet dans un système de coordonnées inertiel, autrement appelé cadre de référence. Il s'agit du concept de vitesse le plus courant en physique moderne. La vitesse d'un objet dans ce sens dépend du système de coordonnées inertiel avec lequel on travaille. Par exemple, un avion en vol a une vitesse d'environ 500 miles par heure dans un système de coordonnées ancré dans une montagne voisine, une vitesse de plus de 60.000 miles par heure dans un système de coordonnées ancré au soleil et une vitesse de 0 en un système de coordonnées ancré dans l'avion lui-même. L'idée largement acceptée selon laquelle le taux de tic-tac d'une horloge est fonction de ce type de vitesse d'horloge est absurde. Cela implique qu'un analyste humain peut contrôler les taux de tic-tac d'horloges physiques grâce à l'acte mental de sélectionner un système de coordonnées. Il s'agit d'un mélange absurde d'imagination et de réalité qui revient à croire qu'un personnage de cinéma peut sauter de votre téléviseur et prendre place dans votre salon. Malgré cette absurdité, l'idée que le taux de tic-tac d'une horloge dépend de sa vitesse dans un systéme de coordonneés inertiel est un élément essentiel de la physique moderne. C'est un pilier de la théorie de la relativité restreinte d'Einstein. Il est au cœur de l'analyse standard du soi-disant paradoxe des jumeaux. Il sous-tend les prédictions de Hafele et Keating concernant les taux de tic-tac des horloges qui voyagent dans les avions. L'absurdité de la vitesse de ce type fleurit aujourd'hui, et elle pourrait bien continuer de prospérer pendant de nombreuses années à venir.

Key words: Velocity; Coordinate System; Reference Frame; Cosmic Microwave Background; Clock; Special Theory of Relativity; Einstein; Herbert Dingle; Twin Paradox; Hafele–Keating Experiment.

I. VELOCITY CONCEPTS

The word "velocity" has many meanings. To begin with, it is sometimes used to designate a scalar quantity and sometimes a vector. In this paper, I will always use the unqualified noun "velocity" to mean a scalar quantity. When the context calls for it, I will include the qualifier "scalar" or "vector" as appropriate.

Scalar velocity in turn can mean different things. Following are three scalar velocity concepts that are in common use.

Scalar velocity in a coordinate system. Physicists make extensive use of the idea of an object's velocity in an object-anchored inertial coordinate system. Inertial coordinate systems are often called reference frames, a term that I avoid for reasons that I need not go into here. The numeric value of an object's velocity in an inertial coordinate system depends on the object that anchors the coordinate system. Consider the example of an airplane in flight. The airplane has a velocity of about 500 miles per hour in a coordinate system anchored in a nearby mountain, a velocity of more than 60 000 miles per hour in a coordinate system anchored in the sun, a velocity close to the speed of light in a

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coordinate system anchored in a cosmic ray, and a velocity of 0 in a coordinate system anchored in the airplane itself. This example is typical. Every object has a velocity of 0 in a coordinate system that it anchors, and any number of other velocities in coordinate systems that are anchored in other objects. To say that a certain object has a certain velocity in a certain coordinate system is to describe a relation between the object and the coordinate system. Although this point is obvious when stated, it can easily get lost because our customary way of describing this relation sounds like an attribution of a property to the object itself. We say, "the velocity of the airplane."

The airplane example makes another appearance in Section VI when I discuss the Hafele–Keating experiment.

Scalar velocity through space. An object's scalar velocity through space is a property of the object itself, much like its shape, chemical composition, or temperature. It has no dependency on other objects or coordinate systems. Just as an object always has some temperature, which can increase or decrease with changing circumstances, it always has some scalar velocity through space, which can increase or decrease if some force accelerates or decelerates it. Scalar velocity through space is sometimes called "absolute velocity." I avoid this term because it carries a lot of baggage, including an association with Newtonian theology, an association with the luminiferous ether, and an aura of obsolescence. I am interested in the plain, naive concept of coordinate-system-independent velocity through space. This is a concept that a child with no knowledge of the history of physics can entertain.

Some writers deny that there is such a thing as scalar velocity through space. The denials often take the form of nebulous slogans such as "motion is relative" rather than fully articulated statements of belief. I leave the question of whether or not objects actually have scalar velocities through space for Section II. Whatever the correct answer to that question is, one of the ideas that people commonly associate with the word "velocity" is that of an object's individual, nonrelative, coordinate-system-independent velocity through space. In fact, I think this is the most common way of understanding the word "velocity." If there is no such thing, then this ordinary meaning of the word is rooted in a misconception.

Scalar velocity due to cosmic expansion. This is the concept that is in play when astronomers speak of the recession velocity of distant galaxies. According to prevailing cosmological theory, space is a kind of fabric that is continuously expanding or stretching. As a result, the distance between our Milky Way galaxy and galaxies that are extremely far away from it is continuously increasing. Although people describe this situation by attributing recession velocities to the distant galaxies, the actual phenomenon involved is the growth of the intervening space. For most kinds of growth, we speak of a growth *rate* rather than a velocity. For example, human populations and economies have growth rates. However, when the thing that grows is a distance, the growth rate has the units of velocity—distance divided by duration—and so it is natural to call it a velocity. It would be more accurate to speak of the growth velocity of the distance separating us from a distant galaxy instead of the recession velocity of the galaxy. The reason we do not do that, I believe, is that our world view is biased toward what we can observe; the distant galaxy is visible whereas the growing distance between the galaxy and us is not.

Some cosmologists do not believe that space is expanding. If they are right, distant galaxies have recession velocities equal to zero. I take no position on that question here. Like the concept of coordinate-system-independent velocity through space, the concept of recession velocity due to cosmic expansion is a concept that some people associate with the word "velocity" whether it applies to the real world or not. In this opening section, I am simply putting these velocity concepts on the table without prejudging their usefulness.

Since a scalar velocity is the computational result of dividing distance by duration, the word "velocity" has further ambiguities that reflect different ways of defining and measuring distance and duration. This aspect of the subject is made complicated by the so-called length contraction and time dilation that are posited in relativity theory. It is not a concern of this paper, however, and so there is no need to go into it here.

Velocity due to cosmic expansion is also not a concern of this paper. I have mentioned it here in order to rope it off from the discussion that follows. This paper is exclusively concerned with the first two concepts of scalar velocity introduced in this section—velocity in an inertial coordinate system and coordinate-system-independent velocity through space.

II. VELOCITY THROUGH SPACE

In Section I, the question came up whether there is such a thing as coordinate-system-independent velocity through space. This section discusses that question, but does not commit to an answer. When I use the concept of coordinate-system-independent velocity through space in the sections that follow, it will not matter whether there actually is such a thing; it will matter only that we are able to imagine that physical objects have such a property. However, in order to show that this act of imagination is not frivolous, I present in this section two arguments for the conclusion that every physical object does always have a coordinate-system-independent velocity through space. These are strong arguments, but they leave room for doubt.

Here is the first argument. In outer space, far from significant gravitational influences, imagine a large number of rocket ships on cruise control, traveling in various directions. Each ship can serve as the anchor of an inertial coordinate system. Each ship has a velocity in each ship-anchored coordinate system, including its own. One can envision a huge matrix that shows the velocity of each ship in each ship-anchored coordinate system. We can call this matrix *the mammoth velocity matrix*. Let us suppose that the columns of the mammoth velocity matrix represent the coordinate systems, while the rows represent the ships considered as objects moving in the coordinate systems. The diagonal of the mammoth velocity matrix contains only zeros, because each ship has a velocity of 0 in the coordinate system that it anchors. There could be an off-diagonal 0 here and there, but in general the off-diagonal entries will be nonzero.

Now suppose that the pilot of one of these ships briefly guns his engines, in either forward or reverse, possibly changing direction in the process, and then resets his cruise control. During this burst of acceleration, the maneuvering ship will not anchor an inertial coordinate system, but once it is back on cruise control it will once again anchor an inertial coordinate system—though not the same one, of course. After the maneuver, the velocity of this ship in the inertial coordinate system that it anchors will once again be 0, but its velocity in every other coordinate system will have changed. Every off-diagonal number in this ship's row of the mammoth velocity matrix will be different from what it was before the maneuver. However, the physical processes triggered by this maneuver are spatially bounded, being confined to the ship that executed the maneuver and its immediate vicinity. The maneuver has no causal impact on any of the other ships that anchor coordinate systems, because they are so far away, and it does not affect the axes of any of those coordinate systems, because the axes exist only in our thoughts.

Here is the crucial question. How can it be that all of these velocities change as a result of a maneuver whose causal impact is confined to such a limited region of space?

The answer to this question is simple if the ship that executes the maneuver has a coordinate-system-independent velocity through space. The maneuver *physically causes* a change in that ship's velocity through space, and that physically caused change has *mathematical implications* for that ship's velocities in the various coordinate systems. If this is a correct account, the situation is analogous to what happens when a person gains or loses weight: The person's diet and exercise have physical effects on that person alone, but the difference between that person's weight and every other person's weight changes as a mathematical implication of the physically caused change in the one person. Algebraically speaking, if k is a constant, then a change in x entails a change in $k - x$. The change in velocity-in-a-coordinate-system is a bit more complicated than a change in weight difference because direction of travel plays a role in addition to the scalar velocity values, but the nature of the dependence is the same. Suppose that ship A has a constant scalar velocity through space of 100 km/s and ship B executes a maneuver that increases its scalar velocity through space from 80 km/s to 90 km/s. If both of these ships are traveling in exactly the same direction, the velocity of ship B in a coordinate system anchored in ship A will decrease from 20 km/s to 10 km/s. If the ships are traveling in exactly opposite directions, the velocity of ship B in a coordinate system anchored in ship A will increase from 180 km/s to 190 km/s. In general, the change in the scalar velocity of ship B in a coordinate system anchored in ship A depends on the angle between the directions in which the ships are traveling.

Now suppose that the ship that executes this maneuver does not have a coordinate-system-independent velocity through space. Under this assumption, no answer to the question seems possible. The ship's localized physical maneuver has got to be part of the answer, because without that maneuver no entry in the mammoth velocity matrix would change. But the physical causation cannot be the whole explanation of the changes in the matrix, because the physical causation does not reach the other ships, which are too far away, or the coordinate axes, which exist only in our thoughts. Only a two-part explanation seems possible: (1) physical causation of a change in the ship's coordinate-system-independent velocity through space, which (2) mathematically entails changes in the ship's velocity in all the coordinate systems except its own.

This argument does not tell us what the velocity through space of any of the ships is. It tells us only that each off-diagonal entry in the mammoth velocity matrix is a secondary quantity that depends on the following three more fundamental quantities:

- The velocity through space of the ship that anchors the relevant coordinate system.
- The velocity through space of the ship whose velocity in that coordinate system is in question.
- The angle between the directions in which these two ships are traveling.

We conclude that these three more fundamental quantities must exist, without knowing what their numerical values are.

To refute this argument, one would have to provide a different explanation of how the causally localized maneuver of one ship manages to change all the off-diagonal entries in a row of the mammoth velocity matrix. I consider the argument strong, because I have no idea what form a different explanation could take.

The second argument involves a recently discovered physical phenomenon, the dipole anisotropy of the cosmic microwave background (CMB) radiation. This argument supports the thesis that every physical object has a coordinate-system-independent velocity through space, and in addition it yields approximate numerical values for the velocities through space of familiar physical objects.

The CMB radiation is thought to have been released everywhere in space billions of years ago when matter first became sufficiently sparse to allow radiation to travel freely. Today it is present everywhere, traveling in all directions with an almost perfectly uniform frequency spectrum and intensity. Its frequency spectrum matches that of radiation that has just been emitted by a black body whose temperature is approximately 2.7 K. According to prevailing theory, it was actually emitted by a black body having a temperature of about 3000 K, and has undergone a steady decrease in frequency during the ensuing eons due to the stretching of space.

Three satellites equipped with microwave antennas—the Cosmic Background Explorer (COBE) launched in 1989, the Wilkinson Microwave Anisotropy Probe (WMAP) launched in 2001, and the Planck satellite launched in 2009—have taken ever more detailed and precise measurements of this very old, very faint radiation. The main goal of these missions was to discover and measure small nonuniformities in the CMB radiation coming from different directions. Such small nonuniformities in the radiation of today would be evidence of similarly small nonuniformities in the distribution of matter at the time the radiation was released. These small primordial nonuniformities in the distribution of matter had been hypothesized to explain the large nonuniformities in the distribution of matter that are observed in today's universe; the small primordial nonuniformities could be transformed into today's large nonuniformities by billions of years of gravitational clumping. They were dubbed "wrinkles in time" by one researcher.[1]

In addition to successfully measuring such small nonuniformities, all three of these satellites also measured a much larger and extremely regular nonuniformity in the CMB radiation. The 2.7-K frequency spectrum shifts slightly as a function of direction in a mathematically smooth way. Specifically, the frequency is highest for the CMB radiation coming from the direction of the constellation Leo and lowest for the CMB radiation coming from exactly the opposite direction. Between these two poles, it declines smoothly from the maximum to the minimum as a function of the angle from the direction of the maximum frequency. This extremely well-defined pattern is the CMB dipole anisotropy.

Like the pattern of changes in the mammoth velocity matrix, the CMB dipole anisotropy has a straightforward explanation with no apparent alternative. The measured frequency of the received radiation is highest in the direction in which the antenna receiving the radiation is moving. The reason is that the antenna is moving directly toward the parade of electromagnetic wave crests that is approaching it from that direction. The reception frequency is lowest in the opposite direction, because the antenna is moving directly away from the parade of electromagnetic wave crests that is approaching it from that direction. One can construct a rough analogy with automobiles. Imagine a slowpoke automobile traveling down a straight multilane highway at 30 mph. Every other car on the road is going 60 mph. All these cars will pass the slowpoke car, but an oncoming car will pass it more quickly than a car that overtakes it from behind. The time interval that begins when the front bumper of a 60-mph car is even with a given spot on the slowpoke car and ends when its rear bumper is even with the same spot corresponds to the time interval between the arrivals of two successive CMB wave crests at the antenna. To transform this automobile scenario into the CMB dipole scenario, (1) replace the slowpoke car with the antenna, (2) replace all the high-speed cars with photons, and (3) add photons coming at the antenna from all other directions.

Using the frequency data for many directions, it is a straightforward exercise to compute the satellite velocity that would give rise to the observed difference between the maximum received frequency and the minimum received frequency. That computed velocity is about 370 km/s. One can conclude that the satellite is traveling in the direction of the constellation Leo with a velocity through space of about 370 km/s. Based on other considerations, astronomers believe that the center of the Milky Way galaxy is moving in the direction of the constellation Leo with a velocity of more than 600 km/s, and that the cause of this motion is the gravitational pull of a huge concentration of mass, known as the Great Attractor, which is located in that direction. The velocity of the earth toward the Great Attractor is slower than the velocity of the center of the Milky Way in that direction because the earth is currently on the side of the Milky Way that is rotating away from the Great Attractor.

One can use the velocity through space of the CMB satellite to estimate the velocity through space of many other objects. Consider an inertial coordinate system that is anchored in the CMB satellite. Any object whose velocity in that coordinate system is less than a few percent of 370 km/s will have a velocity through space that is within a few percent of 370 km/s. This condition is satisfied by the planet earth and all large objects that are gravitationally bound to it. In particular, each of us has a velocity through space of about 370 km/s in the direction of the Great Attractor. At another extreme, any object whose velocity in a coordinate system anchored in the CMB satellite is many times larger than 370 km/s will have a velocity through space that is not too different, percentagewise, from its velocity in that CMB-satellite-anchored coordinate system. This condition is satisfied by all small particles, such as naturally occurring cosmic rays or protons in accelerators, whose velocity in the CMB-satellite-anchored coordinate system is close to the speed of light. This reasoning gives us meaningful estimates of the coordinate-system-independent velocities through space of a wide assortment of objects.

P. J. E. Peebles wrote two books in which he described the likely outcome of these satellite observations of the CMB before any observations were made. In both of these books, he made a point of claiming that such a set of observations "does not violate relativity." In 1971, he wrote:

> The microwave radiation provides a frame of reference, for it can appear isotropic only for one preferred motion…
>
> One should bear in mind that this experiment does not violate relativity, because we are only determining our velocity relative to the radiation.[2]

In 1993, he wrote:

> Blackbody radiation can appear isotropic only in one frame of motion. An observer moving relative to this frame finds that the Doppler shift makes the radiation hotter than average in the direction of motion, cooler in the backward direction. That means the CBR acts as an aether, giving a local definition for preferred motion. This does not violate relativity; it is always possible to define motion relative to something, in this case the homogeneous sea of radiation.[3]

There is a big problem here. On what basis does Peebles declare that the calculated velocity is velocity "relative to the radiation" or "relative to the homogeneous sea of radiation"? The fact that the radiation was used to calculate the velocity gives no reason to think that the velocity thus calculated is relative to the radiation. I can drive this point home with an everyday example. The speedometer of an automobile displays a velocity that is calculated by using the rolling wheels to measure the distance the automobile travels over the pavement. But the velocity of the automobile that is calculated in this way is not velocity relative to its wheels! There is no necessary connection between what you use to determine a velocity and what (if anything) the velocity is relative to. Peebles has no basis at all for saying that the velocity computed from the CMB radiation frequency data is velocity relative to that radiation. He just says it, presumably because it supports his preconceived notion that "all motion is relative."

One can go a step further and question whether it even makes sense to say that an object has a velocity relative to the radiation or relative to the homogeneous sea of radiation. In the work of Einstein, velocity is always in a coordinate system that is anchored in a so-called rigid body. I can see how a nonrigid body might work just as well, if its center of mass is moving uniformly. But an omnidirectional, criss-crossing rush of electromagnetic radiation is not any sort of body. I do not think there is any entity here that an object can have a velocity relative to.

It is true that one can imagine an object that receives exactly the same blackbody spectrum of the CMB radiation from all directions, and that one can define an inertial coordinate system that is anchored in that hypothetical object. The velocity of the satellite in that coordinate system will then be numerically equal to the velocity that scientists have computed using the CMB measurements. However, it does not follow from this that the scientists were computing a velocity in this coordinate system. Suppose that there is such a thing as coordinate-system-independent velocity through space. Then it is a trivial exercise to imagine an object whose velocity through space is zero, and to define a coordinate system that is anchored in that object. Every object will then have a coordinate-system-independent velocity through space *and also* a numerically equal velocity in a coordinate system that is anchored in this hypothetical zero-velocity object. The possibility of defining such a coordinate system is therefore compatible with—indeed it is a necessary consequence of—the reality of coordinate-system-independent velocity through space.

Finally, let us consider Peebles's claim that what has been learned from the CMB satellite missions does not violate relativity. It is difficult to either agree or disagree with this statement because it is not clear what it means. What *proposition* does Peebles wish to defend against a potential attack? Whenever you discuss a proposition, you should state the proposition and not merely gesture toward it with an ambiguous word or phrase such as "relativity." If the proposition at issue is that there is no such thing as coordinate-system-independent velocity through space, I think Peebles is on thin ice because I do not see how to make sense of the CMB satellite observations without attributing to the satellite a coordinate-system-independent velocity though space of about 370 km/s. Yes, you can imagine a coordinate system in which the satellite's velocity is numerically equal to this value, but this imaginary coordinate system plays no role in the velocity computation. The satellite's coordinate-system-independent velocity through space is fundamental; its numerically equal velocity in an imaginary coordinate system is secondary. This statement may not be beyond doubt, but these passages by Peebles present no reason to doubt it.

It is standard practice to describe the CMB satellite's velocity in a way that protects the idea that velocity must be relative to something. George Smoot echoes Peebles when he speaks of velocity "relative to the cosmic background radiation."[4] Smoot also speaks of velocity "with respect to the rest of the universe."[5] Richard Muller speaks of velocity "with respect to the distant universe."[6] John Mather speaks variously of velocity "in relationship to distant parts of the universe,"[7] velocity "in relationship to other parts of the universe,"[7] and velocity "relative to the universe."[8] These are all ill-defined expressions. Moreover, they all seem to describe collections of many things moving in many different directions; how can you define velocity relative to such a chaos? Most importantly, they all seem irrelevant, because the frequency measurements on which the velocity calculation is based concern the satellite's collisions with immediately adjacent electromagnetic radiation. What does the distant universe, or the universe as a whole, have to do with this purely local affair? I believe all these vague locutions stem from a desire to hold onto the dogma that velocity is necessarily relative to something. There is room for these men to sharpen their thinking about velocity.

My mammoth-velocity-matrix argument is based on a thought experiment. My CMB-dipole-anomaly argument is based on a series of real experiments. I think the fact that these two arguments are so different strengthens my case a bit further. Two very different arguments converge on the same conclusion: Every physical object has a velocity through space, without regard to other objects or object-anchored coordinate systems.

I close this section by repeating that I am not going to rely on the reality of coordinate-system-independent velocity through space as a premise in any argument. I recommend this idea as a plausible backdrop for the arguments that follow, but the arguments do not depend on it.

III. EINSTEIN'S VELOCITY ABSURDITY

The first half of this section sets the stage for my discussion of velocity absurdity in the work of Einstein. The second half discusses the absurdity.

The opening paragraphs of Einstein's 1905 paper "On the Electrodynamics of Moving Bodies" strongly suggest that the paper is going to use only one velocity concept, namely, velocity in a coordinate system that is anchored in an object. In the first paragraph, Einstein discusses "the electrodynamic interaction between a magnet and a conductor" and claims that "the observable phenomenon depends here only on the relative motion of conductor and magnet." He takes this as a reason to question the prevailing practice of distinguishing two cases—one in which "the magnet is in motion and the conductor is at rest" and one in which "the magnet is at rest and the conductor is in motion." In the second paragraph, he says that this example and others like it "lead to the conjecture that not only in mechanics but in electrodynamics as well, the phenomena do not have any properties corresponding to the concept of absolute rest."[9] He does not explicitly deny that the relative velocity of two objects is a function of their respective velocities through space—I find his writing a bit coy in this respect—but he makes it clear that he has no use for the concept of an object's "absolute" velocity through space. He is going to present a theory in which this concept plays no role.

After having one's expectations set by these opening paragraphs, it is natural to experience some disorientation upon encountering "the system at rest" in the very first paragraph of Section 1:

> Consider a coordinate system in which the Newtonian mechanical equations are valid. To distinguish it verbally from the coordinate system that will be introduced later on, and to visualize it more precisely, we will designate this system as "the system at rest."[10]

There is a second dose of disorientation in store a few pages later when Einstein introduces the other coordinate system and calls it *the moving system*. Having used his opening paragraphs to criticize the idea that one object is at rest while another object is in motion, he seems to ignore that opening salvo and describe the two coordinate systems he is going to use in precisely the way he has just criticized—one is at rest and one is moving.

He could easily have avoided this asymmetry. Symmetrical ways of describing two coordinate systems in motion relative to each other are and were readily available. For example, he could have achieved his stated goals of distinguishing the two coordinate systems verbally and visualizing them more precisely with a passage such as the following, which uses trains in a way that he did on many other occasions:

> Consider two coordinate systems in which the Newtonian mechanical equations are valid. To distinguish them verbally and to visualize them more precisely, imagine that they are anchored in two locomotives that are traveling away from each other on a straight east-west track. We can refer to these coordinate systems as the westbound system and the eastbound system. Let us look first at the westbound system.

From here, the paper could proceed exactly as it does, with all references to the system at rest and the moving system replaced, respectively, by references to the westbound system and the eastbound system.

Why did Einstein not employ a symmetric way of designating the two coordinate systems, in keeping with the symmetry of magnet and conductor with which he began the paper? One possible explanation is that he simply did not think of doing so; he might have been so preoccupied with the content of his theory that he gave little thought to the niceties of naming coordinate systems. Another possible explanation is that his education had so habituated him to the traditional asymmetric terminology that he backslid into it immediately after rejecting the idea that gives it meaning. Perhaps there is some truth in both of these conjectures; perhaps there is no truth in either of them. In any case, the combination of Einstein's opening rejection of rest/motion asymmetry with his subsequent use of asymmetric rest/motion descriptions for his two coordinate systems is a reason for puzzlement.

In an extended discussion of Einstein's paper, Alberto Martínez calls attention to this puzzling feature of it when he writes:

> In Einstein's analysis, nothing distinguishes material bodies as being really stationary instead of in uniform rectilinear motion. There is only the free decision to identify a given reference frame by the *name* "system at rest." Einstein offset the literal meaning of this expression by enclosing it repeatedly in quotation marks.[11]

This comment is fine as far as it goes, but it does not go very far. There are several important points that Martínez leaves out. First, although naming something as one pleases is indeed a "free decision," naming something with a scare-quoted descriptive phrase that does not correctly describe the thing is not a good decision. One can easily do better. Second, although Einstein did indeed enclose this expression in quotation marks *repeatedly*, he did not do so *consistently*. The first occurrence of this expression is in quotation marks and so are some of its subsequent occurrences. However, other occurrences are not. For example, Section 1 ends with the following sentence, which contains two unquoted occurrences:

> It is essential that we have defined time by means of clocks at rest *in a system at rest*; because it belongs to the system at rest, we designate the time just defined as "the time of the system at rest."[12] (my emphasis)

It is important to note here that the phrase I have italicized is a seriously misleading mistranslation of the German "im ruhenden System,"[13] which plainly means "in *the* system at rest." The words "a system at rest" can only be read as stating a condition that the system must satisfy; this was not Einstein's intent, as Martínez correctly points out. One has to wonder whether Einstein's confusing way of referring to this coordinate system confused the translator. Third and finally, Einstein *never* put the name of the other coordinate system in quotation marks, although there was equal reason to do so. Here is the first paragraph in which he refers to the second coordinate system:

> The origin of one of the two systems (k) shall now be imparted a (constant) velocity v in the direction of increasing x of the other system (K), *which is at rest,* and this velocity shall also be imparted to the coordinate axes, the corresponding measuring rod, and the clocks. To each time t of *the system at rest* K there corresponds then a definite position of the axes of *the moving system,* and for reasons of symmetry we may rightfully assume that the motion of k can be such that at time t ("t" always denotes a time of *the system at*

> *rest*) the axes of *the moving system* are parallel to the axes of *the system at rest*.[14] (my emphasis)

This paragraph contains two unquoted references to the so-called moving system as well as four additional unquoted references to the so-called system at rest. Scare quotes are nowhere to be seen. In sum, there is a twofold inconsistency in Einstein's use of quotation marks when referring to these coordinate systems: He used quotation marks sometimes but not always for the so-called system at rest, and he never used them for the so-called moving system.

Albrecht Fölsing has also commented on this puzzling terminology, somewhat less forgivingly than Martínez. In his biography of Einstein, Fölsing writes:

> To be sure, Einstein is using almost "prerelativist" terminology by referring, throughout this section, to a system "at rest" in which the rod, either at rest or in motion, is observed. While this formulation lets the background of Lorentzian theory—a motionless ether—shine through, it also leads to complications in which even an attentive reader can lose the thread. For that reason I shall use two referential systems: this will deviate from Einstein's text but will not change his argument. In fact, in his next section Einstein himself goes over to this clearer presentation.[15]

Fölsing then proceeds to refer to the two coordinate systems in a strictly symmetric manner as system *k* and system *K*. I should add that Fölsing's comment strikes me as itself somewhat confused, in that he seems to applaud the fact that Einstein's terminology "lets the background of Lorentzian theory—a motionless ether—shine through." That is precisely the problem! Given that Einstein is abandoning the idea of the motionless ether, he should not write in a way that lets that idea "shine through."

In Section 3 of his paper, Einstein derives, or at least claims to derive, the equations that are known as the Lorentz transformations. This paves the way for Section 4, which is titled "The physical meaning of the equations obtained concerning moving rigid bodies and moving clocks." Section 4 begins with a discussion of so-called moving rigid bodies, which Einstein has already discussed a bit in Section 2. It ends with a discussion of so-called moving clocks, which he has not discussed previously.

Concerning so-called moving rigid bodies, Einstein claims that the physical meaning of the Lorentz transformation equations lies in a comparison of two different ways in which one can measure the length of a rod. One measurement procedure is the familiar one, in which the rod to be measured and a person with a meter stick are stationary relative to each other. The person lays the meter stick alongside the rod and reads off a number. In the other measurement procedure, the rod to be measured and the person with a meter stick are in uniform motion relative to each other, possibly at a high speed. In this case, Einstein imagines that one can get the rod to leave behind a kind of footprint as the rod and the person with the meter stick race by each other. The person can then lay the meter stick alongside this footprint to determine the length of the rod that left it. Einstein claims that this second measurement procedure yields a velocity-dependent result, which is related to the result of the ordinary measurement procedure by one of the just-derived Lorentz transformation equations. Here I am omitting details about how Einstein thought one could get a moving rod to leave behind a footprint. I am also omitting all discussion of a huge problem with Einstein's proposed method of length measurement: It depends on the use of two clocks that have been "synchronized" in a covertly skewed way. My paper "Critique of the Einstein clock variable" explains the fateful skewing that is inherent in so-called Einstein synchronization.[16] The important point for present purposes is this: Einstein says that the physical meaning of the Lorentz algebra for so-called moving rigid bodies consists in the fact that two different procedures for measuring the length of one and the same rod yield different numerical results.

I turn now to an examination of Einstein's discussion of so-called moving clocks, which I quote in full:

> We further imagine that one of the clocks that is able to indicate time t when at rest relative to the system at rest and time τ when at rest relative to the system in motion, is placed in the origin of k and set such that it indicates the time τ. What is the rate of this clock when *observed from the system at rest*?
>
> The quantities x, t, and τ, which refer to the position of this clock, are obviously related by the equations
>
> $$\tau = \frac{1}{\sqrt{1-[v/V]^2}}\left[t - \frac{v}{V^2}x\right]$$
>
> and
>
> $$x = vt.$$
>
> We thus have
>
> $$\tau = t\sqrt{1-[v/V]^2} = \ t - [1 - \sqrt{1-[v/V]^2}]t,$$
>
> which shows that the clock (*observed in the system at rest*) is retarded each second by $(1 - \sqrt{1-(v/V)^2})$ sec or, with quantities of the fourth and higher order neglected, by $\frac{1}{2}(v/V)^2$ sec.
>
> This yields the following peculiar consequence: If at the points A and B of K there are located clocks at rest which, observed in a system at rest, are synchronized, and if the clock in A is transported to B along the connecting line with velocity v, then upon arrival of this clock at B the two clocks will no longer be synchronized: instead, the clock that has been transported from A to B will lag $\frac{1}{2}tv^2/V^2$ sec (up to quantities of the fourth and higher orders) behind the clock that has

> been in B from the outset, if t is the time needed by the clock to travel from A to B.
>
> We see at once that this result holds even when the clock moves from A to B along any arbitrary polygonal line, and even when the points A and B coincide.
>
> If we assume that the result proved for a polygonal line holds also for a continuously curved line, then we arrive at the following proposition: If there are two synchronous clocks in A, and one of them is moved along a closed curve with constant velocity until it has returned to A, which takes, say, t sec, then this clock will lag on its arrival at A $\frac{1}{2}t(v/V)^2$ sec behind the clock that has not been moved. From this we conclude 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.[17] (my emphasis)

The two phrases that I have italicized near the beginning of this passage allude to an act of observing a so-called moving clock from the so-called system at rest. These phrases suggest that Einstein's discussion of clocks is going to parallel his discussion of rigid rods. He has just claimed that the Lorentz algebra describes the difference between the results of two different procedures for measuring the length of one and the same rod. Now it seems that he is about to claim that the Lorentz algebra describes the difference between the results of two different ways of observing one and the same clock. One way would be the everyday way of simply looking at a clock that is sitting in front of you. The other way would make use of his theory in a manner that he is about to describe. *This expectation is not fulfilled.* Einstein does not say one word about how to observe a clock that whizzes by you. If this can be done at all, a special procedure is clearly needed, because the relative velocity of clock and observer makes it impossible to even see the clock, let alone read its numerical display or collect sufficient data to compare its ticking rate with that of another clock. For this reason, the italicized references to observing so-called moving clocks are empty. A referee for this paper could reasonably have written the following:

> The author introduces the novel idea of someone observing the ticking rate of a clock that moves past him at high speed. However, he specifies no procedure for doing this. He should either specify a suitable observational procedure or else remove his references to the idea of observing the ticking rate of a speeding clock.

Jumping now to the end of the passage, we see that the clock comparison that Einstein actually makes is not the one that is suggested by the beginning of the passage. Two identical clocks start out side by side with identical readings. They travel along different paths at different speeds and then come together again, at which point it turns out that the readings on the two clocks differ. This scenario involves only one method of observing clocks, namely, the everyday method of looking at a clock that is sitting in front of you. Rather than a comparison between two ways of observing one and the same clock, Einstein gives us a comparison between two clocks that have traveled different paths, both observed in the selfsame ordinary way.

Taking the passage as a whole, the talk at the beginning about observing a clock that is in motion relative to the observer looks like a false start. Part way through the passage, possibly sensing that he has hit a dead end, Einstein stops talking about observing a moving clock and starts talking instead about a moving clock that someone observes in the ordinary way after it has stopped moving. This abrupt switch occurs at the line "This yields the following peculiar consequence," which does a nice job of making a logical gap look like a valid deductive step.

In the middle of the passage, Einstein states that a clock that is moving uniformly with velocity v in the so-called system at rest "is retarded each second by $(1-\sqrt{1-(v/V)^2})$ sec or, with quantities of the fourth and higher order neglected, by $1/2(v/V)^2$ sec" relative to a clock that is stationary in that same system at rest. Note that this is equivalent to saying that a clock that is moving uniformly with velocity v in the so-called system at rest ticks $1/2(v/V)^2(100)$ percent more slowly than a clock that is stationary in that same system at rest. One does not need any conventional unit of measure in order to state this claim, which is all about counting and comparing the number of ticks executed by each of two identically constituted clocks.

Einstein proceeds to compute the accumulated retardation during the trip of the so-called moving clock by multiplying its rate of retardation by the duration of the trip. This yields the conclusion that "the clock that has been transported from A to B will lag 1/2 tv^2/V^2 sec (up to quantities of the fourth and higher orders) behind the clock that has been in B from the outset, if t is the time needed by the clock to travel from A to B." Here, the lag is expressed in seconds because Einstein assumes that t is expressed in seconds. One could equally well use another conventional unit such as minutes or nanoseconds, or a count of the clock's ticks. Once again, conventional units of measure are not essential to the claim.

The situation as Einstein describes it is similar to a foot race. If two runners start a race together and one runs more slowly than the other by a constant amount, the slower runner will fall steadily behind, and the distance between the runners when the winner crosses the finish line will equal the constant difference between their speeds multiplied by the amount of time it took the winner to run the race. Likewise, if two clocks start with identical readings and one "runs" more slowly than the other, the slower clock will fall steadily behind and the accumulated shortfall at any future moment will be the product of the constant rate difference and the elapsed time. Note that Einstein derives this lag formula initially for the case of a single straight-line trip. Having derived it for this case, he proceeds to generalize it to other cases in three quick steps—first to a trip along a polygonal line, then to a trip along a smooth curve, and finally to a trip along a closed smooth curve. There are no further algebraic manipulations, just the claim that the algebra of a steadily increasing lag applies to all these cases.

That is Einstein's reasoning. I turn now to what is wrong with it.

Einstein is describing two clocks. One is stationary in a certain inertial coordinate system, which can be referred to in many ways. Einstein refers to it in three ways:

- "the system at rest" (scare-quoted)
- the system at rest (not scare-quoted)
- system K

Fölsing calls it system K. I have proposed calling it the westbound system. Here, I will call this coordinate system the westbound system and I will call the clock that is stationary in it clock W. The other clock is stationary in another coordinate system, which can also be referred to in many ways. Einstein refers to this other coordinate system in two ways:

- the moving system
- system k

Fölsing calls it system k. I have proposed calling it the eastbound system. Here, I will call this other coordinate system the eastbound system, and I will call the clock that is stationary in it clock E.

All of the algebraic expressions in Einstein's argument employ the westbound system, in which clock W has velocity 0 and clock E has velocity v toward the east. These velocity values describe relationships between the respective clocks and the westbound coordinate system; they do not describe properties that the clocks themselves have. But the ticking of a clock is a property of the clock itself. The argument thus depends on the absurd idea that the actual ticking rate of a clock is a function of a velocity number that a human analyst assigns to the clock by *thinking of it* in the context of an *imaginary* coordinate system that is anchored in an *arbitrarily* chosen object.

One can make this absurdity vivid by describing the same two clocks, clock W and clock E, using various other coordinate systems. Innumerable coordinate systems are available for this purpose.

Consider the eastbound coordinate system. In it, clock E has a velocity of 0 and clock W has a velocity of v toward the west. Using Einstein's reasoning with this coordinate system, one reaches a conclusion opposite to Einstein's conclusion: Clock W falls behind clock E at the rate of $1/2(v/V)^2$ seconds per second.

Now consider a third coordinate system, which is anchored in a telephone pole that stands next to the east-west track along which the eastbound and westbound systems travel. Suppose that the two locomotives have numerically equal velocities relative to the telephone pole. Thus, in the telephone-pole coordinate system, the westbound system has velocity $0.5v$ toward the west and the eastbound system has velocity $0.5v$ toward the east. Let there be a clock fastened to the telephone pole; call it clock P. In the telephone-pole coordinate system, clock P has velocity 0, clock W has velocity $0.5v$ toward the west, and clock E has velocity $0.5v$ toward the east. Using Einstein's reasoning with the telephone-pole coordinate system, one concludes that clocks W and E both fall behind clock P at the rate of $1/2(0.5v/V)^2$ seconds per second. It follows that clock W and clock E run even with each other.

We have now "established" three mutually incompatible conclusions using exactly the same reasoning:

- Clock E runs slower than clock W by $1/2\ (v/V)^2$ seconds per second.
- Clock W runs slower than clock E by $1/2(v/V)^2$ seconds per second.
- Clock E and clock W run at exactly the same rate.

We are able to do this because the reasoning is ridiculous. All three arguments depend on the absurd idea that a clock's relationship to an imaginary coordinate system anchored in an arbitrarily chosen object can affect its ticking rate.

Suppose now that there is a third locomotive on the east-west track, which is heading east but more slowly than the locomotive that anchors the eastbound system. Let the velocity of this third locomotive relative to the telephone pole be pv, where $0 < p < 0.5$. This third locomotive also carries a clock; call it clock Q. In a coordinate system anchored in this third locomotive, clock Q has velocity 0, clock W has velocity $(0.5 + p)v$ toward the west, and clock E has velocity $(0.5 - p)v$ toward the east. Using Einstein's reasoning, one concludes that clock W lags behind clock Q by $1/2\ ([0.5 + p]v/V)^2$ seconds per second and clock E lags behind clock Q by the smaller amount $1/2([0.5 - p]v/V)^2$ seconds per second. It follows that clock W lags behind clock E by $1/2([0.5 + p]v/V)^2 - 1/2\ ([0.5 - p]v/V)^2$ seconds per second, which simplifies to $p(v/V)^2$ seconds per second. The parameter p defines an infinite set of coordinate systems, which we can use to draw an infinite set of conclusions! These conclusions include every logical possibility between no lag at all as $p \to 0$ (the telephone-pole coordinate system) and a lag of $1/2\ (v/V)^2$ as $p \to 0.5$ (the eastbound coordinate system).

In like manner, additional infinite sets of conclusions can be generated from additional infinite sets of coordinate systems, such as the following:

- Coordinate systems anchored in a locomotive that travels westward with velocity pv relative to the telephone pole, where $0 < p < 0.5$.
- Coordinate systems anchored in a locomotive that travels eastward with velocity pv relative to the telephone pole, where $p > 0.5$.
- Coordinate systems anchored in a locomotive that travels westward with velocity pv relative to the telephone pole, where $p > 0.5$.

- Coordinate systems anchored in airplanes that travel in any old direction with any old velocity relative to the telephone pole.

If we set aside the analytic tool of an object-anchored coordinate system and think only about bare unembellished reality, all we have is two clocks, W and E, moving away from each other with the constant relative velocity v. Here, the quantity v describes a relation between the two clocks, not a property of either clock by itself. There is no real-world difference between these clocks that could be the basis for a difference in ticking rates. It is only by introducing the artifact of a coordinate system and describing W and E with respect to that imaginary entity that Einstein is able to associate different velocity numbers with the clocks; W and E have different velocities *in that coordinate system*. This is not a real difference between W and E; it is just a difference in how W and E are related to an imaginary coordinate system that is anchored in an arbitrarily chosen object. It makes no sense that a human being's arbitrary choice of an object to anchor a coordinate system would affect the real ticking rates of real clocks. Imagine yourself choosing the coordinate system anchored in the westbound locomotive, then changing your mind in favor of the eastbound coordinate system, then changing your mind again and using the coordinate system anchored in the telephone pole. The coordinate-system-relative velocities of the two clocks change each time you choose a different coordinate system; do you think the actual ticking rates of the clocks change too, in response to these mental acts of yours?

As I just noted, there is no real difference between the two clocks that could be the basis for a difference in ticking rates; a difference is fabricated by inserting an imaginary coordinate system anchored in an arbitrarily chosen object into the picture. Einstein never makes this point, of course, but his discussion reflects it in an important way: He mentions nothing that causes, or even that could cause, the ticking rate of a clock to change. He gives an algebraic expression—1/2 $(v/V)^2$ —that is said to describe a mathematical relationship between ticking rate and (coordinate-system-dependent) velocity, but he mentions no causal mechanism that could be the reason why such a mathematical relationship obtains. This is a key point that commentators have been remarkably mum about. A clock is a material system—an assembly of interoperating parts composed of protons, neutrons, and electrons. If two such systems *of identical constitution* tick at different rates, one expects there to be something that influences or conditions one of the clocks in a way that *makes* it tick at a different rate. But Einstein mentions no such causal factor. The reason for this omission is simple: No candidate for a causal factor is available. An object's coordinate-system-dependent velocity is not a real, causally capable property of the object; it is just a relation of the object to an imaginary coordinate system anchored in an arbitrarily chosen object.

We are all familiar with the voodoo ritual of sticking pins in a doll in order to inflict harm on a person that the doll represents. It is instructive to compare Einstein's argument about the relation between a clock's velocity and its ticking rate with this voodoo ritual. The voodoo ritual is irrational because there is no reason to believe that there is any causal connection between the doll and the human target. Likewise, Einstein's argument is irrational because it concludes that a clock's ticking rate will change in the absence of any real event or circumstance that could cause it to change. In fact, Einstein's argument is even less rational than the voodoo ritual. With the voodoo ritual, there is a real happening—someone sticks pins in a doll. That is the kind of thing that can have physical effects. The irrationality consists in attributing a fantastic causal power to that happening, which there is no evidence for and much evidence against. With Einstein's argument, there is not even a real happening that could cause a clock to tick differently. Instead of a physical cause, there is only the mental act of thinking of the clock in the context of an imaginary coordinate system that is anchored in an arbitrarily chosen object. Thus, there is the additional irrationality of imagining that a physical happening—the ticking of a clock—can have a mathematical dependence on a human analyst's arbitrary mental act. It is not just that there is no evidence for this dependence; the very idea of a dependence of this sort makes no sense. It is a nonsensical commingling of imagination and reality that is on a par with the idea of a movie character jumping out of your television set and taking a seat in your living room.

It appears to me that Einstein drifted into this sort of velocity absurdity in the first few pages of his 1905 paper inadvertently, and that he did so because he failed to notice a crucial difference between the concept of an object's absolute velocity through space and the concept of an object's velocity in an object-anchored coordinate system. I base this conjecture on the following pair of observations.

First, if a clock has a coordinate-system-independent velocity through space, then the numeric value of that velocity is a real property of the clock, which could conceivably affect the clock's ticking rate. Thus, by blurring the difference between the idea of a clock's coordinate-system-independent velocity through space and the idea of a clock's velocity in a coordinate system that is anchored in an arbitrarily chosen object, one can make it seem that a clock's velocity in an object-anchored coordinate system is also a real property of the clock that could conceivably affect the clock's ticking rate. Blurring the difference between these two velocity concepts would have desensitized Einstein to the absurdity of his reasoning.

Second, there is textual evidence that Einstein quite likely did blur the difference between these two velocity concepts. The evidence is the asymmetry of his repeated references to the system at rest (sometimes scare-quoted, sometimes not) and the moving system (never scare-quoted), which I discussed earlier in this section. His habit of referring to the coordinate systems in this way suggests that "the system at rest" and "the moving system" were not mere labels for him; they also had meaning. He did not think that the so-called system at rest was absolutely at rest, but he thought of it as in some vague way more at rest than the so-called moving system was.

In sum, I think Einstein drifted into this velocity absurdity by treating the idea of velocity in a coordinate system as more similar to the idea of coordinate-system-independent velocity through space than it actually is. Explicitly, he abandoned the idea of absolute velocity, but he then proceeded to use the idea of velocity in an object-anchored coordinate system as if it had a kind of ersatz absoluteness.

I conjecture further that many other people are in a similar muddle regarding the similarities and differences between coordinate-system-independent velocity through space and velocity in an object-anchored inertial coordinate system. This would help to explain why no one has ever pointed out the absurdity of Einstein's reasoning regarding clock velocities and ticking rates, and also why many other physicists have replicated Einstein's absurd reasoning in their own discussions of the special theory of relativity.

Whatever the merits of these conjectures, the absurd thinking about velocity is there in Einstein's paper. It is absurd to suppose that the actual ticking rate of a clock can be a function of a velocity number that a human analyst assigns to the clock by thinking of it in the context of an imaginary coordinate system anchored in an arbitrarily chosen object. One way to highlight the absurdity is to imagine many different human analysts choosing different coordinate systems to work in, thereby assigning different velocity numbers to the same clock. From the different velocity numbers, the different analysts compute different ticking rates. The multitude of mutually contradictory conclusions reflects the absurdity of the reasoning that leads to them.

IV. DINGLE'S CRITICISM OF EINSTEIN

In a series of papers and his book *Science at the Crossroads*, Herbert Dingle criticized Einstein's special theory of relativity for being logically inconsistent in a specific respect.[18] Concerning the case of two clocks that are moving toward or away from each other with constant relative velocity *v*, Dingle claimed that the theory implies that each clock ticks at a slower rate than the other clock. That is a logical impossibility. Dingle's younger colleague Ian McCausland elaborated this same criticism in a series of papers and his book *A Scientific Adventure*.[19] There are others who have made this criticism of the special theory of relativity, but the vast majority of physicists have not. Both Dingle and McCausland devote many fascinating pages to their failed attempts to get prominent physicists to understand and accept their claim that the special theory of relativity is logically inconsistent in this way.

My argument in Section III has the following two significant implications concerning Dingle's criticism of Einstein.

First, Dingle's criticism is correct. It corresponds to my discussion of the clocks in the westbound and eastbound coordinate systems. If you use the westbound coordinate system, clock W has velocity 0 and clock E has velocity *v* toward the east, so by Einstein's reasoning clock E ticks more slowly than clock W. But if you use the eastbound coordinate system, clock E has velocity 0 and clock W has velocity *v* toward the west, so by Einstein's reasoning clock W ticks more slowly than clock E. The symmetry is complete and the respective conclusions are logically incompatible; the upshot is a plain and simple *reductio ad absurdum*. Dingle recognized this absurdity fifty years ago.

Second, Dingle's criticism concerns only a part of the larger absurdity that I described in Section III. Dingle caught sight of a serious problem but he did not see the whole problem. My discussion in Section III goes beyond Dingle's criticism in the following two respects.

One limitation of Dingle's criticism is that he mentions only the two coordinate systems that Einstein mentions. He does not point out that by using other coordinate systems you can use the same reasoning to reach still other conclusions. For example, as noted in Section III, if you use a coordinate system that is anchored in a trackside telephone pole to which clock P is attached, then clock P has velocity 0 while clocks W and E each have velocity *v*/2, so by Einstein's reasoning clocks W and E tick more slowly than clock P by the same amount—from which it follows that clocks W and E tick at the same rate as each other. It is not just that the theory generates two mutually incompatible conclusions; the theory generates infinitely many conclusions each of which is incompatible with all the others. By choosing an appropriate object-anchored coordinate system in which to perform Einstein-style velocity absurdity, you can assign coordinate-system-relative velocities to a pair of mutually moving clocks that enable you to reach just about any conclusion you like regarding the ticking rates of those clocks. In effect, the theory is a dial-a-prediction scheme. As my discussion of the Hafele–Keating experiment in Section VI illustrates, such a scheme can be quite handy if you already know something about the data that you would like to "predict."

By focusing on the contradiction involving the two coordinate systems that Einstein uses, Dingle and McCausland identified a genuine problem, but they did so in a way that blocks insight into the problem's true nature and extent. They were like detectives who viewed part of a room through a keyhole in a locked door. They saw more than the vast majority of physicists, who never looked through the keyhole, but they could have seen even more if they had unlocked the door and searched the whole room. I give Dingle great credit for developing and describing his keyhole view, but now, 50 years later, it is high time that we unlock the door and understand dial-a-prediction velocity absurdity thoroughly.

The other limitation of Dingle's criticism is that he failed to see the muddle regarding different velocity concepts that plays a key role in producing the contradiction. He does not point out that the velocity of a clock *in an object-anchored coordinate system* is not a property of the clock, but merely a relation between the clock and an imaginary coordinate system that is anchored in an arbitrarily selected object. He does not point out that the assertion that there is a mathematical relationship between the real ticking rate of a clock and this sort of arbitrarily assigned velocity number is voodoolike nonsense, as nonsensical as a movie character jumping out of your television set and taking a seat in your living room.

Dingle did search for the source of the contradiction, but his search consisted of some misguided speculation that stems from the following ill-considered statement:

> The theory is based on two postulates and a definition: *if these are granted the rest follows logically*, so there must be an incompatibility in these foundations.[20] (my emphasis)

The italicized clause in this statement is false. Einstein's postulates and definitions do have problems, but there are also problems with Einstein's reasoning, including the two problems that I discussed in Section III—the velocity muddle and the non sequitur that he masks with the words "This yields the following peculiar consequence." Thrown off the scent by this false premise, Dingle devotes the last chapter of his book to various tentative criticisms of Einstein's basic postulates. His discussion is ineffectual in several ways. One, his criticisms of the basic postulates are not compelling. Two, his criticisms point only to the possible falsehood of one or both of the basic postulates, and not to any incompatibility between them, which is what he said he was looking for. And three, he makes no attempt to explain how his criticisms of the basic postulates bear on the contradiction that he correctly identified. This misguided search for the source of the contradiction is a weak part of what is on the whole a very strong book.

There is a related weakness in McCausland's book, which for the most part is also an excellent piece of work. McCausland follows Dingle in presuming that the contradiction that they have identified is rooted in a more fundamental contradiction at the base of the theory. He then plays up the idea that one can validly deduce any proposition at all from a contradiction, from which it would follow that one can validly deduce any proposition at all from the special theory of relativity. This makes it impossible to test the theory experimentally, McCausland claims, because whatever the result of your experiment might be, you can deduce that result from the theory. There are two problems with this line of attack. First, the method by which one can validly deduce any proposition at all from a contradiction belongs to an academic formalism that does not reflect the way people actually think, so there is no danger of anyone using it in real life. To use this method, you have to consciously affirm both a proposition p and its literal negation $\sim p$. The trick is to take the proposition that you want to deduce—for example, "The earth is a giant turnip"—and form the disjunction "Either p or the earth is a giant turnip." The truth of p guarantees that this disjunction is true. Finally, invoke $\sim p$ in order to rule out p, thereby yielding the conclusion that the earth is a giant turnip. This is cute, but no one in his right mind is going to consciously affirm both p and $\sim p$ with equal conviction, so in practice such an argument can get no traction. Second, McCausland, like Dingle, does not identify a contradiction at the base of the theory. He therefore has no actual proposition to play the role of p in the formal argument.

Although McCausland's you-can-deduce-anything-from-a-contradiction line of attack is misconceived, there is something correct and insightful about it. As I have shown, the special theory of relativity does "predict" too much, because it uses an irrational voodoolike procedure to predict the ticking rates of clocks. It is not the case that the theory enables you to predict anything at all, but it is the case that it enables you to make a wide range of mutually contradictory "predictions" concerning a particular subject of scientific interest, namely, the ticking rates of clocks. McCausland mischaracterizes the theory's dial-a-prediction problem, but he is right that it has such a problem. Whenever someone uses the special theory of relativity to predict the ticking rate of a clock, or indeed any other sort of rate or speed, one should study their prediction process to see whether it involves cherry-picking a "friendly" coordinate system. McCausland appreciated the irrational character of the special theory of relativity's prediction process, even though he did not describe the scope of the irrationality accurately.

Some defenders of the special theory of relativity have claimed that Dingle's criticism is misconceived because, they say, the theory speaks only of the *apparent* ticking rates of clocks, not their actual ticking rates. Suppose that observer A and clock A are in one space ship, observer B and clock B are in another space ship, and the space ships pass each other at some high relative velocity. Then it can seem to observer A that clock B ticks more slowly than clock A, while it seems to observer B that clock A ticks more slowly than clock B. There is no logical contradiction in this claim. It is like saying that wherever you are, distant objects look less distinct than objects that are near you.

It is clear where this criticism of Dingle comes from. As I noted in Section III, Einstein does start out talking about observing a clock that is in motion relative to the observer. However, as I also pointed out in Section III, midway through his discussion he abandons the idea of comparing two ways of observing a clock and instead proceeds to compare the actual ticking rates of two clocks, as discovered by looking at both clocks in the ordinary way after the clocks separate and reunite. Thus, this criticism of Dingle is based on a misreading of Einstein; Dingle read Einstein correctly and the contradiction he described is real.

Someone could take the position that Einstein should have stuck with the idea of comparing two ways of observing a clock instead of abandoning it midway through his discussion. If Einstein had stayed the course on this point, one could claim, he would not have drifted into absurd voodoolike thinking about velocity and his theory would not be subject to Dingle's criticism, or mine. However, someone who wishes to take this position must do the following two things. First, one must make it clear that one is not defending Einstein's theory but rather a variation on it. Casting this view as Einstein's view is a mistake. Second, in order to give meaning to this view, one must specify a procedure for observing the ticking rate of a clock that is moving at high speed relative to the observer. As I noted in Section III, this is something that Einstein never did and that may well be impossible. Without such a procedure, talk about the apparent ticking rate of a clock that whizzes by an observer is empty.

In sum, Herbert Dingle's book *Science at the Crossroads* and Ian McCausland's book *A Scientific Adventure* are partial precursors of this paper.[18,19] These two books lay out clearly and correctly a part of the more general criticism of the special theory of relativity that is presented here.

V. VELOCITY ABSURDITY AND THE TWIN PARADOX

The 1905 passage in which Einstein first put into words his voodoolike thinking about velocity and the ticking rates of clocks gave rise to an extensive body of literature on the so-called twin paradox. By all accounts the twins at the center of this controversy were born in 1911 with the appearance of a paper on the subject by Paul Langevin. I am going to speak here of *the twin scenario*, because the use of the word "paradox" in this context is associated with a faulty analysis. I discuss that faulty analysis toward the end of this section.

Einstein's passage is about clocks. However, Einstein gives no definition of a clock; indeed, he says nothing at all about what distinguishes clocks from durable systems of other sorts. In addition, as I noted in Section III, Einstein does not mention any force or process that might be thought to *cause* one clock to tick at a slower rate than another clock. He merely argues that the velocity-dependence of the ticking rate of a clock constitutes the "physical meaning" of a certain equation. For both these reasons, there is broad agreement (with which I concur) that insofar as Einstein's argument in that passage applies to clocks, it applies to all durable systems, including living human beings. Those who consider the argument sound thus conclude from it that if you start with a pair of youthful human twins, and one of them lives a typical life on earth while the other makes a long, high-speed round trip in a spaceship to a distant star, all bodily processes will happen at a slower pace in the spaceship twin, and therefore less will happen in the spaceship twin than in the twin who stays on earth. The spaceship twin will take fewer breaths, host fewer heartbeats, complete fewer sleep/wake cycles, and undergo less of the biological aging process. If the speed of travel is sufficiently high and the star is sufficiently far away, the two twins will be at very different points in the normal human life cycle when they reunite. This will be a plain fact that is obvious to anyone who looks at them. Here are two typical affirmations of this conclusion:

> So when you return to greet your twin sister, you're 20 years younger than she is!
>
> This result is unambiguous. You're standing right next to your sister and all can see that she's much older.[21]

> Ivan will have aged 20 years and Veronica will have aged 12 years, so there will be more wrinkles on his face than on her face.[22]

Proponents of the special theory of relativity stand by this startling claim, while many critics reject it.

Most discussions of the twin scenario focus on the fate of the twins, and to answer this question some writers introduce considerations other than Einstein's 1905 argument. Such additional considerations are a distraction if your aim is to assess the cogency of Einstein's 1905 argument. Although I have my suspicions about what people in the presence of the reunited twins would observe, this is a tangential question that I will leave open here. The key point is that Einstein's 1905 argument sheds no light on that question because it is an exercise in voodoolike velocity absurdity.

Let us name the twin who travels to the star Stella and the twin who stays on earth Ethel. One can think of Stella's round trip as consisting of the following five segments:

1. An initial period of acceleration to get the spaceship moving away from the earth at velocity v.
2. A straight-line trip at velocity v from the neighborhood of the earth to the neighborhood of the star.
3. A second period of acceleration in the neighborhood of the star to turn the spaceship around and moving back toward the earth at velocity v.
4. A straight-line trip at velocity v from the neighborhood of the star to the neighborhood of the earth.
5. A third period of acceleration to slow the spaceship down and land it on the earth.

I will discuss the two inertial segments (2 and 4) first and then the three segments that involve acceleration (1, 3, and 5).

Recall from Section III that the heart of Einstein's argument is the claim that a clock having velocity v will tick $1/2(v/V)^2$ seconds per second—or $1/2(v/V)^2(100)$ percent—slower than a clock having velocity 0, where V is the velocity of light. Recall also that in that argument a clock's velocity is its velocity in an object-anchored coordinate system, which an analyst is free to choose. By using a suitable coordinate system, an analyst can assign to a clock any desired numerical velocity value between 0 and V (the velocity of light). The idea that the actual bodily processes of a real person will proceed at a rate that depends on a velocity number that an analyst arbitrarily assigns to that person is absurd, and this absurdity is reflected in the analyst's ability to predict any of a wide range of outcomes by choosing a suitable coordinate system.

In a coordinate system that is anchored in the earth, during both inertial segments Ethel has velocity 0 and Stella has some large velocity v. Thus, by Einstein's reasoning, Stella ages more slowly than Ethel during both inertial segments and returns home much younger than Ethel. This is what proponents of the special theory of relativity contend.

But now consider a coordinate system anchored in Stan's spaceship, which travels alongside Stella's spaceship during the outgoing inertial segment and continues straight ahead with velocity v when Stella's spaceship turns around and heads home. In Stan's coordinate system, Ethel has velocity v during both inertial segments while Stella has velocity 0 during the outgoing inertial segment and some large velocity $u > v$ during the return inertial segment. Thus, by Einstein's reasoning, Ethel ages more slowly than Stella during the outgoing inertial segment, but Stella ages more slowly than Ethel during the return inertial segment. Accordingly, Ethel will be much younger than Stella when Stella makes her U turn near the star but the age difference will be less when the twins reunite. This is a very different conclusion. A noteworthy corollary here is that Stella ages much more slowly during her trip from the star to the earth with velocity u than she does during her trip from the earth to the star with velocity 0, even though both trips take place in the same ship under the same conditions. The crucial difference, according to Einstein's absurd reasoning, is that Stella keeps pace with Stan's ship on her way to the star but on her way back to earth she recedes from it rapidly.

Another possibility is a coordinate system anchored in Ollie's spaceship, which travels away from the earth with velocity v in the opposite direction from the spaceships of Stella and Stan. In Ollie's coordinate system, Ethel has velocity v during both inertial segments while Stella has some large velocity $u > v$ during the outgoing inertial segment and velocity 0 during the return inertial segment. Thus, by Einstein's reasoning, Stella ages more slowly than Ethel during the outgoing inertial segment but Ethel ages more slowly than Stella during the return inertial segment. Accordingly, Stella will be much younger than Ethel when Stella makes her U turn near the star but the age difference will be less when the twins reunite. This is yet another conclusion. Again, there is a noteworthy corollary regarding Stella alone. Stella ages much more slowly during her trip from the earth to the star with velocity u than she does during her trip from the star to the earth with velocity 0, even though both trips take place in the same ship under the same conditions. The crucial difference, according to Einstein's absurd reasoning, is that Stella recedes rapidly from Ollie's ship on her way to the star but keeps pace with it on her way back to earth.

To sum up, we can predict that at the end of the trip Stella is much younger than Ethel (by using Ethel's coordinate system), or that Stella and Ethel are about the same age (using Stan's coordinate system or Ollie's coordinate system); and we can predict that midway through the trip Stella is much younger than Ethel (using Ethel's coordinate system or Ollie's coordinate system), or that Ethel is much younger than Stella (using Stan's coordinate system). We can also predict that Stella ages at the same rate during her trip to the star and her return trip to the earth (by using Ethel's coordinate system), or that she ages more slowly on her return trip than on her trip to the star (by using Stan's coordinate system), or that she ages more slowly on her trip to the star than on her return trip (using Ollie's coordinate system). In like manner, we can use Einstein's reasoning to make any number of other baseless predictions by using coordinate systems anchored in spaceships that travel away from the earth in any direction that you please with any velocity relative to the earth that you please. There are infinitely many inertial coordinate systems that are eligible for use. You can pick any one of them and use it to compute a baseless coordinate-system-specific prediction for the respective ages of the twins at the end of the trip, or at any point during the trip.

There is no law or principle of physics that says you have to use the same coordinate system to analyze the whole round trip. Any coordinate system is as eligible for use as any other for as long as it remains inertial. So, for example, you can use a coordinate system that is anchored in Stella's outgoing spaceship to analyze the outgoing inertial segment and a different coordinate system, which is anchored in Stella's returning spaceship, to analyze the return inertial segment. With this combination of coordinate systems, during both inertial segments, Stella has velocity 0 and Ethel has velocity v. Thus, by Einstein's reasoning, Ethel ages more slowly than Stella during both inertial segments and therefore is much younger than Stella at the end of the trip. Another possibility is to analyze the outgoing inertial segment using a coordinate system anchored in Howard's spaceship, which is always halfway between the earth and Stella's outgoing spaceship, and the return inertial segment using a coordinate system anchored in Harvey's spaceship, which is always halfway between Stella's returning spaceship and the earth. With this combination of coordinate systems, during both inertial segments Stella and Ethel both have velocity $v/2$. Thus, by Einstein's reasoning, Ethel and Stella age at the same rate and therefore have the same age throughout the trip and when the trip is over. The spaceships of Howard and Harvey play the same role here that the trackside telephone pole plays in Section III. Many other combinations of coordinate systems are possible—infinitely many. Each yields its own coordinate-system-specific, baseless prediction for the respective ages of the twins at the end of the trip or at any point during the trip.

The essential point is that all these examples employ the same reasoning—Einstein's reasoning. All that changes from example to example is the object-anchored inertial coordinate system that is used to assign numerical velocity values to the twins.

I turn now to the three trip segments that involve acceleration. During each of these segments, Ethel will have a constant velocity and Stella will have a changing velocity. The numeric values of each will depend on which coordinate system one uses. When these segments are included in the analysis, the precise predictions made using Einstein's velocity-based argument will be slightly different from those based solely on the two inertial segments. However, the key point that I have illustrated using only the inertial segments still stands: Each coordinate system or combination of coordinate systems yields its own coordinate-system-specific, baseless prediction.

Now let us consider the acceleration that occurs during these segments. This is a phenomenon that Einstein's velocity-based argument says nothing about.

Note first that the clock scenario described by Einstein in his 1905 relativity paper also involves acceleration, even though Einstein does not use acceleration in his argument or even mention that it is present in his example. If one clock parts company from another clock and returns to it at the end of a round trip, the traveling clock must change direction, either during a part of its trip or throughout its trip in the case of a continually curving trajectory. Einstein stipulates that the traveling clock always has *Geschwindigkeit* v (except at the very beginning and very end of its trip), but he does not note that travel with *Geschwindigkeit* v along an "arbitrary polygonal line" or a "continuously curved line" involves changes of direction, and thus acceleration.

I find it curious that Einstein did not call attention to this fact. Since he was using the clock scenario to illustrate a theory that says nothing about acceleration, it is natural for a reader to wonder whether the presence of acceleration in this scenario might make it unsuitable as an illustration of the theory. Thoughtful authors typically anticipate such predictable reader doubts and say something to allay them, but in this case Einstein did not. Is it possible that it never occurred to him that acceleration is present in the scenario he described? Did he think it would be obvious to everyone that the acceleration of the traveling clock did not matter? Did he consider saying something about the acceleration but decided not to for one reason or another? We cannot know Einstein's unwritten thoughts, but we do not need to know them in order to recognize that acceleration of the traveling clock is an aspect of Einstein's clock scenario.

One commentator deals with the acceleration of the traveling clock by saying this:

> In effect, Einstein's assumption was that the rate of a clock depends only on its *velocity* and not on its *acceleration*…[23]

It seems that this way of reading Einstein's argument once had a large enough following to be given a name:

> The statement that the instantaneous rate of a (suitable) clock depends only on its instantaneous speed is known as the *clock hypothesis*…[24]

Here are five reasons why it is a bad idea to read Einstein's argument in this way. First, unless there is no conceivable alternative, it is presumptuous to attribute to an author something that the author did not say. Second, in the case at hand there is the following plausible alternative reading. Einstein wrote the passage to explain his thoughts on the relation between clock velocity and clock ticking rate, and that is all the passage is about; it leaves him free to say whatever he likes about the relation between clock acceleration and clock ticking rate. Third, it is well known that intense acceleration has profound effects on objects, so why not an effect on the ticking rate of clocks? Fourth, clocks are complex systems that one can reasonably expect to be sensitive to a variety of influences, so why not a sensitivity to acceleration? Fifth and finally, years later Einstein claimed, as part of his general theory of relativity, that the ticking rate of a clock depends on the strength of the gravitational field that it is in, and also that gravity and acceleration are intimately related through the so-called equivalence principle. The conjunction of these two claims actually suggests a dependence of a clock's ticking rate on the clock's acceleration.

In light of these considerations, one must admit the possibility that the acceleration that Stella undergoes during the first, third, and fifth segments of her trip has some effect on the rate of her bodily processes. Acceleration could be a fountain of youth or an aging agent. Accordingly, it might be necessary to take Stella's acceleration into account in order to correctly predict her bodily state when she and Ethel reunite. Here is the important point, though. If acceleration plays a role, one must *ignore* it in order to correctly assess the application of Einstein's 1905 argument to the twin scenario, because that argument concerns only velocity. This is a good example of how focusing on the fate of the twins can distract you from Einstein's 1905 argument by mixing in other considerations. My criticism of Einstein's velocity-based argument stands, for both ticking clocks and aging human twins, whether or not acceleration plays a role.

I come now to the term "twin paradox" and the faulty analysis that goes with it. There is a standard treatment of the twin scenario that consists of three parts. In the first part, the author analyzes the entire round trip in the manner of Einstein, using a coordinate system that is anchored in the earth. Conclusion: The twin that makes the trip, having velocity v throughout, ages more slowly than the zero-velocity twin who stays on earth, and therefore is younger when the twins reunite. In the second part, the author presents an objection to the analysis of the first part. The objection is that with equal justification you can analyze the entire round trip using a coordinate system that is anchored in the spaceship, and if you do that you come to the opposite conclusion: The twin that stays on earth, having velocity v, ages more slowly than the zero-velocity twin in the spaceship, and therefore is younger when the twins reunite. This yields the paradox that through these two equally good arguments you can reach two opposite and mutually contradictory conclusions. In the third and final part, the author resolves the paradox by refuting the objection. Because the spaceship undergoes acceleration when turning around in the neighborhood of the star, the coordinate system that is anchored in the spaceship is not a continuously inertial coordinate system, as required by Einstein's theory. Therefore, the objection is misconceived and the analysis that uses the inertial coordinate system anchored in the earth is shown to be the correct one.

This standard treatment gets one thing right. A coordinate system anchored in a spaceship that changes direction is not an inertial coordinate system. Therefore, the objection that is presented in the second part of this standard treatment is indeed misconceived. Now let us look at what the standard treatment gets wrong.

I have yet to read a book or an article in which the author advocates this misconceived objection. I have seen it only in books and articles that present it in order to refute it, in the manner just described. Thus, this objection seems to be a straw man that serves the rhetorical purposes of proponents of the special theory of relativity. Where does this easily debunked objection come from? Maybe it is something that professors hear from beginning students. Maybe it is a conveniently corrupted version of the argument that Dingle and McCausland make using only inertial coordinate systems. In any case, it is a rhetorical gimmick. By considering only this one objection, those who present the standard treatment of the twin scenario promote the false impression that this is the only thing that critics of Einstein's argument have ever said against it. By implicitly equating criticism of Einstein's argument with this spurious objection, they also promote the false impression that all criticism of Einstein's argument is not just wrong but wrong in an elementary way. In addition, by associating rejection of Einstein's argument with this bad reason for rejecting it, they tend to make the rejection itself look bad. Here, it is important to point out that it is easy to construct a bad argument for any view. For example, someone could argue that since everything is white and snow is something, snow is white. This is a ridiculous argument, but snow is white nonetheless. Likewise, the fact that someone constructed this bad reason to reject what Einstein said about the ticking rates of clocks gives no support to Einstein.

While muddying the waters with these bogus insinuations, the standard treatment of the twin scenario endorses Einstein's argument, which has the fatal defect I have been discussing. The velocity of a clock, a human being, or any other physical object in an object-anchored coordinate system is a number that is merely assigned to the object as a result of an analyst choosing to use that coordinate system. If you use another coordinate system, objects get assigned different numeric velocity values. It is an absurd idea that the actual ticking rate of a clock or the actual aging rate of a human being depends on a number that an analyst assigns to these objects by selecting a coordinate system. This absurdity is manifested in the fact that you can predict infinitely many different ticking rates or aging rates by selecting different object-anchored coordinate systems from the infinite set of possibilities.

One reason this problem escapes attention, both in the standard treatment of the twin scenario and in Einstein's 1905 paper, is that the authors focus exclusively on two coordinate systems. Countless other coordinate systems, consideration of which would expose the absurdity of the argument, never enter the thoughts of the authors or their trusting readers. The psychology here is similar to the role of misdirection in a magic trick: No one sees the situation for what it is because everyone's attention is focused on a small part of the whole. There is one noteworthy difference, though: In the case of the velocity trick that is integral to the special theory of relativity, there is no wily magician. Those who perform this trick deceive themselves along with their readers. They do not realize that they have obtained the result that they believe to be right only because they have unwittingly left countless eligible coordinate systems out of consideration and arbitrarily cherry-picked a friendly one.

VI. VELOCITY ABSURDITY IN THE HAFELE–KEATING EXPERIMENT

In September and October 1971, J. C. Hafele and Richard E. Keating conducted an experiment in which clocks traveled around the world in airplanes. They described this experiment in a pair of papers that appeared together in the journal *Science* in July 1972. "Around-the-World Atomic Clocks: Predicted Relativistic Time Gains" describes predictions of clock behavior that they made based on relativity theory.[25] "Around-the-World Atomic Clocks: Observed Relativistic Time Gains" compares their predictions with data that they collected from their clocks—or, more accurately, with numbers that were the result of adjusting data that they collected from their clocks.[26] The data adjustment process will be discussed shortly. These papers have been cited many times as supposed "confirmation" of Einstein's claim that a clock's ticking rate depends in a certain way on its velocity.

In this section, I first summarize the Hafele–Keating experiment and then elucidate its use of absurd thinking about velocity. In addition to the two papers by Hafele and Keating, I cite a paper and a book by Al Kelly, which discuss this experiment at length.[27,28] Kelly's work is valuable because it presents some important information about this experiment that did not make it into the *Science* papers. Kelly found this supplementary information in a Department of Defense report written by Hafele in late 1971, shortly after the experiment was completed and shortly before the papers appeared.

The clocks used in the experiment were "compact and portable cesium beam atomic clocks" of the sort that were state-of-the-art in 1971.[25] The experiment used four of them, which bore the serial numbers 120, 361, 408, and 447. Data was collected from these four clocks over a period of 636 h (26.5 days), which began "at O^h U.T. on 25 September 1971."[25] The clocks spent the first several days of this 636-h period on the ground. They then spent several days traveling once around the world eastward, followed by several more days on the ground, several days traveling once around the world westward, and finally several more days on the ground. The clocks traveled on "regularly scheduled commercial jet flights," which were strung together in a way that Hafele and Keating summarize as follows:

> The eastward trip began on 4 October 1971 at 19h30m U. T. and lasted 65.4 hours with 41.2 hours in flight. The westward trip began during the following week on 13 October 1971 at 19h40m U. T. and lasted 80.3 hours with 48.6 hours in flight.[25]

The *Science* papers give no details about the trip itineraries. However, Kelly wrote the following based on his reading of Hafele's Department of Defense report:

> The eastward and westward flights had 13 and 15 landings/takeoffs respectively; there were several changes of aircraft.
>
> For example, the westward test brought the clocks from Washington to Dulles airport, then via Los Angeles, Honolulu, Guam, Okinawa, Hong Kong, Bangkok, Bombay, Tel Aviv, Athens, Rome, Shannon (an unscheduled fuel stop), Boston, and Dulles, then by road back to the starting point.[27]

Throughout the 636-h period, data was recorded as well from "the reference atomic time scale at the U.S. Naval Observatory" in Washington, DC.[26] Hafele and Keating also refer to this source of data as "the Naval Observatory clock MEAN(USNO)"[26] and "the MEAN(USNO) clock of the U.S. Naval Observatory,"[25] but according to Kelly this "time scale" was not a single clock but rather a computed average of the simultaneous readings of 16 clocks.[28]

The aim of the experiment was to compare the recorded behavior of these various clocks with predictions of how the clocks would behave based on relativity theory. A crucial point is that the predictions were based on the combined application of two logically independent claims. One claim, which is part of the special theory of relativity, is that clock ticking rate depends in a certain way on clock velocity. The other claim, which Einstein first introduced with the general theory of relativity, is that clock ticking rate depends in a certain way on the strength of the gravitational field that the clock is in. Dependence of clock ticking rates on velocity is involved in the prediction, because there are velocity differences between the eastward-traveling clocks, the westward-traveling clocks, and the Naval Observatory clocks. Dependence of clock ticking rates on gravitational field strength is involved, because there are differences of gravitational field strength between the airborne clocks and the Naval Observatory clocks, due to their different distances from the earth's center of gravity. Hafele and Keating wrote that the experiment was intended "to test Einstein's theory of relativity with macroscopic clocks."[25] This statement is true but potentially misleading, because the experiment was actually intended to test in one stroke these two logically independent ideas. The two ideas fall under the phrase "Einstein's theory of relativity" only because this phrase includes so much.

In order to make numerical predictions of the ticking behavior of the clocks, the authors used the relevant equations from Einstein's theories together with a mass of data describing the trips that the clocks made. They summarize how the flight crews collected the necessary data as follows:

> In most cases they traced their flight path on an appropriate flight map and recorded the time and aircraft ground speed and altitude at various navigation check points along the flight path. This information divided the eastward trip into 125 intervals and the westward trip into 108 intervals. The latitude and longitude for each check point, read directly from the flight maps, combined with the time (U.T.) over each check point permits calculation of an average ground speed, latitude, and eastward azimuth for each interval. The average altitude for each interval was taken as the average of the altitudes at the end points.[25]

They present the resulting predictions in Table I, which is reproduced here exactly as it appears in their prediction paper.

TABLE I. Prediction table from the Hafele–Keating prediction paper.

Predicted relativistic time differences (nanoseconds)

Type of effect	Direction: East	Direction: West
Gravitational	144 +/− 14	179 +/− 18
Kinematic	−184 +/− 18	96 +/− 10
Net	−40 +/− 23	275 +/− 21

The numbers in this table represent accumulated nanoseconds of difference between the Naval Observatory time scale and a traveling clock. A positive number is an amount by which a traveling clock is predicted to get ahead of the Naval Observatory time scale. A negative number is an amount by which a traveling clock is predicted to fall behind. The numbers in the Gravitational row are the predicted differences in clock readings due to a difference in gravitational field strength. The East and West gravitational numbers are both positive and of similar magnitude because on both trips the traveling clocks spent similar amounts of time at similar altitudes. Flight direction is irrelevant for the gravitational prediction. I will say no more about the Gravitational row, because the theory behind it is not a concern of this paper. The numbers in the Kinematic row are the predicted differences in clock readings due to differences in velocity. I will discuss the prediction process for the Kinematic row shortly. The numbers in the Net row are the sums of the numbers in the Gravitational and Kinematic rows. If the gravitational theory and the kinematic theory are both correct (and if there is no other difference between the clocks that affects their ticking rates), the Net predictions should be close to the actual ticking behavior of the clocks.

Table II, which is reproduced here exactly as it appears in the Hafele–Keating observation paper, is said to compare the observed ticking behavior of the clocks with the predicted ticking behavior. According to Table II, during each around-the-world trip the four clocks behaved similarly to each other and in line with the predictions. For the eastward trip, the observed ticking behavior is fairly close to the predicted ticking behavior. For the westward trip, the observed ticking behavior is extremely close to the predicted ticking behavior. It seems, then, that observation and prediction are in harmony across the board.

Things are not so tidy, however. Note the phrase "from application of the correlated rate-change method" in the caption of Table II. This is a reference to a procedure that Hafele and Keating used to adjust the raw data that they read off their four clocks. They explain that it was necessary to adjust the raw data because the clocks that they used, like all clocks of

TABLE II. Observation/prediction comparison table from the Hafele–Keating observation paper.

Observed relativistic time differences from application of the correlated rate-change method to the time intercomparison data for the flying ensemble. Predicted values are listed for comparison with the mean of the observed values; S.D., standard deviation.

Clock serial no.	$\Delta\tau$ (ns): Eastward	$\Delta\tau$ (ns): Westward
120	−57	277
361	−74	284
408	−55	266
447	−51	266
Mean +/− S.D.	−59 +/− 10	273 +/− 7
Predicted +/− Error est.	−40 +/− 23	275 +/− 21

that type, were subject to abrupt changes in ticking rate that were unrelated to gravitation, velocity, or any other known factor. They describe these abrupt changes as "random and independent," "spontaneous," and "unpredictable." The abrupt changes occurred many times during the trips, as detailed in footnote 9 of the observation paper:

> The time intercomparison data showed that clock 120 changed rate three times, 361 changed three times, 408 changed twice, and that 447 changed rate once during the eastward trip. For the westward trip, clock 120 changed once and 361 changed four times. No significant changes in rate were found for clocks 408 and 447 during the westward trip.[26]

The stated purpose of the adjustment procedure was to cancel the effects of these random abrupt ticking rate changes so as to produce numbers that could be meaningfully compared with the combined gravitational and kinematic prediction.

The *Science* papers do not present any numbers that describe either the raw clock readings or the adjustments that were made to the raw clock readings. Kelly's work is especially illuminating here. According to him, even Hafele's Department of Defense report does not present the raw clock readings, but it does present numbers from which the raw clock readings can be computed. Table III below is identical to Table II, with one difference. In parentheses, to the right of each adjusted number that Hafele and Keating present, is the corresponding preadjustment number computed by Kelly from numbers in the Department of Defense report.

Wow! The adjustments to the raw clock data are enormous. For both trips, the preadjustment numbers (in parentheses) are widely scattered while the postadjustment numbers are nicely grouped. In two cases—clock 408 on the eastward trip and clock 361 on the westward trip—the traveling clock diverged from the Naval Observatory time scale in the opposite direction from what was predicted; it was only after huge adjustments that the direction of divergence was the same. Evidently, the random abrupt changes in ticking rate were comparable in magnitude to the theoretically predicted changes, and in some cases even greater.

TABLE III. Observation/prediction comparison table showing preadjustment numbers in parentheses.

Observed relativistic time differences from application of the correlated rate-change method to the time intercomparison data for the flying ensemble. Predicted values are listed for comparison with the mean of the observed values; S.D., standard deviation.

	$\Delta\tau$ (ns)	
Clock serial no.	Eastward	Westward
120	−57 (−196)	277 (413)
361	−74 (−54)	284 (−44)
408	−55 (166)	266 (101)
447	−51 (−97)	266 (26)
Mean +/− S.D.	−59 +/− 10	273 +/− 7
Predicted +/− Error est.	−40 +/− 23	275 +/− 21

Commenting on Table II, which shows only the adjusted data, Hafele and Keating wrote that "the consistency among the measured values is striking."[26] This statement is not candid. The numbers in Table II do indeed exhibit a striking consistency, but those numbers are adjusted values, not measured values, and the corresponding measured values exhibit a striking inconsistency. The use of the word "observed" in the Hafele-Keating table caption is also not candid, because the table shows only adjusted numbers, which are procedurally and numerically far removed from the observations that were made.

The large size of these adjustments does not necessarily invalidate the experiment, but it certainly puts a premium on the quality and integrity of the adjustment process. On this issue, the available information is not reassuring. The *Science* papers describe the data adjustment process only in broad terms. They do not spell out the steps involved or work through an example. The authors explain that it was possible to precisely locate the random abrupt changes, because clock readings were taken frequently and only one of the four clocks would change its ticking rate at a time. That sounds reasonable. On the other hand, Kelly notes that "There was no definition as to what precisely constituted an in-flight rate change that warranted correction"[29] and the authors themselves acknowledge some indefiniteness when they speak of "more or less well defined quasi-permanent changes in rate."[25] Such indefiniteness is worrisome, because it opens the door to unprincipled data-adjustment decisions. Incidentally, the adjective "quasi-permanent" again seems to lack candor, given that four clocks during 145.7 h of travel underwent a total of 14 random abrupt changes. That works out to an average of a mere 49 h from one abrupt change to the next for a typical clock, which is well short of permanence. Here is something very strange. Table III shows huge adjustments for clocks 408 and 447 on the westward trip, yet according to the footnote that enumerates the abrupt changes "No significant changes in rate were found for clocks 408 and 447 during the westward trip."[26] Hafele and Keating clearly state that they made adjustments only for the abrupt changes that are enumerated in that footnote. Kelly calls attention to this anomaly for clock 447 on the westward trip. In the course of checking his claim, I noticed that clock 408 on the westward trip exhibits the same anomaly. By the way, is it sheer coincidence that both these clocks have the same postadjustment value—266 nanoseconds? There is a lot to wonder about here.

Taken together, the huge magnitude of the data adjustments and the unanswered questions about the data adjustment process cast a shadow over the authors' sunny conclusion that "These results provide an unambiguous empirical resolution of the famous clock 'paradox' with macroscopic clocks."[26] On the contrary, when the details of the data adjustment process are taken into account, the Hafele–Keating experiment is the epitome and quintessence of empirical ambiguity.

Kelly accuses the authors of deliberate chicanery:

> Hafele and Keating then set about altering the results to get them to line up with the forecast

> results. This needed some ingenuity and considerable secrecy. They did it by publishing a radically altered version of the results instead of publishing the actual results.[30]

"The barefaced effrontery is breathtaking," he says.[31] He speculates that important information was confined to the Department of Defense report, where it was presented in an oblique manner, because "the authors did not want anyone to uncover the awful truth."[30] He condemns the whole project as a "shameful episode" and a "scam."[30] This criticism might be too harsh; it seems possible to me that the authors were guilty of wishful sloppiness but not deliberate fraud. In any case, a fair summary of this experiment must include the dubious data adjustment process and the lapses of candor in the published papers.

I turn now to my criticism of the Hafele–Keating experiment: The process of computing the Kinematic row of their prediction table is an exercise in voodoolike velocity absurdity.

To compute the numbers in the Kinematic row of their prediction table, Hafele and Keating used an inertial coordinate system one of whose axes was the earth's axis of rotation. One can think of the origin of this coordinate system as any point on this axis—the gravitational center of the earth, the North Pole, the South Pole, and so on. This is not a perfectly inertial coordinate system, because every point on the earth's axis of rotation tracks the gently curving path of the earth's orbit around the sun. But let us assume that it is close enough to inertial to be used as such.

As the authors note, it is convenient to visualize the situation from a point on the earth's axis of rotation that is far above the North Pole. Viewed from that vantage point, the earth's eastward spin is a counterclockwise spin. An object sitting on the equator travels counterclockwise with a constant (scalar) velocity of about 1000 mph. The clocks at the Naval Observatory in Washington DC, latitude about 39° north, travel counterclockwise at about 1000(cos 39°) ≈ 780 mph. If we assume that the cruising speed of all the airplanes used in the experiment was about 500 mph and that all the flights followed roughly east-west paths at about the same latitude as Washington DC, then in the chosen coordinate system the four clocks had a velocity of about 780 + 500 = 1380 mph while cruising to the east and a velocity of about 780 – 500 = 280 mph while cruising to the west. These numbers do not appear in the paper; they are my own rough estimates, which I give here to put the paper's analysis in perspective. Note that all three velocities are in the eastward, or counterclockwise, direction, even the velocity of the clocks on the westward flights. The clocks on the eastward flights travel eastward the fastest at about 1380 mph, followed by the Naval Observatory clocks at about 780 mph, and the clocks on the westward flights at about 280 mph.

Imagine a clock that is stationary in the chosen coordinate system. It could be situated, for example, precisely at the North or South Pole. The computational strategy that Hafele and Keating used was to compute the predicted differences between the ticking rate of this hypothetical clock and the ticking rates of the various real clocks in the experiment. Having computed predicted ticking rate differences relative to this hypothetical clock for the eastward-traveling clocks, the Naval Observatory clocks, and the westward-traveling clocks, they obtained the predicted ticking rate differences between the various real clocks by subtraction. This incidentally is the same logic that I used in Section III and again in Section V when I said that two clocks that tick slower than a third clock by the same amount must tick at the same rate as each other.

The formula that Hafele and Keating used to compute the "kinematic" ticking rate differences between the hypothetical clock and the real clocks was Einstein's formula that a clock that is moving with velocity v ticks $1/2(v/V)^2$ seconds per second slower than a clock that is stationary, where V is the velocity of light. Hafele and Keating followed the modern convention that the velocity of light is c; thus their formula was $1/2(v/c)^2$. Since larger v implies a slower predicted ticking rate, the predicted slowing relative to the hypothetical zero-velocity clock is least for the westward-traveling clocks, more for the Naval Observatory clocks, and most for the eastward-traveling clocks. This is why, in the Kinematic row of the prediction table, the eastward-traveling clocks at the end of their trip are predicted to be behind the Naval Observatory clocks (−184), while the westward-traveling clocks at the end of their trip are predicted to be ahead of the Naval Observatory clocks (+96). Of course, these Hafele–Keating predictions were not computed from my velocity estimates. They were computed using a precise value for the spinning of the earth together with the detailed ground speed, latitude, and flight direction data that were recorded by the flight crews at the 100-plus checkpoints on each around-the-world trip.

As in Einstein's 1905 paper (Section III) and the standard treatment of the twin scenario (Section V), the velocity absurdity consists in the idea that the actual ticking behavior of real clocks is a function of numeric velocity values that a human analyst assigns to those clocks through his choice of a coordinate system. As in those other examples, the absurdity can be made obvious by bringing other inertial coordinate systems into the discussion—coordinate systems that the analyst could have used but did not. In the case of the Hafele–Keating experiment, the arbitrarily assigned velocity numbers reflect the arbitrary decision to use a coordinate system whose origin is on the earth's axis of rotation. The authors declare their intention to use this coordinate system in the following passage:

> Because the earth rotates, standard clocks distributed at rest on the surface are not suitable in this case as candidates for coordinate clocks of an inertial space. Nevertheless, the relative timekeeping behavior of terrestrial clocks can be evaluated by reference to hypothetical coordinate clocks of an underlying (nonrotating) inertial space.
>
> For this purpose, consider a view of the (rotating) earth as it would be perceived by an inertial observer looking down on the North Pole from a great distance.[25]

This passage uses a rhetorical device that is also found in the standard treatment of the twin scenario. As I explained in Section V, writers who claim to resolve the twin paradox typically contrast the inertial coordinate system anchored in the earth with a noninertial coordinate system that makes a U turn in the neighborhood of the distant star. Here, Hafele and Keating contrast the (approximately) inertial coordinate system anchored in the earth's axis of rotation with a noninertial coordinate system anchored on the earth's spinning surface. In each case, by contrasting the chosen inertial coordinate system with an unacceptable noninertial coordinate system, the presenter diverts attention from the countless other inertial coordinate systems that he could have chosen instead. The fact that the coordinate system being used has been cherry-picked is thereby obscured—for those who chose it along with everyone else.

Now let us consider a few other inertial coordinate systems that Hafele and Keating could have used to predict the ticking behavior of the clocks in their experiment.

One can fly an airplane on an inertial path by flying at a constant speed along an ascending straight line that diverges at an increasing rate from the curved and spinning ground below. A simple computation shows that an airplane flying at 500 mph that starts near sea level can follow such an ascending inertial path for about 10 min, before it reaches a limiting altitude of 7 miles or so. While the clocks in the Hafele–Keating experiment are cruising eastward, wherever on earth they may be, imagine an "inertial escort plane" that flies nearby at the same scalar velocity and in almost the same direction, along such an ascending inertial path. In an inertial coordinate system anchored in the escort plane, the velocity of the plane carrying the clocks eastward will be close to zero while the velocity of the Naval Observatory clocks will be much higher. The velocity of the Naval Observatory clocks in an escort plane's inertial coordinate system will depend on where on earth the escort plane is, but it will always be much larger than the velocity of the eastward-flying clocks, which is close to zero. Therefore, by the same reasoning that Hafele and Keating use, during the 10 min or so that the inertial coordinate system anchored in an escort plane exists, the Naval Observatory clocks will tick more slowly than the clocks in the eastward-flying airplane. Since one can bring another inertial escort plane into service as the last one reaches its maximum altitude, it follows that the Naval Observatory clocks will tick more slowly than the clocks in the eastward-flying airplane during the entire trip. This is opposite to the prediction that Hafele and Keating make using their arbitrarily chosen earth-axis coordinate system.

Next consider an inertial coordinate system whose origin is at the center of the sun, or anywhere on a line that runs through the center of the sun in a direction perpendicular to the plane of the earth's solar orbit. In place of the Hafele–Keating "view of the (rotating) earth as it would be perceived by an inertial observer looking down on the North Pole from a great distance," imagine a view of the solar system as it would be perceived by an inertial observer situated far above the North Pole of the sun. In this sun-anchored coordinate system, the center of the earth has a very nearly constant scalar velocity of about 30 km/s. The vector velocity of each clock in the experiment will be the vector sum of the earth-circling velocity component that preoccupies Hafele and Keating and the 30 km/s sun-orbiting velocity component that is absent from the Hafele–Keating analysis. It is difficult to compute the net scalar velocities that go into the algebraic expression $1/2(v/c)^2$ because the sun-orbiting velocity component of each clock maintains an almost constant direction while the earth-circling velocity component changes direction continuously as the clock traces constant-latitude circles that are tilted at approximately 23° relative to the plane of the earth's orbit. However, it is not necessary to do any computations in order to see that the sun-centered coordinate system yields different ticking rate predictions than the earth-axis coordinate system does.

Viewed from a point above the North Pole of the sun, the earth orbits the sun counterclockwise and rotates on its axis counterclockwise. Therefore, when it is midnight where a clock is, the clock's earth-circling velocity component will be in roughly the same direction as its sun-orbiting velocity component, with the result that its net scalar velocity will attain a maximum value. Likewise, when it is noon where a clock is, the clock's earth-circling velocity component will be in roughly the opposite direction to its sun-orbiting velocity component, with the result that its net scalar velocity will attain a minimum value. Thus, the clock's scalar velocity in the sun-centered coordinate system will vary in a cyclic way. This means that the clock's predicted ticking rate will vary in a cyclic way. The variation will not be great, because the earth-circling velocity components of all the clocks in the experiment are well under 1 km/s, compared to their sun-orbiting velocity components of about 30 km/s. Still, there is a dramatic difference between a predicted constant ticking rate and a predicted cyclically varying ticking rate, no matter what the numbers are. A practitioner of velocity absurdity can predict a cyclically varying ticking rate for any clock that is traveling in a circular path by doing the relevant computations in a coordinate system in which the center of the clock's circular path has a nonzero velocity.

There is another interesting difference between a coordinate system whose origin is above the earth's North Pole and a coordinate system whose origin is above the sun's North Pole. In the former, all the clocks in the experiment have scalar velocities well under 1 km/s, whereas in the latter all the clocks have scalar velocities in the neighborhood of 30 km/s. Therefore, by the reasoning of Hafele and Keating, the ticking rate of each clock in the experiment will be slower than the ticking rate of a hypothetical clock that is stationary in the sun-anchored coordinate system by a greater amount than it is slower than a hypothetical clock that is stationary in the earth-axis coordinate system. But the ticking rates of all the real clocks in the experiment are what they are, irrespective of what hypothetical clock you compare them with. It follows that the hypothetical clock that is stationary in the sun-anchored coordinate system ticks faster than the hypothetical clock that is stationary in the earth-axis coordinate system. This in itself is logically possible. However, the hypothetical clock that is stationary in the sun-anchored coordinate system has a velocity of about 30 km/s in the earth-axis coordinate system. Thus, by the reasoning of Hafele and Keating, a hypothetical clock that is stationary in the sun-anchored coordinate system must tick considerably *slower* than the hypothetical clock in the earth-axis system, and indeed considerably slower than all the clocks whose readings were recorded in the experiment. This is an instance of the contradiction that Dingle noticed long ago: When the rhetorical gimmicks and the cherry-picking of coordinate systems are stripped away, it becomes clear that Einstein's theory implies that each of two mutually moving clocks ticks slower than the other one.

A qualitatively similar but numerically more extreme example is an inertial coordinate system that is anchored in a cosmic ray whose velocity in an earth-axis coordinate system is more than 90% of the speed of light. In the cosmic-ray-anchored coordinate system, the clocks in the experiment have velocities that change gradually in a cyclic manner, due to their circular paths around the earth. The velocities of all of them are always more than 90% of the speed of light, and so, by the reasoning of Hafele and Keating, they must tick much more slowly than a hypothetical clock of identical constitution that is stationary relative to the cosmic ray. But the ticking rates of all the clocks in the experiment are what they are, irrespective of what hypothetical clock you compare them with. It follows that the hypothetical clock that is stationary in the cosmic-ray-anchored coordinate system ticks much faster than the hypothetical clock that is stationary in the earth-axis coordinate system. However, the hypothetical clock that is stationary in the cosmic-ray-anchored coordinate system has a velocity of more than 90% of the speed of light in the earth-axis coordinate system. Thus, again by the reasoning of Hafele and Keating, it must tick much *slower* than the hypothetical clock that is stationary in the earth-axis coordinate system and all the real clocks in the experiment. Thus, we have yet another instance of Dingle's contradiction.

As noted earlier in this section, there is reason to suspect Hafele and Keating of fudging their data in order to bring it in line with their predicted values. Now we see that their predicted values are a product of voodoolike velocity absurdity. Hafele and Keating unwittingly executed an absurd dial-a-prediction scheme that has the same epistemological status as predictions based on astrology or card reading. Even if Kelly's criticism of their data adjustment process is not justified, the close match of observed and predicted values displayed in Table II is still a charade, due to the dependence of the predicted values on voodoolike velocity absurdity. In principle, it makes sense to test a theory by comparing numbers that it predicts with numbers that are read off measuring instruments, but if the theory includes an arbitrary choice that drives a dial-a-prediction scheme, comparing its predictions with experimental data is a meaningless and ridiculous exercise.

In this paper, I take no position on the relation between the ticking rates of clocks and gravitational field strength. I do want to stress, however, that the gravitational field strength at the location of a clock is a real physical circumstance of the clock, which could possibly affect the clock's ticking rate. It seems more likely to me that gravity would alter the ticking rates of different types of clock in different ways depending on how the clocks work, as opposed to having the same effect on all clocks of all types—but that is a question for empirical investigation.

The situation is the same for a clock's coordinate-system-independent velocity through space, if there is such a thing. That too would be a real physical circumstance of the clock, which could possibly affect the clock's ticking rate, either in a way specific to how the clock works or in a way that is common to all clocks of all types. For example, it would not be absurd to hypothesize a functional relationship between the ticking rate of a clock and the velocity of the clock as computed from the anisotropy of the CMB radiation that strikes it. Whether the hypothesized relationship is real would be a question for empirical investigation.

However, the situation is not the same for a clock's velocity in an object-anchored coordinate system. This is not a real physical circumstance of the clock. It is a number that gets assigned to the clock as a result of someone arbitrarily choosing to use that coordinate system. It makes no sense that a clock's actual ticking rate could depend on such a number. It makes no sense that someone can control the actual ticking rate of a real clock by simply choosing to think of the clock in the context of a certain coordinate system. That is velocity absurdity.

VII. VELOCITY ABSURDITY TODAY AND TOMORROW

In the course of this paper, I have mentioned several highlights in the history of absurd, voodoolike thinking about velocity. Einstein was perhaps the first practitioner; absurd misuse of velocity-in-a-coordinate-system is at the heart of his 1905 discussion of the ticking rates of so-called moving clocks. In 1911, Langevin launched the twin paradox debate by applying absurd thinking about velocity to a fantasy of interstellar travel. In 1972, Hafele and Keating published their often-cited papers, which compare dubiously adjusted clock data with predictions based on absurd thinking about velocity. In that same year, Dingle published his book that identified an important symptom of the prevailing velocity absurdity but without getting at the essence of it.

This paper is not primarily an historical study, however. Its main message is that velocity absurdity flourishes today, embedded in the thought habits of thousands of professional physicists. There is evidence of this wherever you look. The part of Einstein's 1905 paper that depends on absurd thinking about velocity is never criticized for doing so. On the contrary, most commentators praise that entire paper as a work of genius. Books and papers continue to be published that employ absurd thinking about velocity in support of an erroneous analysis of the twin paradox. Books and papers continue to be published that cite the velocity-absurdity-based Hafele–Keating experiment as solid science that "confirms" the special theory of relativity. Books and papers continue to be published that imitate Einstein's exclusive focus on two coordinate systems, thereby blocking the insights that come flooding in when you ask how a situation would be described in various other coordinate systems that go unmentioned. Books and papers continue to be published that use Einstein's confusing terminology of the system at rest and the moving system—with or without scare-quotes. Velocity absurdity is a canker at the heart of modern physics.

It is an aim of this paper to set physics on a better course by loosening the grip of velocity absurdity. What is the prospect for success? What chance is there that the absurdity will come to be understood and avoided in the years ahead? There is hope, of course, but there is also reason for pessimism. The fact that voodoolike velocity absurdity has flourished for over a century attests to the existence of strong pro-absurdity forces, whatever they may be. Dingle's failure to get even a single colleague to see the contradiction that he saw underscores the challenge. It is true that Dingle was not working with the complete explanation of velocity absurdity that I have presented in this paper, but he had enough of it to make a compelling argument—to no avail.

What are the pro-absurdity forces that keep this irrational practice in place?

I think Dingle put his finger on part of the answer. He said that the physicists he knew could be roughly divided into two groups, the experimenters and the mathematicians. The experimenters refused to discuss the special theory of relativity with him, dismissing it as "too abstruse for their comprehension" and "beyond their understanding."[32] The mathematicians claimed to understand the theory, but they did not understand Dingle's argument—because it was not about the mathematics. The point is that there is a part of the theory—the extra-mathematical part—that few physicists bother to think about, and it is in this seldom-visited neighborhood that velocity absurdity lives. In fact, this seldom-visited neighborhood is home to multiple problems. Velocity absurdity concerns confusions that bedevil the variable v. My paper "Critique of the Einstein clock variable" discusses confusions that bedevil the variable t.[16] Einstein went in for novel interpretations of the basic variables of physics, and his interpretations are defective. Anyone who thinks of these variables in a merely mathematical way, as nothing but letters that stand for numbers, is ill-equipped to confront key questions about what the numbers mean. Dingle's book contains a fascinating discussion of the widespread tendency to see the views of Einstein and Lorentz as more similar than they actually are because both men embraced the same equations, the so-called Lorentz transformations. In fact, Einstein and Lorentz interpreted every letter in these equations differently—v, t, x, and c. Neglect of these differences is an excellent example of the low ebb in many physicists of extra-mathematical thought.

Another part of the answer is the fact that the special theory of relativity has the status of an institutionally blessed official body of belief. Physics students must internalize velocity absurdity along with the rest of the special theory of relativity in order to pass exams and get their degrees. Physicists who suspect that something might be wrong with this theory have an incentive not to worry too much about it because dissent in this area is bad for your career. Physicists who have a public history of supporting the theory have an incentive not to change their minds because they have reputations to preserve. All physicists have an incentive to maintain the glory of their profession, which would take a hit if the errors of relativity theory were generally acknowledged. In sum, there is a vast complex of social and psychological factors that works to shelter voodoolike velocity absurdity and other errors of relativity theory from fair scrutiny.

This is a lot for mere clear thinking to overcome.

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