Analyzing the "Twin-Paradox"

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Abstract: *Paul Langevin's so-called "Twin Paradox," based upon Albert Einstein's Special Theory of Relativity, seems to be by far the most argued topic in physics. Many hundreds of articles have been written about the "Twin Paradox," but all they seem to accomplish is to make the subject even more confusing. This is an attempt to simplify the subject by identifying the causes of the confusion. And it proposes a relatively simple experiment to clarify how time dilation works.*

Key words: twin paradox; clock paradox; Einstein; Langevin; Relativity

I. What is the "Twin Paradox"?

Virtually every one of the many hundreds of physics journal articles about the "Twin Paradox" and every one of the many textbook chapters on the subject includes some complication related to time dilation that the author wants to introduce and discuss. Here is my version of the "paradox" *without* any complications:

> Einstein's Special Theory of Relativity[1] states that "the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good." This means that if you are in a stationary laboratory or a laboratory that is moving at a constant velocity, **performing identical experiments should produce identical results**. Einstein's Theory of Special Relativity *also* states that a moving clock runs slower than a stationary clock - which implies time also slows down for a moving observer traveling with the moving clock.
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> This becomes a "paradox" when the facts above are *mis*interpreted to mean that, if Observer-A considers himself to at rest in his frame of reference, he will see Observer-B as moving, and he will see time as running slower for Observer-B. Equally, if Observer-B considers himself to be at rest in his frame of reference, he will see Observer-A as moving, and he will see time as running slower from Observer-A. This is

the “paradox.” **Each imagines himself as stationary and the other as moving, thus each sees the other’s clocks as running slower**. It is a “paradox,” which Merriam-Webster[2] defines as “a statement that is seemingly contradictory or opposed to common sense and yet is perhaps true.” It is paradoxical and contradictory to claim that two observers are both “stationary” when one observer is clearly moving relative to the other.

It becomes the “Twin Paradox” when the observers are considered to be a pair of identical 30-year-old twins, and Twin-A stays at home on Earth while Twin-B travels at 99.498833956657% of the speed of light to another star and back. Because time moved slower for Twin-B due to his movement, he only aged 4 years during what he considered to be a 4-year round-trip journey, but Twin-A aged 40 years while waiting for his brother to return from what Twin-A considered to be a 40-year journey. When they meet after Twin-B returns, Twin-B is 34 years old and Twin-A is 70 years old.

The only “paradox” is an imagined paradox. Twin-B *felt* like he was stationary while he was actually cruising at a very high velocity, and when he looked out the windows it *seemed* like the earth was moving away from him. And Twin-A felt considered himself to be stationary as his twin flew off into the cosmos. So, if both imagined the other as moving, why did one brother age more than the other?

Obviously, there is no actual paradox. While Twin-B may have felt no sense of motion while cruising at 99.498833956657% of the speed of light, he obviously was moving, since his rocket ship expended a great deal of energy to cause him and his ship to move.

There is only a “paradox” if you misinterpret Einstein’s Special Theory of Relativity as saying that what one imagines, experiences or feels inside his frame of reference is what is actually happening in the universe. I.e., Twin-B felt no motion while traveling at cruising speed, so he wasn’t moving. In reality, regardless of what Twin-B felt, he *was* the one who expended energy to cause movement. Twin-A expended no such energy.

Paul Langevin is credited (or blamed) for creating the “twin paradox.” In reality, the paper Langevin wrote about time dilation in 1911[3] mentions no twins. It just has one traveler who makes a journey at speeds very close to the speed of light as he travels to a nearby star and back, while everyone on earth waits for his return. The traveler ages 2 years during his trip while *two hundred* years pass for everyone he left behind on earth. Except for indicating that the slowing of time was due to *acceleration* instead of to traveling a constant high speed, the paper accurately describes Einstein’s theory, fully accepts it, and never mentions any paradox.

II. Einstein’s point.

The main point of Einstein’s Special Theory of Relativity is that time slows down for objects that are caused to move. The faster an object moves, the slower time passes for that object – until you reach the speed of light where time stops. And nothing can go faster than the speed of light.

In Einstein's view, this made "superfluous" the "luminiferous ether" dreamed up and used by mathematicians to measure velocities. Instead of measuring velocities relative to an imaginary ether that is assumed to be stationary in the universe, actual velocities in space can be measured relative to the speed of light. If "speed" is defined as the distance traveled in a specified amount of time, i.e., 30 miles per hour, speed in empty space (where there are no mile markers) does not have to be relative to any imaginary ether, it can be relative to the speed of light. And the way to tell how fast you are going is to compare the tick rate of your clocks relative to the tick rate of clocks on some other object – or relative to the speed of light at which clocks stop ticking and time stops.

So, when two spaceships pass each other in some remote section of space where there are no nearby reference bodies, the crews can compare the rates at which their clocks tick to determine which ship is moving faster than the other. Passengers and crew aboard each of the two spaceships may feel that they are stationary in space and may even see the other ship zipping past them at high velocity, but a comparison of clock tick rates will show who is actually moving faster than whom.

It is all very simple and straight-forward. There is no paradox.

III. The Hafele-Keating Experiments.

Einstein's Theory of Special Relativity has been confirmed in many ways, including by many actual experiments. The most famous experiments are the ones done by Joseph C. Hafele and Richard E. Keating[4] in October of 1971.

Richard Keating worked as an astronomer at the United States Naval Observatory. Part of his job was to transport atomic clocks to laboratories around the world and to reset them upon arrival so that they matched the master atomic clock at the Naval Observatory. He gave a lectures on that subject, and during one such lecture, Joseph Hafele was in attendance. Hafele was convinced that time dilation could actually be measured by atomic clocks traveling aboard moving aircraft, and after the lecture he discussed it with Keating. Together they calculated estimates as to the time differences they would expect to find after completing such experiments. Then they obtained funding and performed the experiments.

They flew 4 atomic clocks on two trips around the world via commercial aircraft, first flying eastward as one experiment, and then flying westward as a second experiment. (They used 4 clocks so they could compute average times and not depend upon the accuracy of a single clock.) Before and after each flight they compared the times shown on their four atomic clocks to a "stationary" U.S. Naval Observatory atomic clock that remained on the ground. Their before-flight calculations were within the margin of error of the actual after-flight results.

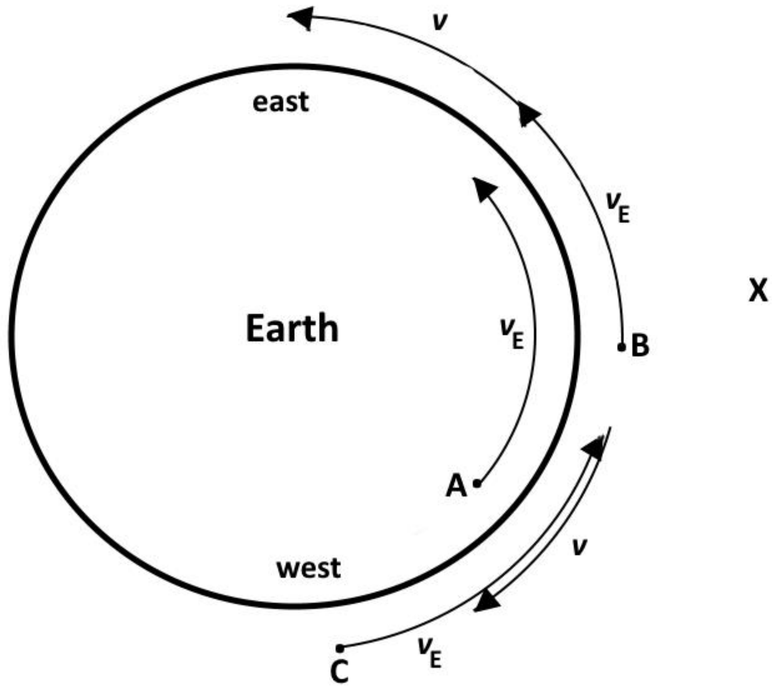

Figure 1

Figure 1 above represents a view of the Earth spinning on its axis from west to east as seen from above the North Pole and also from a relatively fixed or "stationary" point off the one side in space, such as the sun, represented by "X." From point "X," the earth can be seen to spin from west to east at roughly 1,040 miles per hour at the equator.

"A" represents the "stationary" atomic clock on the earth. The "stationary" clock is not actually stationary, of course. Relative to "X," it moves with the earth at speed v_E (the velocity of the earth at that latitude) as the earth spins. Likewise, "X" (the sun) is not really stationary, either, of course. The sun is moving at 486,000 miles an hour around the center of the Milky Way galaxy. So, the experiment has no "stationary frame of reference." All objects are actually moving at different speeds relative to one another.

"B" represents the first trip with the 4 atomic clocks on the airplanes traveling eastward at aircraft velocity v and thereby adding the clocks' velocity to the v_E velocity of the spinning Earth. The added velocity caused the clocks on the airplane to tick slower than the clock on earth.

"C" represents the westward trip where the speed of the airplane v had the effect of subtracting from the v_E velocity of the spinning earth and the stationary clock. Because the atomic clocks on the aircraft were moving slower than the "stationary" clock on the earth, they ticked faster.

While traveling eastward, where their *__relative__* movement *adds to* the roughly 1,000 mph movement of the earth rotating on its axis below them, the four atomic clocks ran slower by 59 nanoseconds compared to the stationary atomic clock on the ground. While traveling westward, where their *relative* movement *subtracted from* the velocity of the spinning earth below them (making time run *faster*), the four atomic clocks gained 273 nanoseconds compared to the stationary atomic clock on the ground.

Of course, gravitational time dilation and the General Theory of Relativity also affected the clocks. Clocks aboard flying airplanes will tick faster than a clock on the ground, and the higher you fly the faster clocks will tick at that altitude. Hafele and Keating included those effects in their computations, as shown in Figure 2 below.

Hafele-Keating statistics	**Predicted nanoseconds difference**			**Actual Nanoseconds difference**	**Difference**
	Gravitational (General Relativity)	**Kinematic (Special Relativity)**	**Total**		
Eastward	**+144±14**	**-184±18**	**-40±23**	**-59±10**	**0.76**
Westward	**+179±18**	**+96±10**	**+275±21**	**+273±7**	**0.09**

Figure 2

In summary, when their moving atomic clocks moved faster than the clock on earth, the moving clocks ticked at a slower rate. Thus, when traveling eastward and causing the clocks to run slower, the traveling clocks accumulated 59 *fewer* nanoseconds (billionths of a second) than the "stationary" clock on the ground. When traveling westward, which caused the traveling clocks to move through space slower than the clock on the ground, the four atomic clocks ticked faster and accumulated on average 273 *more* nanoseconds than the slower running "stationary" clock on the ground.

Hafele and Keating made this statement as part of the last sentence in their paper describing their experiments:

> There seems to be little basis for further arguments about whether clocks will indicate the same time after a round trip, for we find that they do not.[5]

IV. Some causes of confusion.

As stated in Section I, confusion begins when people mistakenly claim that Einstein's Theory of Special Relativity says that what one experiences or feels inside his frame of reference is what is *actually* happening in the universe. Therefore, they believe and claim that time passes at the same rate everywhere because it is *felt* (a.k.a. "*observed*") to pass at the same rate everywhere.

The confusion is amplified by that fact that you cannot easily compare clocks *while* they are traveling at different speeds. Scientific paper after paper argues that if you could somehow use a telescope to view a clock on a spaceship, that spaceship clock will appear to run "slow" only because of the time it takes for the light from the spaceship clock to reach the observer on Earth. While traveling, every second the spaceship will get farther from Earth, so every second it will take longer for someone on Earth to receive the light from the spaceship and its clock. The reverse is also true, of course. If someone on the spaceship uses a telescope to view clocks on Earth, they will see clocks on Earth as running slow. As each observer gets farther and farther from the other observer, light will take longer and longer to travel the distance, and thus it will appear that the other clock is running slower and slower.

That, of course, has absolutely *nothing* to do with relativistic time dilation.

More confusion is added when the "twin paradox" is examined as an actual experiment, instead of just a thought experiment. In a thought experiment, the traveling twin travels at some high percentage of the speed of light for the entire trip to his destination and back. In an actual experiment, the rocket ship would have to accelerate to reach those speeds. In a real-life trip to a distant star, a year can be spent just accelerating to reach cruising speed. Then, after cruising for years at its maximum speed, the ship will have to decelerate down to zero so that it can turn around and make the trip back. And the return trip will again include a year spent accelerating, then some cruising time, and then another year spent decelerating until arrival at Earth. In real life, if all the acceleration was done in the first few minutes (or hours) of the trip, the occupants of the space ship would be crushed flat.

V. The main cause of confusion.

The main cause of confusion when discussing time dilation and the so-called "twin paradox" is a simple misunderstanding of Einstein's Theory of Special Relativity. Einstein's theory says that experiments in inertial reference frames will appear to produce identical results, even when one frame is moving and the other is not (or more correctly, when one frame is moving at a different rate than the other frame). However, *the results will not actually be identical* because time moves at a slower rate in the faster moving frame. By comparing clock tick rates in the frames you can determine whose clock is running slower, which demonstrates whose frame is moving faster. If time is a factor in an experiment (such as measuring velocity per second), the experiment in the faster moving frame will have longer seconds. Both frames will define a second to be "the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom,"[6] but it will take longer for a clock in the faster moving frame to reach that number.

Those who *mis*understand Einstein's theory appear to believe Einstein simply stated that experiments in inertial frames will produce identical results. And if duplicate experiments in different reference frames produce duplicate results, then there is no way to tell which frame is moving faster than the other. Period.

Here is how that misunderstanding is very clearly stated in one college physics course:

> ***Time dilation is reciprocal.*** If Δt is the proper time for a clock in S, then the two observers in S' would measure $\Delta t' = \gamma \Delta t$. If this effect were not reciprocal, there would be a way to distinguish between inertial frames. [7]

In the last sentence above, the author makes it very clear why he believes what he believes. He is misinterpreting Einstein's theory. The author then goes on to say, "Time dilation applies to any periodic phenomenon, electronic, mechanical, or biological." So, there can be no way that one twin will age slower than the other due to his motion. Aging must be reciprocal.

Another college text book states three times on the same page that time dilation is reciprocal. Here is the how that belief is justified in the last mention on the page:

> Time dilation is reciprocal because the observers do not agree on which events are simultaneous. In Euclidean geometry the corresponding fact is commonplace: if you look in horizontal direction from a lighthouse at sea level to a second lighthouse of identical construction also at sea level some miles away then the other lighthouse does not reach the height of the first one because the surface of the earth is curved. Height depends on which direction is horizontal and the horizontal directions of both lighthouses do not coincide.[8]

In other words, the author is claiming that time dilation is just an illusion, no different than how I look to be the size of your thumb when I'm a half block away from you, and you look to be the size of my thumb when you are a half block away from me.

VI. A proposed experiment.

It also seems that part of the confusion is the result of Einstein's belief that time is somehow related to distance, and that a measuring rod will somehow contract in length when moving fast. In 1905, he had no other way to explain the cause of time dilation.

Today it appears that time is related to the spin of subatomic particles, and time dilation occurs when the spinning atoms and subatomic particles conflict with the natural limit of the speed of light.[9] A spinning object cannot move at the speed of light because the spin would result in one side of the object moving faster than the maximum speed allowed by Nature – the speed of light. Due to that Natural speed limit, atomic clocks routinely demonstrate that the faster they are moved, the slower they will tick. Likewise, the faster any object moves, the slower its atoms and particles will spin. Time simply slows down for an object when the atomic particles that comprise that object must spin slower due to the natural limit upon how fast objects and particles can travel in our universe – the speed of light.

It appears that a relatively simple experiment can demonstrate how gravity and velocity can work together to significantly slow down time in a laboratory here on Earth. All you have to do is put an atomic clock (or multiple atomic clocks help verify the results) on a large centrifuge like those used to test the effects of gravity on astronauts and pilots. The centrifuge at NASA's Ames Research Center in Mountain View, California, can reportedly generate 20 Gs of gravity for as long as 22 hours. **[10]** It would be perfect for the experiment. A master atomic clock to be used for comparisons can be positioned outside of the centrifuge room. While the centrifuge spins, the tick rate of the clocks aboard the centrifuge will be slowed due to velocity time dilation, and the tick rate of the clocks would be *further* slowed by the acceleration and increased simulated gravity of the centrifuge. (If the experiment works as expected, the experimenters might then perform a simple additional experiment by repeating the first experiment with dry ice placed around the clocks to see if **temperature** *also* slows time.**[11]**)

Such experiments should undeniably confirm that time is not related to distance, and measuring rods do not change their lengths when moving at high speeds. Nor is space curved. Time dilation is simply caused by Nature's natural speed limit on light, which affects the spin of the subatomic particles that comprise everything in our observable universe.

VII. Conclusion.

Time dilation is real. The Hafele-Keating Experiment confirmed that fact, as have other similar experiments. There is no basis for any claim that motion <u>or</u> time dilation are reciprocal, nor is there anything paradoxical about time dilation. Any claim that motion is reciprocal is equivalent to a claim that if I use a gun to fire a bullet at a target, it is equally likely that I somehow caused the target, the earth on which it stands and the entire universe around the target to move to meet the stationary bullet as I and my gun moved away from the bullet.

An experiment in which an atomic clock is placed on a high-speed centrifuge would not only confirm that time dilation is not relative, it could provide answers to some questions many physicists haven't yet thought to ask.

VIII. References.

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