Variable Time and the Variable Speed of Light

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Abstract: *Einstein's Special and General Theories of Relativity state that time is a variable depending upon motion and gravity. The theories also state that the speed of light is variable. Einstein's theories are being verified virtually every day. Yet, a few physicists still argue that time does not vary, and many physicists appear to inexplicably argue that Einstein's theories state that the speed of light is <u>in</u>variable. This is an attempt to clarify what Einstein wrote and show how experiments routinely confirm that the speed of light is variable.*

Key words: Speed of Light; Time; Time Dilation; Relativity; Einstein.

I. Measuring the speed of light.

The fact that the speed of light is variable is demonstrated almost every day. No matter where you measure the speed of light, if you measure it correctly, you will get a result of 299,792,458 meters ***<u>per second</u>***. Does this mean that the speed of light is the *same* everywhere? No. It means the speed of light *<u>per second</u>* is the same everywhere. And, according to Einstein's Theories of Special and General Relativity, *the length of a second* can be *<u>different</u>* almost everywhere. That means that if you measure the speed of light to be 299,792,458 meters *<u>per second</u>* in one location, and if you also measure it to be 299,792,458 meters *<u>per second</u>* in another location, if the length of a second is different at those two locations, then the speed of light is also different.

And the same applies to light frequency. Light is measured by its wavelength (in nanometers) or frequency (in Hertz). One wavelength equals the distance between two successive wave crests or troughs. The frequency of visible light is referred to as color, and ranges from 430 trillion hertz, seen as red, to 750 trillion hertz, seen as violet. Frequency (Hertz) equals the number of waves that passes a given point *<u>per second</u>*. If the frequency of a light is 430 waves _per second_ in two different locations and the length of a second is different in those two locations, then the frequency of light is different.

II. Measuring the length of a second.

The length of a second is officially defined as "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."[1]

In other words, it is a _count_. When you count 9,192,631,770 of those periods of that kind of radiation you have counted one second. And, if you are doing the counting at one location, you can reach a count of 9,192,631,770 before someone at another location has reached that count. Or they can reach that count before you do. The difference is the result of velocity time dilation (VTD) and/or gravitational time dilation (GTD). VTD causes time to move slower when an object moves faster. The faster the object travels, the longer its seconds are. GTD causes time to move slower for an object the closer that object is to a gravitational mass. The closer the object is to a gravitational mass, the longer its seconds become.

If you have a quartz watch, the quartz crystal inside the watch ticks 32,768 times per second.[2] If you have an electric clock on your wall or bedside table, it ticks 60 times per second.[3] And using a different atom than a cesium-133 atom would require a different count to measure a second. Each is just a different way of counting ticks to measure the length of a second at a location. There is nothing about any count that makes it superior to any other count, but the more ticks you have per second the more precise your measurements are, and the easier it is to measure time dilation.

III. Measuring Time Dilation.

It is vastly easier to demonstrate GTD than VTD. With GTD you can verify that an atomic clock ticks at a faster rate when it is at a higher altitude by simply raising one clock above a duplicate clock. But with VTD, you have the problem of trying to see and measure the tick rates of two atomic clocks when one is next to you and the other is off somewhere moving at very high speeds. The simplest way to do it is to use Einstein's suggested method of comparing *elapsed* times. You begin with two identical clocks that are side by side. You can verify that they tick at the same rate, and you set both to zero accumulated time. When you have verified that they are measuring elapsed time at the same rate, you then move one clock away from the other (the farther and faster the better) and bring it back. When you examine the two clocks again, they will once again be ticking at the same rate because they are again in the same location, but the clock that was moved will show less time has elapsed than the clock that was not moved.

The problem is that you have to move the clock very fast and for a considerable period of time to register any measurable amount of VTD. And that is extremely difficult to do while also keeping the clocks at exactly the same altitude to avoid GTD complicating the effects.

Measuring GTD is much simpler. According to Einstein's General Theory of Relativity (GTR), time moves faster and the length of a second becomes shorter as you move away from a gravitational mass such as the earth. The National Institute for Standards and Technology (NIST) confirmed that fact for altitudes as small as one foot.[4] An atomic clock raised just one foot higher than an identical clock ticked faster than the clock that was not raised. To accomplish that measurement, the NIST had to build a clock that ticked faster than a cesium-133 clock's 9,192,631,770 ticks per second. They built an aluminum ion clock that ticks 1,100,000,000,000,000 (1.1 quadrillion) times per second.[5]

On a larger scale, it has also been confirmed by using strontium atoms in an optical lattice clock (which ticks nearly as fast as an aluminum ion clock, but is more reliable under less-than-ideal laboratory conditions) that a second is shorter at the top of a mountain than at the bottom of the mountain. In the 2018 "Geodesy and Metrology experiment,"[6] an optical lattice clock was used to measure the altitude difference between a laboratory inside a mountain in France and another laboratory 90 kilometers away in Torino, Italy. The experiment showed the altitude difference to be 1,000 meters, or 3,280 feet.

Probably the most famous time dilation experiment thus far performed was the Hafele-Keating experiment.[7] In October 1971, physicist Joseph C. Hafele and astronomer Richard E. Keating took four cesium-133 atomic clocks aboard commercial airliners and flew them *twice* around the world, first eastward, then westward. Before and after each flight they compared the four clocks against clocks at the United States Naval Observatory in Washington, D.C. When reunited, the accumulated time differences were consistent with the predictions of STR and GTR. The experiment has been repeated by others many times.

IV. What is Time?

At this point, the standard argument from people who dispute the reality of time dilation is, "But clocks are not time, they just *measure* time." That is true, but everything that measures time at a location is affected by time and by time dilation. It isn't just the atomic clock that ticks faster at the top of the mountain, the person viewing the atomic clock is also *aging* faster, his heart is *beating* faster, his hair is *growing* faster, the bacteria in his stomach are *digesting* food faster, his clothes are decaying faster, and the iron nails in his shoes are rusting faster. The only difference is that the only action we currently have the capability to measure with high precision is the ticking of the atomic clock, and even that would not be possible with an ordinary wall clock or alarm clock.

Experiments have also shown that muons (an unstable subatomic particle of the same class as an electron, but with a mass around 200 times greater) traveling at speeds approaching that of the speed of light will decay slower than muons traveling at much slower speeds.[8]

This all seems to confirm that time is an effect of *particle spin*.[9] And how fast particles can spin seems to relate to a natural speed limit for time and light. When you reach the speed of light, particles can no longer spin and time stops. Likewise, when you encounter the massive gravitational effects at the event horizon of a black hole, particles can no longer spin and time stops there as well.

When traveling less than the speed of light, time fluctuates. When driving around in your car, time ticks slower at city speeds than when you at the speed limit on an open highway. Time ticks faster and faster when you are going uphill and slower and slower when you are going downhill. The differences are just so small that you wouldn't notice if it you weren't carrying an atomic clock along with you.

V. What is light?

Contrary to what is taught in most college physics classes, light consists of individual photons, not waves or rays. Richard Feynman made that point very clearly in his book "*QED*"[10] when he wrote:

> **I want to emphasize that light comes in this form — particles. It is very important to know that light behaves like particles, especially for those of you who have gone to school, where you were probably told something about light behaving like waves. I'm telling you the way it *does* behave —like particles.**

And in that same book Dr. Feynman also wrote:

> Newton thought that light was made up of particles — he called them "corpuscles" — and he was right (but the reasoning that he used to come to that decision was erroneous). **We know that light is made of particles because we can take a very sensitive instrument that makes clicks when light shines on it, and if the light gets dimmer, the clicks remain just as loud — there are just fewer of them.** Thus light is something like raindrops — each little lump of light is called a photon - and if the light is all one color, all the "raindrops" are the same size.

So, light consists of particles – known as "photons" – not as waves. Photons differ from other particles in that they do not experience any effects of time, they have no mass, which means they have no weight, and they travel at the speed of light in a vacuum. Photons from distant galaxies have been traveling unaltered though empty space for billions of years until they are destroyed in our eyes and photographic telescopes. Dr. Feynman also had something to say about that:

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The human eye is a very good instrument: it takes only about five or
six photons to activate a nerve cell and send a message to the brain.
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But, exactly what is a photon? A photon consists of electromagnetic energy, but it has no mass. When an astronomer looks through his telescope at a very distant galaxy, the arriving photons which activate the nerve cells in his eye were created billions of years ago. And those photons were created by the actions of other photons. Generally speaking, photons can be considered to be the universe's excess energy traveling from point to point. And it takes a photon to create a photon.

The process begins with a stable atom and an approaching photon, as imagined in Figure 1 below.

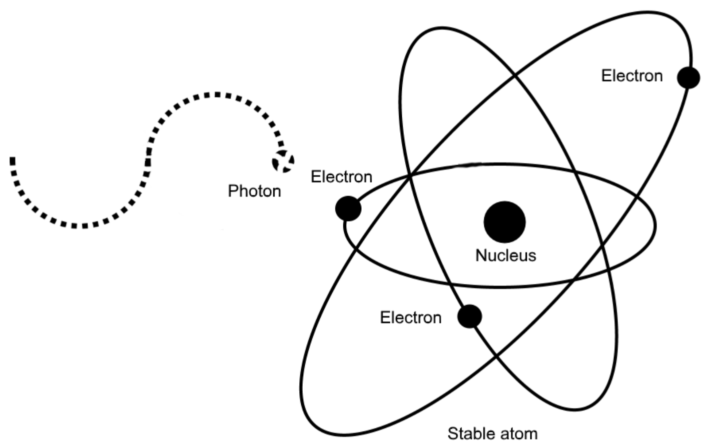

Figure 1

An electron in the stable atom is hit by the photon and the energy of the photon is combined with the energy of the electron. The photon ceases to exist. The combining of energies causes the electron to jump to a higher energy level, as shown in Figure 2 below.

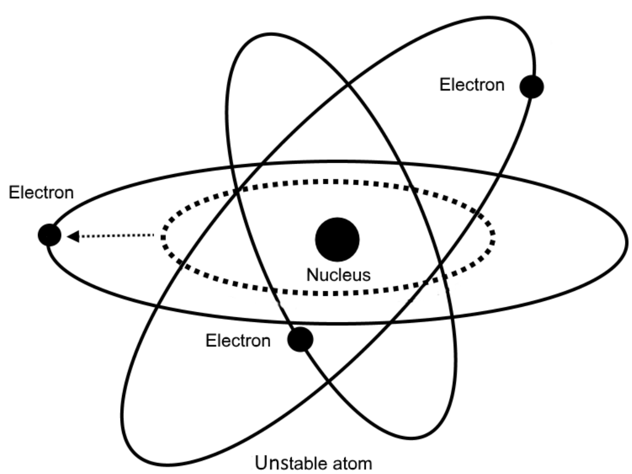

Figure 2

This causes the atom to become unstable. Unable to hold the excess energy, the atom then ejects the excess energy in the form of a brand new photon, and the affected electron drops back to its stable level. The new photon is emitted at the local speed of light, and it is generally emitted in a random direction (photons emitted by silver atoms in a mirror are an exception). This is illustrated in Figure 3.

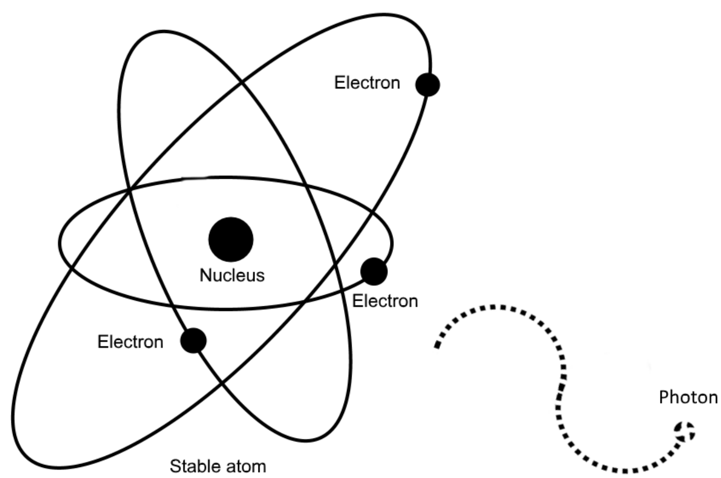

Figure 3

So, a photon only “exists” while it is traveling from atom to atom. If the atoms are billions of light years apart, an individual photon can “exist” for billions of years. The photon ceases to exist when hits an atom and its energy is combined with the energy of an electron. That process generally results in the creation of a totally new photon which again travels at the local speed of light to its next destination.

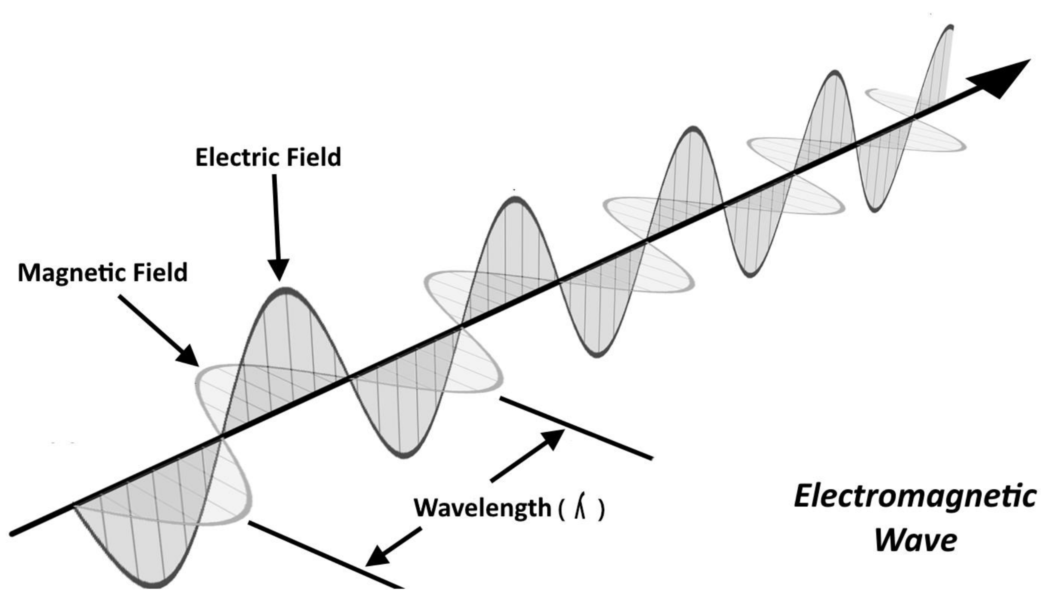

Figure 4

Figure 4 represents what an electromagnetic wave is generally imagined to look like when you ignore the fact that all forms of electromagnetic energy consist of photons, not waves. By simply adjusting the wavelength, the image represents everything from gamma rays with a wavelength of .0001 nanometers (billionths of a meter) or less, to AM radio waves with a wavelength of 100 meters or more. As viewed by those who believe light consists of waves, the electric field oscillates at right angles to the oscillating magnetic field as the wave moves through space like something shot from a ray gun.

However, Figure 4 is also fully compatible with a photon if you view Figure 4 as the path followed by a single photon. Then you simply have to realize that, during one unit of time (which equals one full wavelength of electric and magnetic field oscillation), the individual photon evidently must leave a pattern that looks something like Figure 5 below.

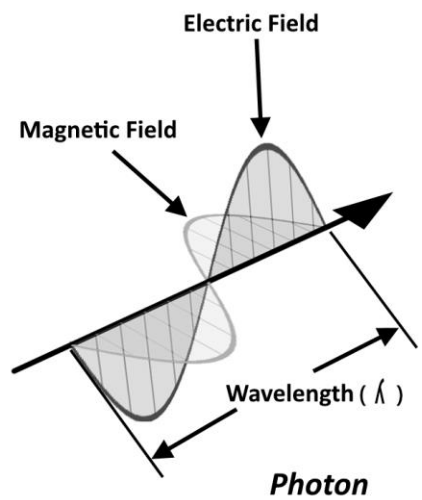

Figure 5

When viewing the moving photon pattern shown in Figure 5, one tends to try to imagine what a photon would look like when it is standing still. But, there is no such thing as a photon that is standing still. A photon is created when it is ejected from an atom, and the atom ejects the photon at the local speed of light.

VI. Comparing light speeds.

When measuring the speed of light, it is normally (and almost always) done by measuring the "two-way" speed of light. A short pulse of light is emitted toward a mirror which reflects the light pulse back to a detector adjacent to the emitter, and the time between emission and detection is measured by an atomic clock, as shown in Figure 6 below.

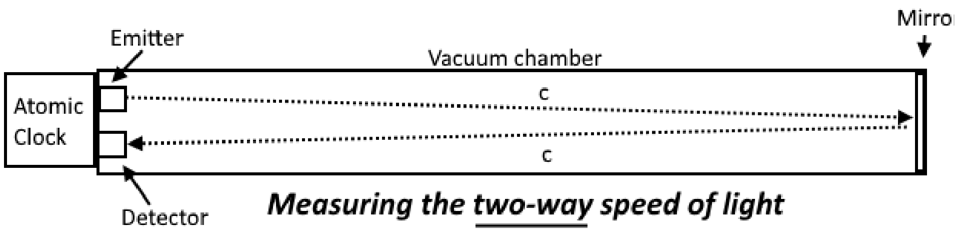

Figure 6

This is how light is measured at the top of a mountain and at the bottom of the mountain, and it is why both measure the same speed of light. They use different length seconds.

If you want to directly compare the speed of light as emitted from the top of a mountain to the speed of light emitted at the bottom of the mountain, it would require an emitter at the top and a detector at the bottom, *and* a separate atomic clock for each. But we already know the clocks will not tick at the same rate, so two *identical* but separate atomic clocks at different altitudes cannot be used to make time comparisons. Of course, that also means there is no way to compare the speed of the light coming from the Sun to the speed of the light coming from the North Star - or any other star. You cannot measure a speed if you only know the arrival time and not the departure time.

We *can*, however, precisely measure certain time dilation effects. As stated before, we know and can demonstrate that a second is longer at the bottom of a mountain than at the top of the mountain. And, since the speed of light *per second* is the same at both locations, we know that logically means that a photon travels at a slower speed when it is emitted at the bottom of the mountain versus at the top.

This also means that if you shine a light from the top of a building to the bottom of that same building, the light frequency will be observed to be "blue-shifted" at the bottom of the building. This is because the frequency of the photon oscillations (measured *per local second*) will be higher for the photons emitted at the top of the building than for photons (measured and emitted *per local second)* at the bottom of the building.

The famous Pound-Rebka experiment[11] performed in 1959 sent gamma ray photons from the top of a building at Harvard University to the bottom, a distance of 74 feet. An examination of books and papers about the Pound-Rebka experiment indicates that many authors assume it proves that light *changes frequencies* when it moves from one altitude to another. They call it "red-shifting" and "blue-shifting." Here is what Dr. Sten Odenwald writing on a Stanford University web site[12] has to say about red-shifting:

> The gravitational redshift happens when light tries to escape from a gravitational field. This is actually a phenomenon that you can explain using ordinary Newtonian physics. Thanks to Einstein's famous

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E= m c squared, and Planck's equally famous law relating the energy of
light to its frequency, E = h x frequency, we can see that as a
particle of light (photon) moves out of a gravitational field, it must
loose energy working against the gravitational field. Since photons
always travel at the speed of light, the only place where this energy
loss can show up is in a change of frequency. The frequency of the
photon must decrease so that the energy carried by the photon is lower,
and this corresponds to a 'red shift' to longer wavelengths. This
phenomenon has been confirmed in laboratory experiments carried out by
Pound and Rebka at Harvard University over 30 years ago. It's not a
theory, it's real.
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A college textbook about gravity[13] says, "A light ray in a gravitational field must fall with the same acceleration as other objects. Gravity attracts light." And the book then asks you to "imagine that Alice and Bob are in a rocket ship in empty space, far from any source of gravitation, and accelerating with acceleration *g*. Because of the acceleration Bob catches up with the signals faster and faster and thus receives them at a faster rate than they were emitted. The equivalence principle implies that the same relationship rates will be observed in the rocket at rest in a uniform gravitational field."

So, which is it? Does the frequency of light speed up as it moves downward because it gains energy by falling, or does light speed up as it moves downward because the observer is accelerating toward the source of the light?

The facts say neither claim is correct. In reality, light is ***emitted*** at different frequencies at different altitudes, and the idea that light somehow changes frequency ***while*** moving up or down in a gravitational field is totally wrong.

Instead of using photons, dropped stones can be used to illustrate the problem.

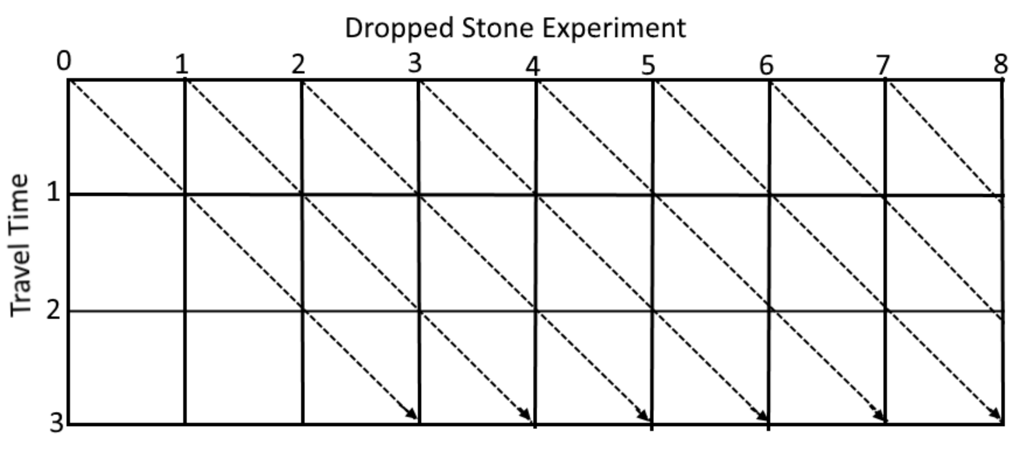

Figure 7

Figure 7 above shows that when you drop objects (like stones), each object speeds up at an identical rate. That means that all the objects will reach the ground at the same rate they were dropped. If stones are dropped at each unit of time (say one per second), and if it takes 3 units of time for the first stone to reach the ground (the dotted line between top and bottom), it will also take 3 units of time for the second stone to reach the ground, and the third, and fourth, etc. Each stone accelerates at the same rate as it falls, therefore there is nothing that will cause a difference between the rate the stones are dropped and the rate they hit the earth. Anyone who claims that photons speed up as they fall and thereby alter the frequency at which they are received is implying that they will hit the Earth at a faster rate than the rate at which they were emitted.

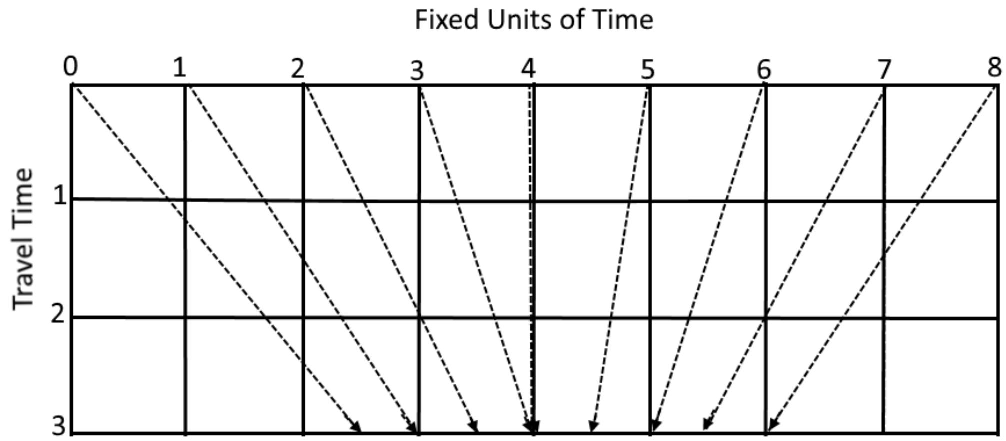

Figure 8

Figure 8 above, shows the impossible results of any claim that the speed of a light photon increases as it falls toward the Earth, resulting in a higher observation rate than the emission rate. A photon is emitted at each unit of time, and the Earth is 3 units of time away. The dotted lines show that *if* each photon speeds up along the way and takes only 2.5 units of time to reach the Earth, instead of 3 units of time, the fifth photon will have to travel instantly to the Earth, and all subsequent photons will have to arrive on Earth before they are emitted.

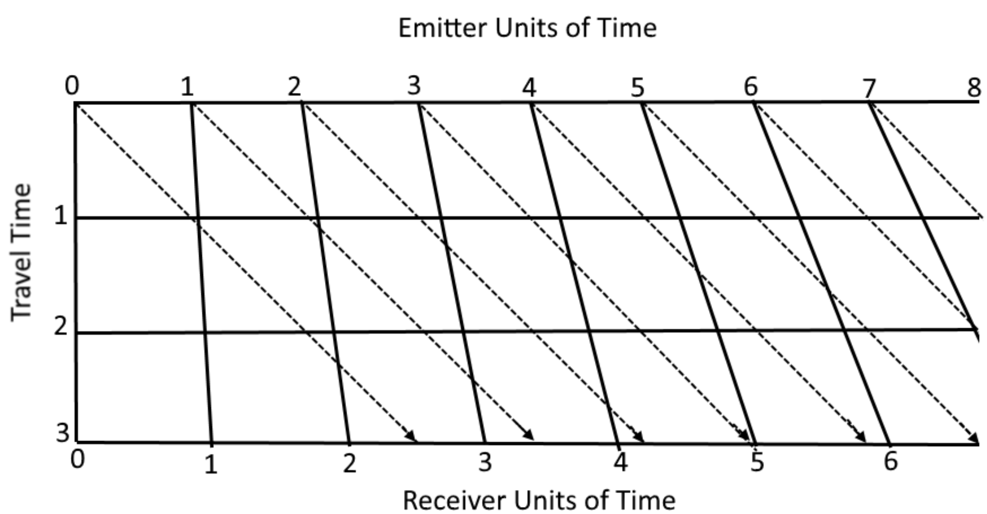

Figure 9

According to Einstein's GTR, however, a unit of time is just a small fraction longer at the bottom of a building (or mountain) than it is at the top of the building (or mountain). As a result, we get the effect shown in Figure 9 above. It still takes 3 units of the emitter's time for the emitted photons to travel from the emitter to the Earth, but because the receiver's unit of time is 20% longer, slightly more photons will arrive in each unit of the receiver's time.

VII. Conclusion.

There can be no doubt that time is variable and the speed of light is variable. Those who believe otherwise mostly seem unable to deal with mathematics that do not include a stationary "ether" or some other "preferred frame of reference" against which time and the speed of light can be measured. Without such a "preferred frame of reference" they reject any claim that light can be variable, and they distrust any experiment which shows that time is variable. They argue that Einstein claimed that all motion is relative, and they interpret that to mean that relative motion is reciprocal.

They generally won't argue that you cannot tell if a rocket sent to Alpha Centauri is moving away from the Earth or if the Earth is moving away from the rocket, but they will argue that if the rocket passes another rocket in space, there is no way to tell who is moving relative to whom. They argue that, according to Einstein's theories, the crews of both rockets can claim and demonstrate that they are stationary and the other is moving. In reality, Einstein's theories say that both crews can perform experiments *within* their rockets that produce the same results that would be produced *as if* they were stationary, but when they compare results between the rockets, time dilation and the different lengths of their seconds will show their duplicate tests actually produced different results. And they can tell who is moving faster than whom.

The Geodesy and Metrology experiment showed that two laboratories, one 1,000 meters higher than the other, will measure time ticking at different rates. And the difference in rates is in direct relation to the difference in altitude. The NIST experiment showed that the effect can be measured for altitude differences as small as one foot.

And it is known that the speed of light will be measured to be 299,792,458 meters *per second* at all altitudes. All that is needed to confirm that both time *and the speed of light* are variable is to demonstrate that the two-way speed of light *per second* at the two locations is the same even though the lengths of their seconds are different.

Then the only remaining task would be to convince the naysayers that it isn't some kind of trick.

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