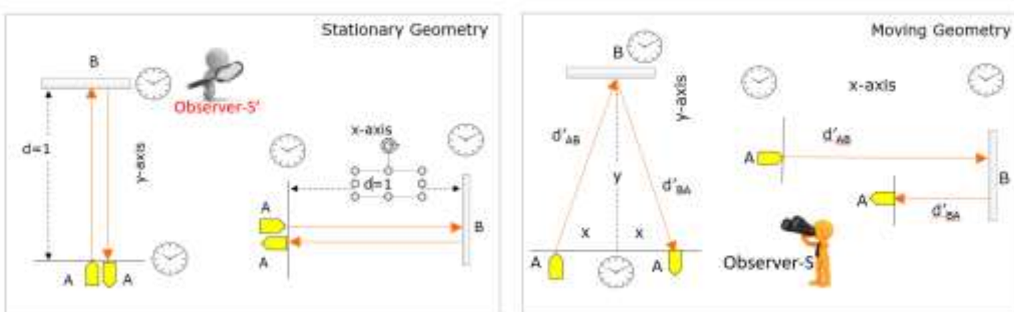
Causality and Relativity

1.1 Addendum: Causality and Relativity

Within the context of *website-3*, the issue of special relativity (SR) has been discussed on several occasions, the most recent being entitled '*Relativity Issues'* to which this discussion is an addendum. This last discussion was part of a series that tried to highlight issues related to '*Accepted Science*' covering both relativity and quantum theories, where one specific discussion focused on the issue of '*Causality*' and another on the '*Experimental Evidence'* supporting relativity. In this latter discussion, the primary issue raised was whether SR, based on the Lorentz transforms, offered up any causal explanation of either length contraction or time dilation. Based on some of the assumptions underpinning various wave models discussed in *website-3*, a causal mechanism for *length contraction* was considered. However, finding a causal explanation of time dilation proved more allusive, such that the idea was questioned as to whether time dilation had more to do with how we measured time using clocks rather than any universal effect on time itself. Therefore, a YouTube video titled '*What Time Dilation actually is in Relativity'* appeared to suggest a possible answer. In essence, the video presents the idea of a sound clock, as a variation of the light clock often used to explain the discrepancy between time displayed on a stationary and moving clock. However, the key issue as to why these clocks measure different elapsed time is based on the assumption of a constant wave propagation velocity between two points in space. The constancy of the wave propagation velocity [c] is also a fundamental assumption of special relativity, such that the propagation velocity [c] is independent of the velocity [v] of both the source and receiver. While the video raises a number of interesting points, it does not discussed how a sound clock may differ from a light clock. However, before we can discuss some of these issues in more detail, we first need to consider the basic geometry of a stationary and moving frame of reference, where either a sound or light wave may follow different paths.



In the stationary geometry, shown left, the distance [d] is the measure of the separation between [A] and [B] in both the vertical [y] and horizontal [x] configurations. As such, the time [t] taken for a wave having velocity [c] to propagate between [A] and [B] can be calculated from the relationship [t=d/c]. In the moving geometry, [A] and [B] both have velocity [v], such that [B] changes position in the time [t] it takes the wave to propagate with velocity [c] between [A] and [B]. However, as shown right, the geometry of the vertical [y] and horizontal [x] configurations is now different, such that the calculation of [d'_{AB}] and [d'_{BA}] also differs.

> *Note: While the basic geometry suggested above can be used for both a sound and light clock, the scale of the basic geometry shown requires the velocity [v] of the moving frame to be proportional to [c]. If we use [v=0.5c] as an example, the velocity of light [$c_0=3*10^8$m/s] requires a proportional frame velocity [$v_0=1.5*10^8$m/s]. However, the velocity of sound [c_1=343m/s] only requires a much smaller velocity [v_1=172m/s]. As such, we might reasonably assume that a velocity [v_1=172m/s] is so small relative to the speed of light [c_0] that any relativistic effects, such as time dilation and length contraction, can be ignored in the sound clock model, but will require further consideration in the case of a light clock.*

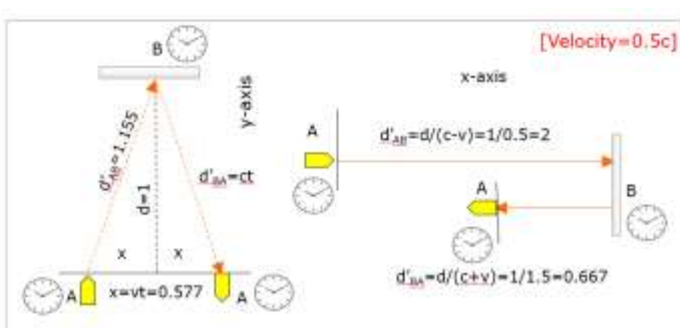
As shown, the geometry of the stationary and moving frames does not reflect any relativistic effects, such as time dilation or length contraction. As such, this geometry may only apply to the sound clock, although we might still consider it as a geometric baseline for the light clock model.

Note: While we have discounted any relativistic effects in the sound clock model, this cannot be assumed for a light clock. The sound clock video suggests some sort of physical connection between [A] and [B], although we might imagine a similar configuration where [A] and [B] are simply travelling on parallel paths, which might then negate the idea of any physical length contraction. If so, we might also want to consider this issue in the case of a light clock as it might also suggest that length contraction could not affect the geometry of the moving frame.

To clarify the issue of length contraction raised above, we might consider the example of a conceptual spaceship that travels between two points [A] and [B], which are considered to be 1 lightyear apart. If this conceptual spaceship was travelling close to the speed of light [c], then we might expect a discrepancy between the clocks onboard with any clocks at [A] and [B]. If this spaceship had an invariant velocity [v=0.99c], time dilation would suggest that the clocks onboard would tick 7 times slower than at [A] or [B], such that the journey time of [1/0.99=1.01] years would only take [t'=0.143] years according to the onboard clocks. Of course, if we accept that the distance between [A] and [B] of 1 lightyear cannot be subject to a wholesale contraction of space, the inference of the onboard time dilation might suggest that the spaceship had a velocity 7 times the speed of light [c] in direct conflict with a SR postulate. If we now put aside the issue of length contraction, it is clear that the moving geometry, as shown in the previous diagram, implies a longer propagation path for a wave with constant velocity [c], although the vertical [y] and horizontal [x] configurations are different in the moving geometry. However, it is also a postulate of SR that any inertial frame of reference can assume itself to be stationary, such that the results implied by the stationary geometry must agree with a comoving observer in the moving geometry, even though the vertical [y] and horizontal [x] configurations are different.

Note: According to SR, a comoving observer in a moving frame may assume themselves to be stationary. If so, the geometry of the moving frame can only be perceived by another observer who might also believe themselves to be stationary and can measure velocity [v] of the moving frame being described.

With the caveat above noted, we might establish, using a numeric example, whether the [y] and [x] configurations in the moving geometry produce the same result and how these results differ from the stationary geometry.



In the example above, it is assumed the entire reference frame is moving with velocity [v=0.5c] to the right. As such, we can now calculate the revised path lengths based on the constancy of the wave velocity [c=1] and the stationary distance [d=1], as summarised below, where the first row reflects the stationary geometry.

	d_{AB}	d_{BA}	Total
[y=x]; v=0	1	1	2
	d'_{AB}	d'_{BA}	Total
[y]; v=0.5	1.155	1.155	2.31
[x]; v=0.5	2.000	0.667	2.667

As the previous geometry makes no reference to any length contraction in the moving frame, we might initially assume that it only applies to the sound clock model and not the light clock model. However, as suggested, if there were no physical connection between [A] and [B] in either the [y] or [x] configuration, we might question how length contraction could alter the geometry even in the light clock model. This said, we now have two issues that need to be addressed, where on the basis of [t=d/c], the times in the moving frame are different to the stationary frame plus there is an asymmetry of time in the [y] and [x] configurations. On the first issue, the time differences in the stationary and moving frame appears to be as a consequence of the increased path length resulting from velocity [v], such that this difference has nothing to do with time dilation. While we might also assume that the asymmetric times are real in the sound clock model, this asymmetry would be more problematic for a light clock model assumed to operate according to SR.

> *Note: SR is based on the assumption that all inertial frames are equivalent, such that a comoving observer in either frame might assume themselves stationary. If so, relativity would require the times for the [y] and [x] configurations to be the same. However, on the basis that fastest man-made object, the Helios 2 space probe, only had a velocity [v=70,220m/s] equating to ~0.02% of [c], we may only have a limited understanding of what might be perceived from within a moving frame, where velocity [v] approaches [c].*

While the note above might rightly be considered speculative with respect to the light clock model, we have little empirical evidence to substantiate the perspective of a comoving observer at [v=0.5c]. So, while the [y] configuration of this geometry conforms to Pythagoras' theorem, as shown in [1] and cited in the video, it is not applicable to the [x] configuration because of the asymmetry.

[1] $$ct = \sqrt{(ct')^2 - (vt')^2} = ct'\sqrt{1-\left(\frac{v}{c}\right)^2} \Rightarrow t = t'\sqrt{1-\left(\frac{v}{c}\right)^2} = \gamma t'$$

In the context of the sound clock, we might interpret [ct] as equating to the propagation distance of a sound wave with velocity [c] in time [t], such that it corresponds to the stationary [y] geometry [d_{AB}=1]. However, this distance does not necessarily correspond to any physically measured length, but rather one calculated from the time [t] taken. On the right-side of the equation is the Pythagoras' formulation for a right-angled triangle, but where distance is now determined by time [t'] and where velocities [c,v] are considered invariant in both reference frames. However, the difference between time [t] and [t'] has nothing to do with time dilation and simply reflects the change in the length of the wave propagation path in the moving frame, as shown in [2] when [v=0.5c].

[2] $$t = t'\sqrt{1-\left(\frac{v}{c}\right)^2} = t'\sqrt{1-\left(\frac{0.5}{1}\right)^2} = 0.866 * t' \Rightarrow t' = \frac{1}{0.866} = 1.115$$

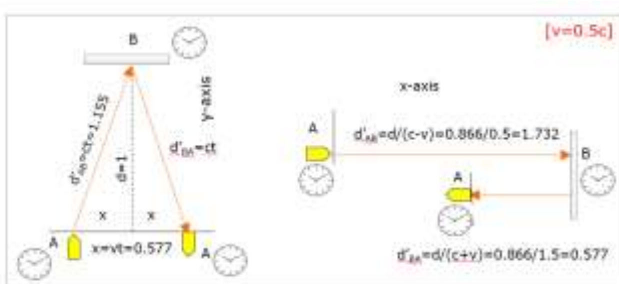
While [1] and [2] apply to the [y] configuration, we need to use [3] for the [x] configuration.

[3] $$d'_{AB} = \frac{d}{c-v} = \frac{1}{0.5} = 2 \quad and \quad d'_{BA} = \frac{d}{c+v} = \frac{1}{1.5} = 0.667$$

If we use [2] and [3] to determine the length of the roundtrip path, then we might confirm the figures shown in the previous table of 2.31 for the [y] configuration and 2.667 for the [x] configuration.

So, how might relativity change the geometric results?

Let us assume that we are now considering the light clock model, which from a geometric perspective might look almost identical to the sound clock model with one exception – length contraction that only takes place along the [x] axis of motion. This geometry is illustrated below, where [A] and [B] are connected by a physical rod, such that it is assumed subject to length contraction, where [d=1] is reduced to [d=0.866] in the [x] configuration only.



While [1] and [2] still hold true, [3] is modified as shown in [4].

[4] $$d'_{AB} = \frac{d}{c-v} = \frac{0.866}{0.5} = 1.732 \quad and \quad d'_{BA} = \frac{d}{c+v} = \frac{0.866}{1.5} = 0.577$$

Again, we might collate the results for this new geometry as shown in the table below, where the roundtrip path for the [y] and [x] configuration are now both equal, but still differ from the stationary frame by the relativistic gamma factor [ϒ=1.155] for velocity [v=0.5c].

	d_{AB}	d_{BA}	Total
[y=x]; v=0	1	1	2
	d'_{AB}	d'_{BA}	Total
[y]; v=0.5	1.155	1.155	2.31
[x]; v=0.5	1.732	0.577	2.31

In relativity, time dilation has to be interpreted as the rate of each tick of a clock in each frame of reference. As such, one tick of the clock in the stationary frame [t=1] takes [t'=1.155] in the moving frame, such that the rate of time is slower in the moving frame, although we might need to question this assumption further.

Note: As previously outlined, it is possible for the sound clock to be conceptually designed with or without any physical connection between [A] and [B]. However, if no physical connection exists between [A] and [B] in the moving frame, it is unclear that there is a causal mechanism for length contraction, at least, as described in terms of a standing wave compression. As a consequence, the difference between two clocks, one in a stationary and one in the moving frame, might only be resolved in terms of time dilation, if the moving geometry is unchanged by any form of physical length contraction.

At this point, we might question whether the absence of any physical connection between [A] and [B] might be conceptually considered for the light clock model. If so, the asymmetry of the first geometry would still apply, which leads us back to a central postulate of relativity requiring all inertial frames to be considered equivalent.

But why does causality create so many contradictions?

The *Lorentz Transformations* were published prior to 1904. Einstein's idea of special relativity (SR) was published in 1904 and influenced by the earlier work of Lorentz from 1892. Much of the focus of this earlier work was an attempt to explain the null results of the Michelson-Morley experiment (MXX), first performed in 1887.

*Note: After the null results were published, the existence of what was called the '*Luminiferous Aether'* was questioned, such that SR would reject the idea of any wave propagation media. However, at this time, there was no obvious causal mechanism that might explain* length contraction *or why the* Michelson-Morley Experiment *always produced a null result – see* Relative and Relativistic Frames *for more details.*

While there are a number of *mathematical transforms* linked to different geometric configurations, we might now focus on the *Lorentz Transforms*. However, as the previous link provides the details behind these transforms, we shall only consider some of the basic issues surrounding the Lorentz transforms as summarised below.

[5] $$x=\gamma(x'\pm\beta t');\quad y=y';\quad z=z';\quad ct=\gamma(ct'\pm\beta x');\quad \text{where } \beta=\frac{v}{c} \text{ and } \gamma=\left(\sqrt{1-\left(\frac{v}{c}\right)^2}\right)^{-1}$$

Given that [ϒ] has to be equal or greater than unity, [x>x'] might suggest some form of length contraction, while [t>t'] might suggest a time dilation with respect to the stationary frame, although it might only imply that the measure of [x',t'] are different to [x,t]. For the mathematical formulation in [5] is without reference to any causal mechanism for either length contraction or time dilation. While this does not mean these relativistic effects are not real, it might be argued that science requires some additional causal explanation before acceptance along with sufficient Experimental Evidence. Within this discussion, reference has only been made to two basic geometric models, where the stationary and moving frames are separated by an invariant velocity [v] – see Relative Geometry for more details. The first geometry associated with the sound clock implied no relativistic effects, such that it conforms to a Galilean Transform. The second geometry conforms to a Lorentz Transform in that it accounted for a length contraction between [A] and [B] along the [x] axis of motion in the moving frame. However, even if we accept length contraction of a physical connection between [A] and [B], it is possible to imagine that the [y] and [x] configurations have no physical connection, such that it might negate the idea of length contraction. If so, we have to return to the two problems highlighted in the first geometry, namely 1) why the path lengths and times differ between the stationary and moving frames and 2) why the times for the [y] and [x] configurations differ in the moving frame. So, let us summarise some of the key assumptions of both a wave model and SR.

> *Note: In a wave model, the velocity [c] is a property of some wave propagation media and explains why it is independent of the velocity [v] of the source or receiver. However, SR questioned the existence of a wave propagation media, at least, in the form of a 'luminiferous aether' on the basis of the null results of the Michelson-Morley experiment. Without a propagation media, SR postulated that there could be no absolute frame of reference, such that all inertial frames can assume themselves to be stationary and all other frames having velocity [v] relative to it.*

In many ways, it is the last assumption about the equivalence of all inertial frames that has led to so many *paradoxes* that surround time dilation and length contraction. As described, the basic geometry of a sound clock and light clock differ only in terms of an assumed length contraction of a physical connection between [A] and [B] in the [x] configuration associated with the moving frame, which may or may not exist depending on the clock design. If we start with the sound clock model, there are no assumed relativistic effects, such that any time difference in the stationary and moving frames simply reflects the increased wave path length caused by velocity [v]. As such, it appears that we must accept the asymmetry of the times in the [y] and [x] configurations in the moving frame to be real.

So what is really different in the light clock model?

As indicated, more than any other assumption or postulate of SR, the equivalence of inertial frames necessitates a length contraction in the [x] configuration of the moving frame in order to avoid the asymmetry of time within the [y] configuration. However, it would appear that this asymmetry must exist in the sound clock, such that the sound clock could actually determine whether it was in motion by rotating the sound clock into the [x] axis of motion.

So could this rotation test be apply to a light clock?

Let us consider an Einstein-like '*Gedanken-experiment'* for a light clock on a satellite orbiting the Earth with velocity [v=10,000m/s]. In this light clock, [A] and [B] are connected by a physical rod, where [d=1 metre], such that it might, or might not, be subject to length contraction, if the light clock is orientated along the [x] axis of motion. However, if this contraction does not take place, we should be able to determine an asymmetry between the [y] and [x] roundtrip times based on [1] and [3], where [v=10,000m/s, ϒ=1.000000000056]

Stationary	Moving [y]	Moving [x]	Difference
2	2.0000000011	2.0000000022	$1.1*10^{-9}$

So, based on the figures in the table above, the difference between the wave path length in the [y] and [x] configurations without length contraction in a moving frame having a velocity [v=10,000m/s] would be about 1 nanometre [Δd]. As such, the time difference [t=Δd/c] would be $3.8*10^{-18}$s, such that we might question whether this gedanken-experiment could actually be carried out in any near future. Therefore the results in the table might possibly be more reflective of the limits of the current ability to verify relativistic effects in a moving frame when the frame velocity [v] is approaching the speed of light [c].

Are there any other differences between the sound clock and light clock models?

The following bullet points only try to summarise some potential causal issues in accepted science:

- The sound clock model is based on known wave physics, such that it can be empirically verified. Sound waves are longitudinal waves that propagate through the 3-dimensional media of air with an approximate velocity [c_1=343m/s], which is about a million times slower than light [c_0=3*10^8m/s]. The propagation media of air is tangible and can therefore be considered as an absolute frame of reference against which a moving frame can have an unambiguous velocity [v]. Typically, a sound wave can be described as propagating outwards from a source in all 3 dimensions [xyz], this latter point is an issue for the photon model of light raised below.

- In contrast, the physics of a light clock model is still subject to debate in terms of relativity, both special (SR) and general (GR) plus quantum theory (QT). From the perspective of SR, we have the issue of a questionable propagation media based on the null findings of the Michelson-Morley Experiment, such that it is normally assumed that no absolute frame of reference exists. This assumption then leads to the SR postulate that all inertial frames are equivalent, such that all other inertial frames can assume the role of a stationary frame.

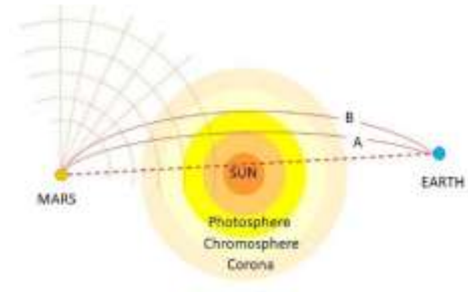
- On the basis of the Lorentz transforms, SR forwarded the argument that time dilation and length contraction are a relativistic effects that occur in a moving frame as the velocity approach the speed of light [c]. However, the relativistic effects can only be detected from another arbitrary frame from which velocity [v] is measured, such that any comoving observer within the moving frame only perceives themselves as a stationary frame. If so, all relativistic effects have to be based on conceptually remote observations or mathematical models.

- Unlike SR, GR assumes light follows the geodesic curvature of 4-dimensional spacetime – see *Flat Space, Curved Spacetime* and *Concept of Space-Time* for more details. The *cosmological model*, heavily influenced by GR, assumes spacetime expands– see *Equations of Cosmology* for more details. While it is left to the reader to a coherent description of quantum time, they might start by considering *The Idea of Time*. While controversial to the accepted consensus, quantum theory is possibly another model that has too much dependence on mathematics – see *A Flawed Perspective* for more details.

- Next we come to the somewhat confusing description of light, both as an electromagnetic (EM) wave and particle-like photon. It is often generally assumed that an EM wave is produced by an oscillating charge, e.g. electron, from which EM waves propagate outwards, except along the path of the oscillating charge. In the case of a photon, it is usually described as being sourced by a transition between a higher and lower atomic orbital, such that its energy is quantized, which does not seem to apply to the EM description - see EM-Wave Issues and Photon Issues that discuss some further issues related to causality.

It was Einstein's paper on the *photoelectric effect* that introduced the idea of a quantum of energy, i.e. a photon, in 1904, although its physical structure is still questionable. However, irrespective of whether we use the EM wave or photon model, it is generally assumed that light propagates in a straight line with velocity [c=1]. However, individual photons within an aggregated beam passing through a material may be delayed due to collisions i.e. absorption and emission, within the atoms and molecules of the material. As such, a beam of photons may appear to have an aggregated velocity [c'=c/n] due to the refractive index [n] of the material. As such, velocity [c'] is the statistical averaging of the time for [n] photons to pass through the material, even though individual photons always propagates with velocity [c=1]. So while the upper limit of the velocity of light is [c=1] in a perfect vacuum, it might be premature to assume that this velocity is always attained in the '*vacuum of space'* or follow a straight path. For example, it is estimated that different regions of interstellar space have between 1-1000 atoms/cm^3, which might be compared with the estimated 10^9 atoms/cm^3 in the Sun's corona or the 10^{16} atoms/cm^3 in the Sun's photosphere. By way of another comparative measure, Earth's atmosphere has about 10^{19} molecules/cm^3 at sea level, while we might approximate glass having 10^{23} atoms/cm^3.

> *Note: The figures above represent the mass-density rather than the optical density that would affect the refraction of light. In the EM wave model, the speed of light [c] is a function of electric permittivity (ε) and magnetic permeability (μ) associated with* Maxwell's electromagnetic theory*. It is unclear whether a photon has a causal explanation of its velocity [c].*



Based on the diagram right, we might visualise a source of light propagating outwards in all directions into the vacuum of space, such that it might be described as a series of expanding shells of EM energy or alternatively an almost infinite stream of photons moving out along radial paths. However, the diagram also suggests that the radial paths might be subject to curvature when passing close to the Sun. Typically, this curvature is explained in terms of GR, although we might ask why the idea of a refractive index does not apply. For if the region around the Sun has layers of different particle/optical density, might it not also imply different degrees of refractive index that create a curved path.

What else might affect the light clock model?

While this discussion has only tried to table a range of issues that possibly need to be better understood in terms of physical causality, it might raise one last issue that might affect the light clock model in a moving frame as its velocity [v] approaches the speed of light [c]. In the [y] configuration, the length of the light path was calculated on the basis of Pythagoras' theorem, which was shown to underpin the gamma factor [ϒ]. However, in the moving frame, the light must follow a diagonal path between the source at [A] and the receiver positioned at [B], but now subject to a displacement [vt]. While the sound clock in the video suggests that the sound wave radiates outwards along all paths from [A], we might question whether this would apply to a directional light source, such as a laser beam or stream or single photons. Generally, it is assumed that the velocity [v] of the source cannot impart any momentum onto a photon, if so a photon emitted vertically from [A] would not arrive at [B], at some later time [t], when displaced by [vt]. If so, a stream of photons emitted at incrementing time [t] would simply propagate along their own vertical path from [A]. Therefore, it is unclear whether a light clock using a directional light source would work at a relativistic velocity and, if so, it could not be used to support the special theory of relativity. Finally, given the seemingly unresolved causal issues cited, the idea that time dilation would affect the aging process of living cells is possibly best left as yet another open issue.

> *While many might see this discussion as a wholesale rejection of accepted science, its primary arguments have all been related to causality. Therefore, this discussion will close at this point with Voltaire's statement: doubt is not a pleasant condition, but certainty is absurd.*