Accelerating Clocks Run Faster <u>and</u> Slower

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Einstein's relativity contends that time, as measured by clocks, slows with increasing speed, becoming especially noticeable as the speed of light is approached. Discussions of this usually focus on constant speeds, albeit near the speed of light, and phenomena such as muon decay (near light speed), or even the Hafele-Keating experiment (at much slower speeds), are cited as 'proof.' Dissident scientists often contend that time remains invariant, although clocks may appear to run slower at increasing speeds. At least one such scientist contends that accelerated clocks can run both slower and faster, an interesting departure that I decided to examine via some examples. To the extent that my examples are correct, I too would agree with this conjecture, namely that, while time remains invariant, clocks can run faster and slower when accelerated (but not at constant velocity).

1. Introduction

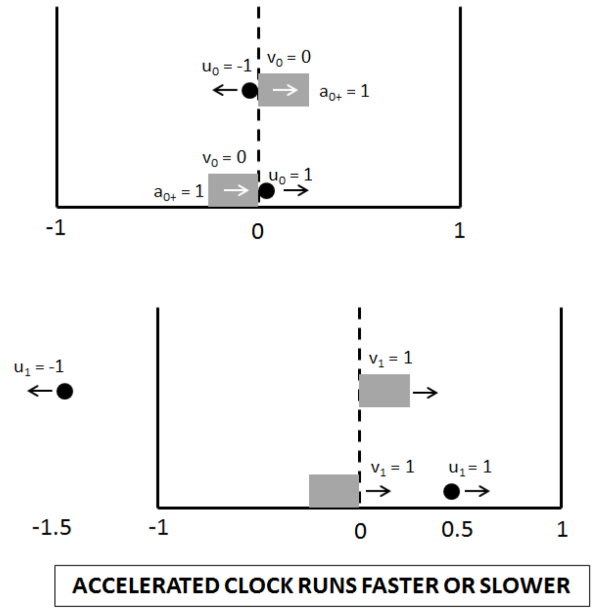
While perusing Don E. Sprague's website on "Complex Relativity" (http://complexrelativity.com), I read the following discussion:

> *Clocks lose time but also gain time. The Hafele and Keating experiment has atomic clocks going around the world showing less time in one direction but time gain in the other direction. We know that Einstein predicts that time slows with movement and eventually time is varied to a singularity where time end which is an impossibility. Since Einstein predicts that time slows, the Hafele and Keating experiment refutes Einstein. The clocks in the Hafele and Keating experiment show both a time loss and a time gain. According to Einstein, they just have time loss. Thus, the time gain portion goes against Einstein. However; the clock gain and loss is accurately predicted using CM* [Classical Mechanics] *and ChR* [Classical hierarchy Relativity] *with relative c. That is because ChR specifies that acceleration of a clock will result in a clock change in reading or clock error. Any examination of the Hafele-Keating experiment must consider the total acceleration of the clocks as they relate to the known universe.*
>
> *Consider an atomic clock experiment with the clock moved up a foot and down a foot resulting in a clock reading variation or error. This acceleration of the clock caused a loss of synchronization in the clock as predicted in ChR. The combination of the Hafele and Keating and the atomic clock one foot elevation experiments are confirmation that Maxwell/Einstein constant c relativity is wrong. It is proof that ChR with relative c is correct.*
>
> *The combination of the Hafele and Keating experiment and the atomic clock 1 foot acceleration could loosely be considered to be the ChR equivalent of the Eddington observation about Einstein's relativity where he interpreted a gravitational lens bending light as confirmation that the time changed. In the case of the accelerating clocks, there isn't any way to interpret the clock gain as conformation of Einstein that predicts just time loss. There can only be clock error with accelerated clocks as specified in ChR.*
>
> *It isn't a matter of if Einstein is wrong while CM and ChR with constant space and constant progression of time and relative speed of light is correct in a hierarchy of frame relativity. It is just a question of when and how the physics world will acknowledge the truth I have shown.*

Others have disputed the contention that the Hafele-Keating results support Einstein's relativity (e.g., Spencer and Shama, "Analysis of the Hafele-Keating Experiment," Third Natural Philosophy Alliance Conference, Flagstaff, Arizona, June 1996; Kelly, "Hafele & Keating Tests: Did They Prove Anything?" [http://www.anti-relativity.com/hafelekeating debunk.htm]). Never being one to accept Einstein's conjecture that time slows due to movement at constant velocity, I nevertheless never considered the possibility of clocks (not time) showing variation under accelerated movement. The above discussion prompted me to consider this possibility by postulating three examples of acceleration: (1) change in speed, but not direction; (2) change in direction but not speed; and (3) change in both speed and direction. As my 'clock,' I postulate a gun shooting a projectile into a target, with the time between ejection from the gun and striking of the target becoming the unit of time measurement.

2. Case 1. Acceleration due to Change in Speed but not Direction

In Figure 1, a boxcar of length two (arbitrary units) has a pair of guns (grey) mounted to fire in opposite directions at its midpoint (shown here as 'upper' and 'lower'). At time 0, when the boxcar is stationary, both guns fire projectiles at equal speeds of $u_0 = 1$/sec (s). At an infinitesimal time later (0+), the boxcar, and therefore the two fixed guns, is accelerated to the right at $a_{0+} = 1/s^2$ (white arrows). Since both projectiles have already left their guns, neither 'feels' this acceleration, so each continues on its path at the original, constant speed. After 1 s, the boxcar has traveled $x = (1/s^2)(1\ s)^2/2 = 0.5$ to the right, now also the positions of the two guns (now with speeds of $v_1 = [1/s^2][1\ s] = 1/s$ to the right). Relative to their starting points in the boxcar, the projectiles have now reached the following positions: lower at +0.5, upper at –1.5 (having passed through the left wall of the box car).



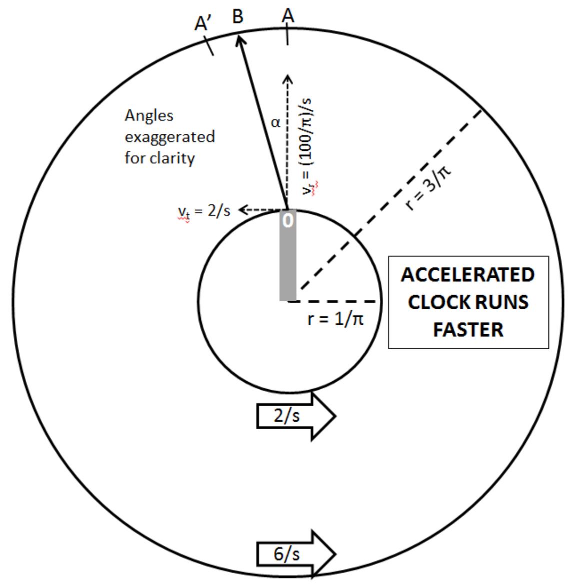
<u>FIGURE 1</u>. Case 1 – Boxcar Accelerating in Speed only, not Direction (Top Shows Boxcar at Time 0 and 0+; Bottom Shows Boxcar at Time = 1 s)

When stationary, an observer measures the 'standard' unit of time on the boxcar as that for a projectile to reach a wall, the same for each gun-projectile system. However, now the accelerated observer, assuming equal-speed projectiles, would conclude a clock calibrated to the upper gun runs faster than one calibrated to the lower gun because its projectile reaches a wall sooner – and that the upper clock runs faster than 'standard' time while the lower one runs slower. Direction matters.

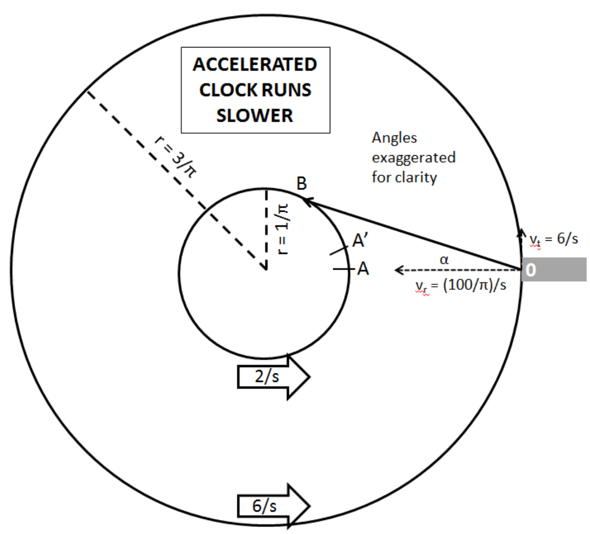
3. Case 2. Acceleration due to Change in Direction but not Speed

For the next two cases, it is convenient to examine circular motion, as that inherently involves directional acceleration and, if rotational speed is changed, acceleration in speed as well. First, we consider the case of acceleration due only to directional change, as shown in Figures 2 and 3. In Figure 2, a carousel (torus) rotates at a constant speed of 2π radians/s, such that the tangential speeds v_t of the inner and outer rims are 2/s and 6/s, respectively, given the radii shown (in arbitrary length units). A grey gun fixed to the inner rim, with its end rotating at v_t = 2/s, shoots a projectile from Point 0 at radial speed v_r = (100/π)/s such that it travels at speed $v = ([2/s]^2 + [\{100/\pi\}/s]^2)^{0.5}$ = 31.89/s at angle α = arctan (2/[100/π]) = 0.06275 radian (3.595°). It follows Path 0-B to hit the outer rim at Point B after traveling a length of $\{2\cos(\pi-\alpha) + ([2\cos(\pi-\alpha)]^2 + 32)^{0.5}\}/2\pi$ = 0.6370, using the law of cosines. The elapsed time is (0.6370)/(31.89/s) = 0.01997 s. Point A, on the outer rim, immediately above the gun, rotates to Point A' = (0.01997 s)(2π radians/s) = 0.1255 radian (7.191°) from the original Point A. Point B corresponds to rotation by arccos $\{(\pi^2/6)\,(10/\pi^2 - 0.6370^2)\}$ = 0.04185 radian (2.398°).

Define a new time unit, the 'zek' (z), as the time for the projectile to hit the outer rim. When stationary, one z = (3/π - 1/π)/([100/π]/s) = 0.02 s. When rotating as shown, one z = 0.01997 s, i.e., 'time' appears to have sped up by (0.02 – 0.01997)/0.02 = 0.001313 (~0.13%). But really time has not varied; only the directional acceleration has caused an apparent speeding up by ~0.13%. If we use the projectile hitting the outer rim as a clock and standardize it when the carousel is stationary (one z), we conclude that, when accelerated, the clock runs faster (1 + 0.001313 = 1.001313 z by the standard clock).



<u>FIGURE 2</u>. Case 2 – Carousel Rotating at Constant Speed with Gun Mounted on <u>Inner</u> Rim – Directional Acceleration Only



<u>FIGURE 3</u>. Case 2 – Carousel Rotating at Constant Speed with Gun Mounted on <u>Outer</u> Rim – Directional Acceleration Only

Figure 3 is the same as Figure 2, but now with the gun mounted on the outer rim. With its end rotating at $v_t = 6/s$, it shoots a projectile from Point 0 at radial speed $v_r = (100/\pi)/s$ such that it travels at speed $v = ([6/s]^2 + [\{100/\pi\}/s]^2)^{0.5} = 31.93/s$ at angle $\alpha = \arctan(6/[100/\pi]) = 0.1863$ radian (10.67°). It follows Path 0-B to hit the inner rim at Point B after traveling a length of $\{6 \cos\alpha - ([6 \cos\alpha]^2 - 32)^{0.5}\}/2\pi = 0.6738$, again using the law of cosines. The elapsed time is $(0.6738)/(31.93/s) = 0.02111$ s. Point A, on the inner rim, immediately below the gun, rotates to Point A' = (0.02111 s)(2π radians/s) = 0.1326 radian (7.598°) from original Point A. Point B corresponds to rotation by arccos $\{(\pi^2/6)([10/\pi^2 - 0.6738^2)\} = 0.4029$ radian (23.08°).

Now define the zek (z) as the time for the projectile to hit the inner rim. When stationary, one z again = 0.02 s. When rotating as shown, one z = 0.02111 s, i.e., 'time' appears to have slowed by (0.02111 – 0.02)/0.2 = 0.05523 (~5.5%), an opposite effect. But really time has not varied; only the directional acceleration has caused an apparent slowing by ~5.5%. If we again use the projectile hitting the inner rim as a clock and standardize it when the carousel is stationary (one z), we conclude that, when accelerated, the clock runs slower (1 - 0.05523 = 0.94477 z by the standard clock). As with Case 1, direction matters.

4. Case 3. Acceleration due to Change in Both Speed and Direction

For the final two cases, we continue with our rotating carousel, but now with the addition of acceleration in rotational speed. In Figure 4, the carousel rotates as before, with the grey gun mounted on the inner rim shooting a projectile as before. However, now at an infinitesimal time later (0+), the carousel is accelerated at 2π radians/s^2, such that the tangential accelerations a_t of the inner and outer rims are $2/s^2$ and $6/s^2$, respectively (grey arrows). The projectile does NOT experience this acceleration and, as before (Figure 2), reaches the outer rim in 0.01997 s. Because the carousel now speeds up, it will rotate by [4π radians/s + (2π radians/s^2)(0.01997 s)](0.01997 s)/2 = 0.1268 radian (7.262°), such that the projectile strikes the outer rim at Point B', with a perceived trajectory 0-B' now of length $[(10 - 6 \cos[0.1268])/\pi^2]^{0.5} = 0.6404$.

When the carousel was not speeding up, the trajectory 0-B length was 0.6370 and required 0.01997 s (1.001313 z) to reach the outer rim. Now the length (trajectory 0-B') is longer (0.6404) and requires 0.6404/([100/π]/s) = 0.02012 s, or ([1.001313 z][0.02012 s]/[0.01997 s]) = 1.008644 z, to reach the outer rim. That is, more time has elapsed, which means the additionally accelerated clock (speed plus direction) now runs faster by (1.0086443 – 1.001313)/(1.001313) = 0.007321 (~0.73%).

Figure 5 is the same as Figure 4, but now with the grey gun mounted on the outer rim with its end rotating at $v_t = 6/s$. Again, at an infinitesimal time later (0+), the carousel is accelerated at 2π radians/s^2, such that the tangential accelerations a_t of the inner and outer rims are $2/s^2$ and $6/s^2$, respectively (grey arrows). The projectile does NOT experience this acceleration and, as in Figure 3, again reaches the inner rim in 0.02111 s. Because the carousel now speeds up, it will rotate by [4π radians/s + (2π radians/s2)(0.02111 s)](0.02111 s)/2 = 0.1340 radian (7.677°), such that the projectile strikes the inner rim at Point B', with a perceived trajectory 0-B' now of length $[(10 - 6 \cos[0.1340])/\pi^2]^{0.5} = 0.6409$.

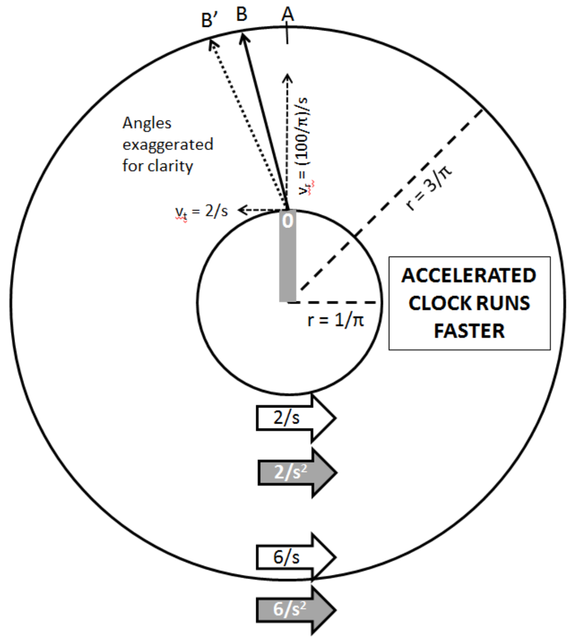


FIGURE 4. Case 3 – Carousel Rotating at Increasing Speed with Gun Mounted on Inner Rim – Both Speed and Directional Acceleration

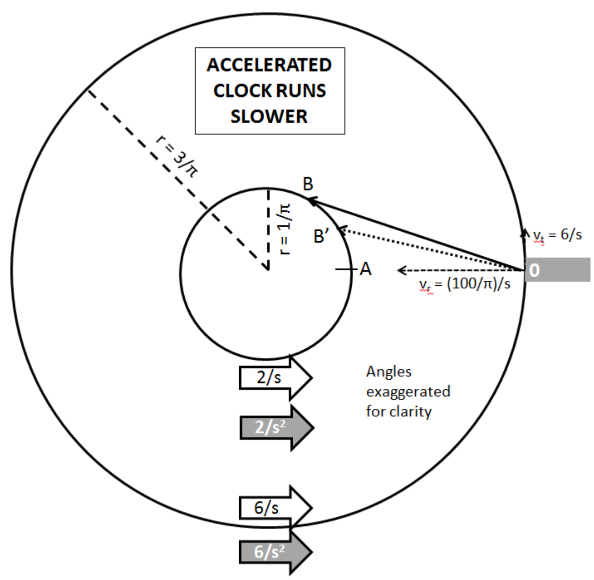


FIGURE 5. Case 3 – Carousel Rotating at Increasing Speed with Gun Mounted on Outer Rim – Both Speed and Directional Acceleration

When the carousel was not speeding up, the trajectory 0-B length was 0.6738 and required 0.02111 s (0.94477 z) to reach the inner rim (remember the zek has different durations based on direction). Now the length (trajectory 0-B') is shorter

(0.6409) and requires 0.6409/([100/π]/s) = 0.02013 s, or ([0.94477 z][0.02013 s]/[0.02111 s]) = 0.90132 z, to reach the inner rim. That is, less time has elapsed, which means the additionally accelerated clock (speed plus direction) now runs slower by (0.94477 – 0.90132)/(0.94477) = 0.04599 (~4.6%). Again, as with Cases 1 and 2, direction matters.

5. Conclusion

Can accelerating clocks run both faster and slower? Sprague believes so and provides his arguments on his website. I endeavored to examine this possibility using three cases considering both speed and directional changes as part of acceleration. As a result, I come to the same conclusion. This does not imply any belief in the variation of time itself, whether under constant or accelerating velocities, but merely a physical effect on an <u>accelerating</u> 'clock.' It also does not imply any belief that a clock moving at a <u>constant</u> velocity, even near the speed of light, will show any variation. The key is acceleration. And direction matters.

6. Acknowledgement

The author acknowledges correspondence with Don E. Sprague regarding his theory and my development of the three examples.