Moving Clocks and Special Relativity Rest Reference Frames

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Abstract

Einstein's special relativity theory predicts that time will go slower on moving clocks than stationary clocks. Without an absolute rest reference frame, how do we know which clock is moving and which is stationary? Although there is no absolute rest reference frame there are some practical rest reference frames. When the appropriate rest reference frame is chosen, clocks moving with respect to that rest reference pass time slower than those at rest in that reference frame.

Background

There has been some confusion concerning Einstein's (1905) special relativity theory (SRT). It appears to come about because there is no absolute rest frame of reference. All measurements are made relative to the observer. Additionally, whether an observer is moving or stationary with respect to another observer, he/she will have no concept that time is other than moving at his/her normal experience of time. To all observers, each accurate clock will still pass time at sixty billion (6×10^{10}) nanoseconds for each minute of their local time. How can moving observers tell who is moving the fastest and hence whose time is going the slowest? The answer lies in selecting the correct rest reference frame.

Practical Rest Reference Frames

There is no absolute rest reference frame. All motion is relative. Most people are familiar with ground as their normal rest reference frame. You stand on it and consider yourself "at rest". Everything you see is moving relative to your "fixed" position. It is not fixed. Earth's rotational velocity is ≈ $0.46\cos\theta$ km/sec, where θ is the latitude. That corresponds to ≈ $1.5 \times 10^{-6}\cos\theta.c$, where c is the speed of light in vacuum, compared to regarding Earth's centre as a fixed rest reference frame. Under Einstein's (1905) special relativity theory (SRT) corrections this gives time intervals

$$\Delta t' = \Delta t / \sqrt{1 - v^2/c^2} \qquad (1$$

where $\Delta t'$ is the time interval on the moving clock, Δt is the time interval on the stationary clock and v is the velocity of the moving clock relative to the stationary clock. There is a maximum time difference of ≈ 2×10^{-12} between clocks on Earth between the equator and poles.

With those rest reference frames in mind, consider two highly accurate clock sets at rest with respect to each other. They will keep the same time. One set of clocks, A, is placed in rocket payloads and launched into Earth orbit. The others, clocks B, remain on Earth. That clearly defines which clock is moving with respect to the other in an Earth centric frame. In the case of the Global Positioning System (GPS) satellites, clocks A orbit Earth at a speed of ≈ 3.5 km/sec or ≈ 1.1 x 10^{-5}.c. Clocks A run slower than the ground based clocks, B, by about 7 microsecond per day. That has been measured and clearly indicates the "traveling" clocks, A, have a slower time than the "stationary" clocks, B. Those corrections are taken into consideration for the accuracy of GPS navigation (Ashby 2002).

A third rest reference frame is the sun's centre. Earth's orbital speed about it is ≈ 29.8 km/sec, or ≈ 10^{-4}.c. It is here that care needs to be taken in selecting the correct rest reference frame. Earth's orbital speed about the sun does not need to be considered in calculations of the time difference between Earth and its orbiting satellites because it is their relative speed differences that matter. The sun's centre does provide another convenient rest reference frame.

Consider two accurate clocks, D and E. Clock D is sent into space to remain in stationary orbit around the sun. It would require acceleration in the retrograde Earth orbit direction to a velocity of ≈ 29.8 km/sec. It could be held in position by solar sails. It would appear to Earth based observers as being accelerated and therefore be considered as the moving clock. When Earth returned to its position the following year, the Earth bound clock, E, would show the time slower by ≈ 0.32 sec. In that situation, Earth is the moving object, even though clock D was accelerated. That is the situation in which the correct rest reference frame is the sun's centre.

The positions of the stars in our local region of the galaxy remain approximately fixed with respect to each other, even though they have a galaxy rotation speed of over 220 km/sec, ≈ 7 x 10^{-4} c, with respect to the galaxy's centre (Liu, 2018). That means the sun's rest reference frame sets a good rest reference frame for local interstellar travelers originating from star systems within a few thousand light years (at least 2,000 parsec). The only difference would be the speed of their planet's orbit around its star. That is approximately 10^{-4}.c for Earth and a similar speed for the other planet. That could make the initial speed difference less than 10^{-4}.c. In round figures, that could produce a "fuzzy" time zone difference of ≈ 2 x 10^{-4}.c, with an accuracy of ≈ 4 x 10^{-8}, in which it may not be possible to tell which traveler was moving the faster. That is a minor correction.

Consider a situation in the far distant future. An intrepid traveler from a planet around another star approaches an Earth based interstellar traveler. Both travelers would have their stellar centers as almost identical rest reference frames. Beyond the small planetary orbital differences, both travelers originate with similar rest reference frames having a time difference of ≈ 4 x 10^{-8}. Beyond that small difference, both would know who was traveling the faster if they had a means of measuring the Doppler blue shift from the approaching craft. They need only compare the observed blue shift of the other craft with the red or blue shift from a fixed star and take into account the gravitational redshift from those stars.

Summarizing the above. There is no absolute rest frame of reference. There are three commonly used rest reference frames. The first is our position on Earth's surface. It is that which most people regard as their rest reference frame. The second is the centre of the Earth. Observers on the Earth's surface are travelling at ≈ 0.46cosθ km/sec relative to that rest frame. The third rest reference frame is that of the centre of the sun. Because other stars in our galactic neighborhood occupy relatively fixed positions, that forms a rest reference frame for the local stars at distances of over 2,000 parsec. Compared to that rest reference frame, Earth is moving at ≈ 29.8 km/sec.

Sidereal time, the time measured with respect to the "fixed stars", provides a practical rest reference time frame against which all extra, as well as some intra solar system activities can be calculated. Most Earth based activities can use Earth's centre as a fixed rest reference frame. Their most obvious use is in accurate international timing and global positioning systems. One major exception is an accurate clock accelerated in retrograde Earth orbit and held in position by solar sails or some other mechanism.

A fourth rest reference frame is the centre of the Milky Way Galaxy. Compared to that reference frame, the local region of our galaxy is moving at about 220 km/sec, 7×10^{-4}.c around that centre. There is a fifth rest reference frame. The Milky Way Galaxy is moving towards the Norma cluster of galaxies and the Great Attractor at over 600 km/sec, 2×10^{-3}.c (Stavely-Smith 2016). The speed of intra or intergalactic travellers can be determined by measuring the blue shift of the photons from them. Travellers originating from beyond ≈ 2,000 parsec may regard themselves as travelling slightly faster. Even then travellers from tens of millions of parsec in the direction from the Norma galaxy cluster and the Great Attractor would only have time differences measured in tens of microsecond compared to the speed determined from their spectral blue shift.

Reciprocity

That raises the question: Is there reciprocity between moving and stationary clocks?" As mentioned above, it has been measured that clocks in satellites orbiting Earth run slower than those stationary on it. Other observations of time slowing down can be found in the cosmic ray showers. Muons, which have a half life of about 2 microsecond (μS), time for most them to travel only about 0.5 to 2 km. They are generated by cosmic rays in our upper atmosphere and detected many tens of km lower. That can only happen if their time reference frame slows down at their high velocity and the apparent distance they travel is shortened. Additionally, Einstein's SRT corrections must be used to get accurate travel of particles in particle accelerators. The answer is no! There is no reciprocity. A stationary clock will "tick by" at its constant rest reference frame rate. The moving clock will "tick by" at a slower rate compared to the stationary clock's time rate. When the moving clock is returned to the stationary clock's position, the travelled clock will show a time delay with respect to the stationary clock.

Cosmic rays provide the best evidence there is no reciprocity. They have energies in the GeV range, giving them velocities approaching c. Local observer speeds are significantly less than c. Cosmic ray protons have higher mass than terrestrial protons. SRT indicates cosmic ray particles are the faster travelers, not Earth. There is no confusion about whether it is the cosmic rays or Earth that is travelling the fastest. There is no reciprocity.

The use of the solar centric rest frame takes care of which twin moves and will age less in the so called "Twin Paradox". There is no reciprocity. The twin moving the fastest with respect to the solar rest reference frame will age less than the twin remaining at rest with respect the same frame. An example of choosing the wrong rest reference frame is the use of an Earth rest reference frame and accelerating one twin in retrograde Earth orbit to remain stationary in the sun's rest reference frame and use Earth as the rest reference frame.

Complexity?

The problems associated with the current teachings of special relativity are that Einstein's mathematics was so complex that most mathematical physicists don't understand it. Derivations of SRT corrections need not be much more complex than Pythagoras' theorem with the constant speed of light making up the hypotenuse (Robinson 2019 a), Robinson (2020). When that is understood the complexities that lead to misunderstandings disappear. It shows that the SRT corrections are an inherent property of every moving particle. Although there is no absolute rest reference frame in space, there are relatively fixed frames of reference as mentioned above. It is the motions against those that determine which observer is moving and which is stationary. With that, all confusion about SRT should disappear.

However, SRT corrections are not the only variations to accurate time keeping. Consider sending a clock in a satellite from Earth to Jupiter's orbit distance, although not around Jupiter. It would give it a final velocity according to the sun's reference of ≈ 13 km/sec. Compared to a synchronized clock on Earth, the Jupiter satellite clock's time would first slow down because of its escape velocity and then speed up as it neared Jupiter's orbital speed of ≈ 13 km/sec. At Jupiter's orbit, Earth's clock would be traveling at ≈ 16.8 km/sec (5.6×10^{-5}.c) faster than the clock in the Jupiter orbit distance satellite. The Jupiter orbit clock would go slower than the Earth clock by ≈ 3×10^{-9} based on SRT corrections only.

Einstein's gravitational field equations (GFEs) from his general relativity theory (GRT) predict that, in the lower gravitational field at Jupiter's orbit, its time would speed up. Extending Einstein's (1911) calculations show that, to a first approximation, the time difference is given by

$$t_{JO} = t_{EO}.\left[1+\left(z_{EO} - z_{JO}\right)\right] \qquad (2$$

where the $_{EO}$ and $_{JO}$ subscripts represent the properties of time t and the sun's redshift z at Earth and Jupiter orbit distances respectively (Robinson 2019 b). For stationary objects, time at Jupiter's orbit will go faster than time at Earth orbit by ≈ 1.9×10^{-9}. That leaves a residual time difference between clocks at Earth and Jupiter orbits of ≈ 1.1×10^{-9}. Using the sun's rest reference frame, sidereal time, Earth orbit clock's time would lag behind the Jupiter orbit clock. The SRT corrections for Earth's orbital speed around the sun are slightly greater than the GFE corrections for the sun's gravitational redshifts between Earth and Jupiter's orbits. Earth orbit clock's time would lag behind the Jupiter orbit clock's time. Checking that time delay would need to include calculations of the time taken for photons traveling from Jupiter orbit to Earth, the blue shift of the photons bringing that signal, as well as Doppler shift if the measurements were not made when the sun, Earth and satellite were not in a straight line.

Summary and Conclusions

For most purposes, positions referenced to the "fixed" stars in our galactic neighborhood, at distances of thousands of parsec from Earth, provide a convenient rest reference against which movement can be measured. Einstein's SRT time corrections, equation 1, apply to objects moving against that reference. All other situations can be calculated against that reference frame. For convenience, most Earth bound motions such as satellites orbiting it, can use Earth's centre as a rest reference frame and get the correct answer.

Moving clocks running slower than stationary clocks have been experimentally verified for decades. It is hoped the above gives physicists a better understanding of the time dilation predicted by Einstein's special relativity theory and as observed experimentally. Einstein's special relativity theory is a simple, non-confusing topic when its origins are understood.

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