Keeping Time: From Marking the Seasons to Counting Picoseconds

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Quid est enim tempus? Quis hoc facile breuiterque explicauerit? Quis hoc ad uerbum de illo proferendum uel cogitatione comprehenderit? Quid autem familiarius et notius in loquendo commemoramus quam tempus? Et intellegimus utique cum id loquimur, intellegimus etiam cum alio loquente id audimus. Quid est ergo tempus? Si nemo ex me quærat, scio; si quærenti explicare uelim, nescio. Fidenter tamen dico scire me quod, si nihil præteriret, non esset præteritum tempus, et si nihil adueniret, non esset futurum tempus, et si nihil esset, non esset præsens tempus. Duo ergo illa tempora, præteritum et futurum, quomodo sunt, quando et præteritum iam non est et futurum nondum est? Præsens autem si semper esset præsens nec in præteritum transiret, non iam esset tempus, sed æternitas. Si ergo præsens, ut tempus sit, ideo fit, quia in præteritum transit, quomodo et hoc esse dicimus, cui causa, ut sit, illa est, quia non erit, ut scilicet non uere dicamus tempus esse, nisi quia tendit non esse? ?"—**Augustine of Hippo**, *Confessiones* lib xi, cap xiv, sec 17

The keeping of time encompasses a multitude of questions. One can structure a discussion of time by examining several prevalent conceptions and the queries to which they invariably lead. The first is whether common *a priori* assumptions about time are valid. Does time, in fact, exist, and what is its importance within and without the construct of human existence. The Oxford Living Dictionary's definition of time is, "The indefinite continued progress of existence and events in the past, present, and future regarded as a whole," "The continued progress of existence as affecting people and things," and "Time or an amount of time as reckoned by a conventional standard."1 This could be reasoned as saying that the meaningfulness of time is predicated upon the progress of human existence, and as such, time is one way in which we structure our experience of living, to wit, the accomplishment or enjoyment of those things we value in the span of human life quantified by the metric of time. This is in line with the Kantian view of space and time. Dr. George Mattey, of the Philosophy Dept of UC Davis in his lecture entitled, "Critique of Pure Reason", summarized Kant, stating that, "Space and time do not exist in and of themselves, but in some sense are the product of the way we represent things. The[y] are ideal, though not in the sense in which Leibniz thought they are ideal (figments of the imagination). The ideality of space is its mind-dependence: it is only a condition of sensibility.... Kant concluded ... 'absolute space is not an object of outer sensation; it is rather a fundamental concept which first of all makes possible all such outer sensation'. '...Much of the argumentation pertaining to space is applicable, *mutatis mutandis*, to time, so I will not rehearse the arguments. As space is the form of outer intuition, so time is the form of inner intuition....' Kant claimed that time is real, it is 'the real form of inner intuition.'" 2

It is said that time is objective, continuous and directional, yet as we shall see, these properties can be called into question; yet by common experience, lunar, solar and earthly rotation as well as pendular motion are phenomena easily observed and have passed into common parlance and consciousness as measures of time. 3 Pervasive debate was a hallmark of ancient civilizations as to whether time is linear or cyclical, endless or finite. Later eras continued the debate as to whether time is real or purely an intellectual concept and whether the past and future truly exist or whether the present is all there is. The 5th century B.C. philosopher, Antiphon, believed that time *was purely a measure*, Parmenides argued that it was *illusory*-the present, being, then, the only true reality, while Heraclitus believed that the *flow* of time itself was reality. There was to come with the Pythagoreans, a foreshadowing of medieval thought that time began with the creation of the world, with the end of time commencing another cycle. The last reference to antiquity discussed here is the Aristotelian concept of time which was a "*numeration of continuous movement*," the present being only an instant between past and future. 4

The 5th Century A.D. theologian St. Augustine of Hippo believed that time is a "'*distension*' of the mind which allows us to simultaneously grasp the past in memory, the present by attention and the future by expectation.'" 5 "For what is time," Augustine asks, "Who can easily and briefly explain it? Who even in thought can comprehend it, even to the pronouncing of a word concerning it? But what in speaking do we refer to more familiarly and knowingly than time? And certainly we understand when we speak of it; we understand also when we hear it spoken of by another. What, then, is time? If no one ask of me, I know; if I wish to explain to him who asks, I know not. Yet I say with confidence, that I know that if nothing passed away, there would not be past time; and if nothing were coming, there would not be future time; and if nothing were, there would not be present time. Those two times, therefore, past and future, how are they, when even the past now is not; and the future is not as yet? But should the present be always present, and should it not pass into time past, time truly it could not be, but eternity. If, then, time present — if it be time — only comes into existence because it passes into time past, how do we say that even this is, whose cause of being is that it shall not be — namely, so that we cannot truly say that time is, unless because it tends not to be?" 6

The Newtonian concept of time –which is absolute, would be challenged by the antirealist Liebnitz, who said that time only allows us to "sequence" events temporally and later of course, by Einstein who proved the relativity and mutability of time in special and general relativity. 7 In the *Philosophiae Naturalis Principia Mathematica*, one reads that, "Absolute, true and mathematical time, of itself, and from its own nature flows equably without regard to anything external, and by another name is called duration: relative, apparent and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time ... " 8 This view, prevalent until the time of Minkowski and, later Einstein and his colleagues speaks to a concept of time being a sovereign entity, flowing steadily, and (one can read), inexorably, through the universe, unaffected by any external force, which in itself has meaning as a physical entity.

The concept of the "*specious present*" promulgated by E. Robert Kelley and William James states that the "present is the most recent part of the past," "the short duration of which we are incessantly sensible," and that any event in the present has an immediate past and an immediate future." The phenomenologists further expanded on this, stating, "We cannot have any perception of the immediate present without some memory of the past and some expectation of the future to give it context." This is to be contrasted with the more somber theory that the present is all that there is and all events are to be referenced in relation to the absolute present, the name of which theory is "presentism." Lastly, Eternalism is the modern condensation and development of the thought that both past and future exist in very real ways and this is in keeping with a relativistic understanding of time. 9 This is interestingly similar to the Cabalistic view that "in the context of experiencing time," a "level of consciousness leads one to identify a Divine synchronization of timeframes whereby past, present and future all exist simultaneously within Creation." 10

It seems a common tendency to rapidly shift attention to the practicality of measuring time, rather than debating its existence as a sovereign entity, as the human lifespan, measured by units of time is soon passed. "An operational definition of time," according to the Anderson Institute, " wherein one says that observing a certain number of repetitions of one or another standard cyclical event (such as the passage of a free-swinging pendulum) constitutes one standard unit such as the second, is highly useful in the conduct of both advanced experiments and everyday affairs of life. The operational definition leaves aside the question whether there is something called time, apart from the counting activity just mentioned, that flows and that can be measured." 11

In any discussion of keeping time, there needs to be some appreciation of the history of horology. Horology in its most basic form is predicated upon man's recognition of the periodicity of natural phenomena: the earth travels around the sun once per year, the moon around the earth once a month, and the earth around its axis once a day. As it happens, the division of the 24 hour period into a twelve hour day and a twelve hour night originated with the Sumerian civilization which employed a duodecimal system of measurement derived from the division of each of four fingers into three segments and a sexigesimal system combining the four fingers of one hand with five of the other. The duodecimal system is fortuitous as well, as there are twelve lunar revolutions around the earth per year, seen as lunar months. 12 Water clocks, which the Ptolemaic Dynasty would call clepsydra were historically first invented during the Eighteenth Dynasty under the reign of Amenhotep I, possibly by the courtier Amenemhet. Known as the "Karnak clock," it was within 15 minutes of accuracy, given the keeping of civil time in Egypt, with its division of the night into 12 hours varying with the season of the year. 13 However, the truest measure of time was with the refinement of the clepsydra by Ctesibius and its later modification by Archimedes in the design of a continuous inflow from a reservoir, which mitigated the difference in flow rate due to gravity that had hitherto been accommodated by graduated scales. It is interesting to note that until the continuous inflow modification, clepsydra were merely timers, often used to give equal time for the speeches of lawyers in court, with one clepsydra for a speech in minor cases and multiple clepsydra per speech in cases of more complexity, as in felonies, in which is found the origin of the phrase, "running out of time." 14 The Persian scholar Al-Biruni during the eleventh century AD was able to calculate the times of the new moon in minutes, seconds, thirds and fourths, each in divisions of sixty. This feat was also performed by Roger Bacon in the thirteenth century, in relation to the appearance of full moons. 15

John Flamsteed in the early 1670s set the local time in Greenwich to the average, or "mean," time that the sun crossed the meridian. John Harrison, however was able to solve the problem of longitude by having British sailors keep one clock on board ship set to Greenwich Mean Time and calculate their longitude from the Greenwich meridian, which was set at 0°. 16 At the present era, time is defined in terms of nuclear physics. As it stands, "the second is the duration of 9,192.631,770 cycles of the radiation associated with a specific transition of the cesium 133 atom," as per the National Institute of Standards and Technology. 17

Spacetime is a 4 dimensional structure that represents every location in space and every moment in time. A slice of spacetime represents the current instant, and the location of everything in the world around us at that instant. However, when movement through spacetime is taken into account, it cuts spacetime at a different angles. For example, as an observer travels away from the earth, it theoretically cuts an angle through spacetime towards the past and if one travels towards the earth, the slice is cut through spacetime into the future. Thus, the past, present and future are all present simultaneously in the construct of spacetime. 18

The concept of the nature of time changed with Einstein. Expanding on Minkowski's theory of spacetime, Einstein believed that time itself could be relative, depending on the observation of one's own inertial reference frame, in comparison to an external inertial reference frame in motion. Consider the light-clock, a thought experiment by Einstein. The light clock is a theoretical device which emits a beam of light which strikes a reflective surface, is deflected back to the origin, and in which the emitter is the same as the detector. A full tick of the light clock would comprise of the emitted light reaching the reflective surface and returning to the point of origin. In this experiment, Einstein has two subjects, an observer on Earth, and a traveler on a spacecraft. The observer on earth is stationary (presumably not accounting for the rotation of the earth upon its axis or around the sun). The space traveler's spacecraft is moving at a certain velocity, v, which is less than the speed of light, known as c. It is immediately apparent, in Figure 1, that the stationary observer on earth would see the light emitted and returned in straight paths at a constant velocity, (c), as the speed of light is constant over a distance, (d). Therefore the time for one full tick would be equal to twice the distance divided by the speed of light. To the traveler in space, time would progress to him at the same rate as for the observer on earth, as the space traveler is within his own inertial reference frame, and he would see the light emitted and returning in a straight path, exactly as does the observer on earth. Where time dilation occurs, however, is when the earth observer looks up at the spacecraft (and at the light clock on that spacecraft) and sees that time on board is running slower than his time on earth. 19

FIGURE 1.

In Figure 2, we see the spacecraft from the earth observer's position. In it, we see that the light clock in space travels with the same velocity as that of the spacecraft. In the figure we trace the light clock from its current position to its future position and to its even further future position. Here we see that light is travelling diagonally , rather than vertically, and will strike the mirror of the future light clock, and be reflected back to its source at times later than that of the clock on earth. The light will travel at the constant velocity, c, over the distance of a hypotenuse defined by the vertical axis of the light clock, and the horizontal axis of the spaceship's distance travelled in half a tick. The Pythagorean theorem can be used in this case, as the path of light defines a right triangle. Initially, we set up the equation to solve for the vertical distance of the clock. [20]

FIGURE 2.

We then solve for the time needed for half a tick of the clock in the spacecraft. [21]

FIGURE 3.

As should be apparent, the equation can be resolved into definable parts that will make the understanding of time dilation possible. From the final equation of this figure, we can relate the time for half a tick of the space clock to the quantity 2d/c multiplied by a number incorporating the spacecraft's velocity and the speed of light. [22]

FIGURE 4

We can see in figure 4, that the value of 2d/c is a constant, as the vertical distance in both the light clocks on earth and in space are constant, as is the speed of light. In fact, 2d/c is the entire time of one full tick of the light clock on earth. We can in fact, rewrite the equation to say that time dilation in the spacecraft for one tick of the space clock is equal to the relatively shorter time for a tick of the earth clock multiplied by a number, γ, that takes into account the velocity of the spacecraft. 23

FIGURE 5

In other words, for the Earth observer's observation of light moving up in the first half-tick of the earth clock, he would think that the spacecraft's light would travel diagonally for a further distance and would therefore think that the spacecraft's clock was running slowly. 24

Time slows down for a person who is in motion, relative to a person who is stationary, and it logically follows that if time slows down, age must also slow down. The closer to the speed of light one can achieve, the slower time will run. Einstein took time dilation one step further with positing the "Twins Paradox," a thought experiment in which he supposed that two twins, at relatively the same age, start from the same point on earth, one remaining on earth and one leaving earth on a spacecraft at velocity, v. In Figure 6, one arbitrarily assigns a velocity to the spacecraft of 87% of the speed of light, or 0.87c. Solving backwards through the last equations, one sees that when β is broken into its component parts, and velocity defined, the time dilation of the space traveler is twice that of the observer on earth upon the traveler's returning to earth. This means that if the space traveler were to proceed at this velocity for five years, for example, and then turn around and return to earth for another 5 years, keeping velocity the same, he would be exactly half the age as the twin who remained on earth. This is itself not a paradox-it simply demonstrates time dilation, however as all inertial reference frames are relative to each other, one can say that the spacecraft, for example, is the stationary reference frame and it is the earth that moves relative to the spacecraft. In that case, when the twins complete their 10 years it would be the twin on earth, who actually had aged less. This is the paradox. It is still under debate as to its resolution. 25

FIGURE 6

FIGURE 7

Lastly, gravity also affects time according to Einstein's General Theory of Relativity. As an example, if two clocks are placed in an elevator, one on the wall and one on the floor, the clock that is closer to the source of the gravitational field will run slower. This affects Global Positioning Systems in which satellites gain over 45,000 nanoseconds per day due to gravitational time dilation. 26 The formula by which gravity dilates time is represented in Figure 7, in which the time which is to be dilated is equal to the time at rest multiplied by a factor that is directly proportional to the gravitational constant and the mass of the planet generating gravity and inversely proportional to its radius. 27

In summation, time is a subject both meaningless and meaningful. It is in theory, mutable, yet in the common experience of humanity, directional and to some, finite. Yet, taking Pascal's wager, life is bounded by a fixed span of time, and as such, time is precious. A physician, for example is in a prime position to observe that time, spent with a certain quality of life is meaningful, yet existence without life is meaningless. Time redeemed from wastage can be used to live out the capacity of several lives in one's limited allotment. Time spent away from family and loved ones is lost, as is time not utilized to live out one's full potential. The Psalmist says in his prayer, "So teach us to number our days, that we may apply our hearts unto wisdom." – Psalm 90:12, KJV. So may we all.

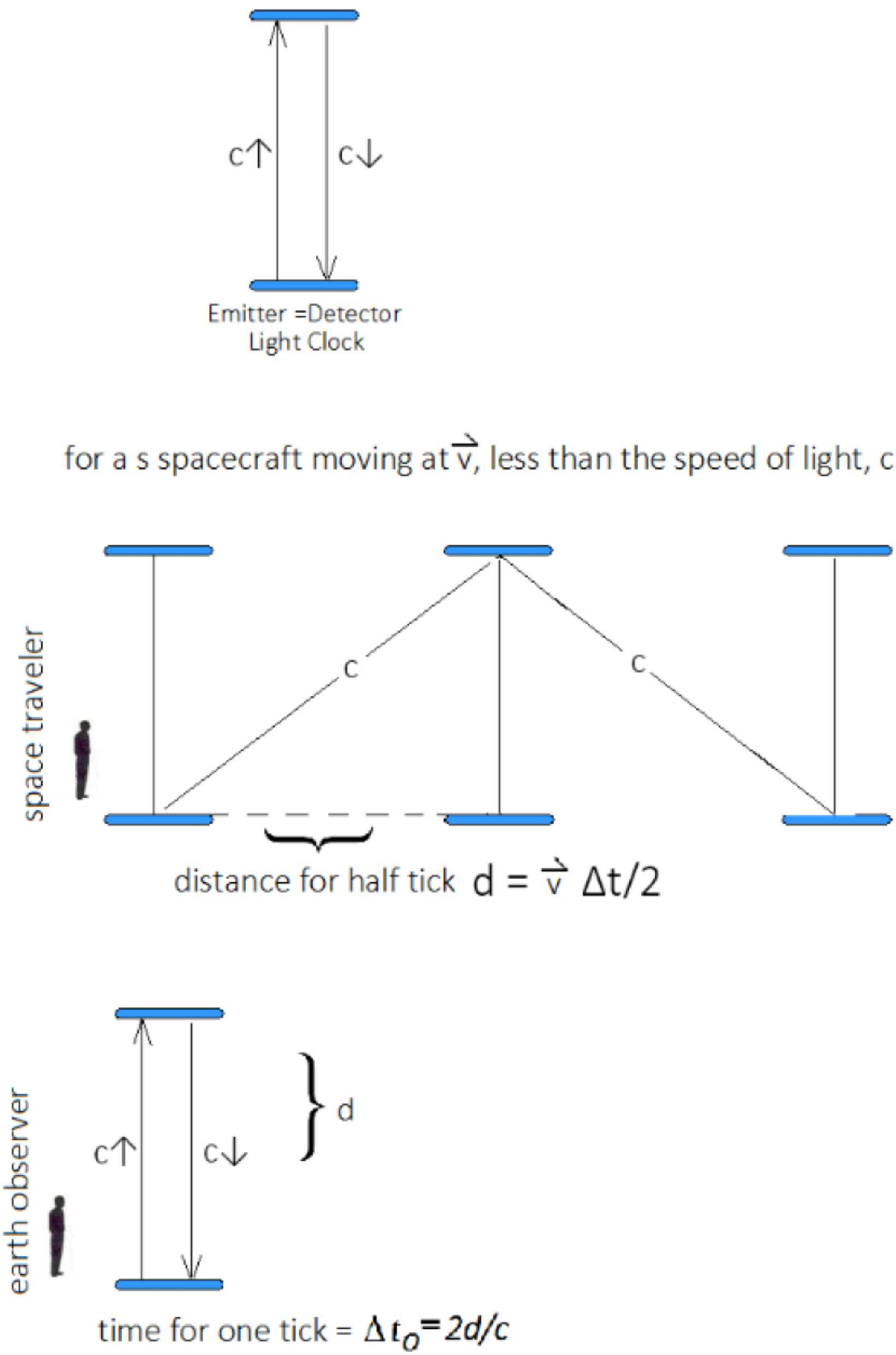
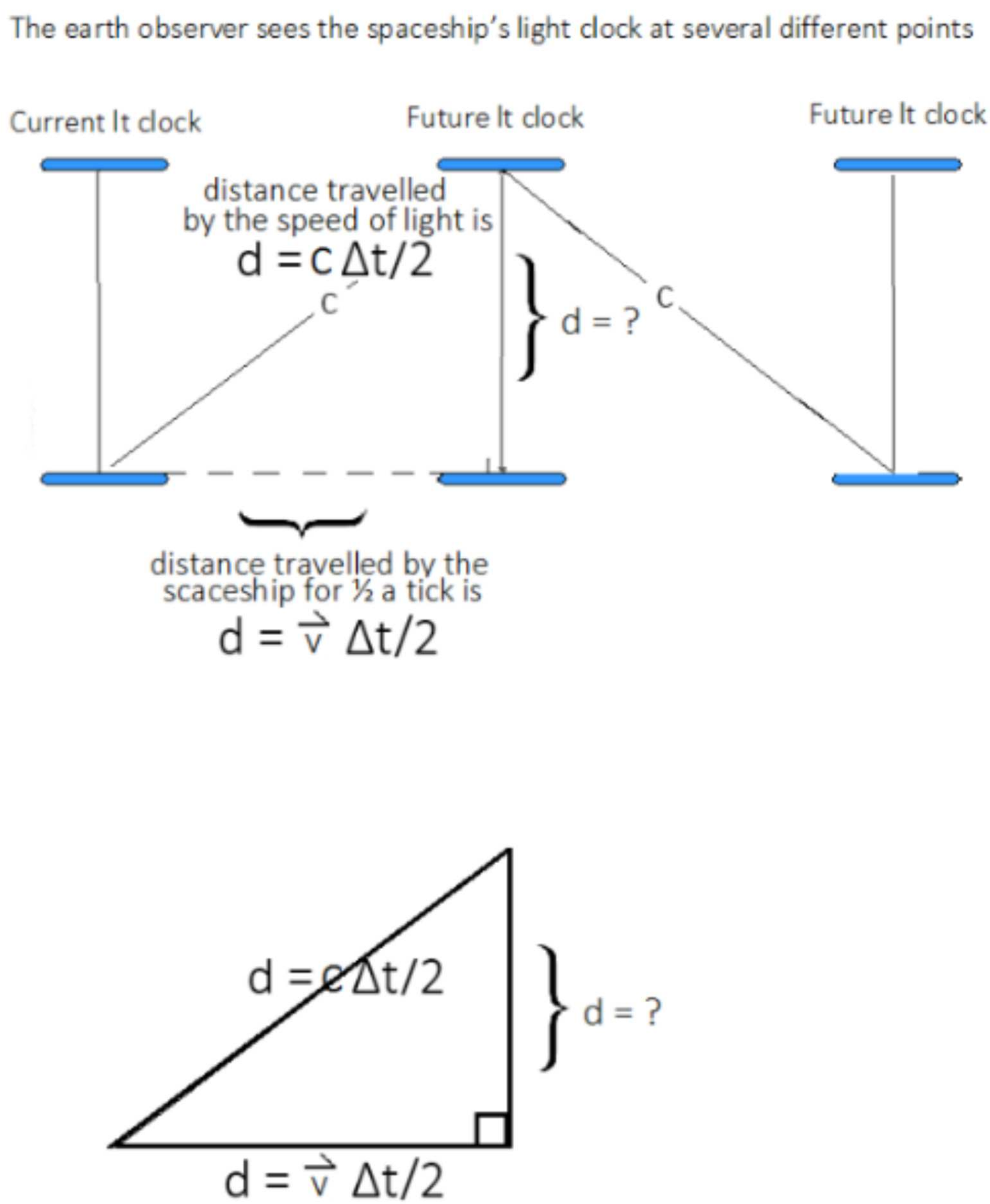


FIGURE 1. A conceptualization of time dilation in Special Relativity.



By the Pythagorean Theorem, Solve for d

$$d^2 + \left(\frac{\vec{v}\,\Delta t}{2} \right)^2 = \left(\frac{c\,\Delta t}{2} \right)^2$$

$$d^2 + \frac{\vec{v}^2 \Delta t^2}{2^2} = \frac{c^2 \Delta t^2}{2^2}$$

FIGURE 2. Set-up of the Pythagorean Theorem to begin the calculation for time dilation

$$d^2 = \Delta t^2 \left[\frac{c^2}{2^2} - \frac{\vec{v}^2}{2^2} \right]$$

$$\Delta t^2 = \frac{2^2 d^2}{c^2 - \vec{v}^2}$$

$$\Delta t = \sqrt{\frac{2^2 d^2}{c^2 - \vec{v}^2}}$$

$$\Delta t = \frac{2d}{c \sqrt{1 - \frac{\vec{v}^2}{c^2}}}$$

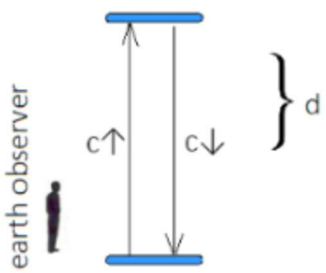
Defining $\frac{\vec{v}}{c}$ as β

$$\Delta t = \left(\frac{2d}{c}\right) \frac{1}{\sqrt{1 - \beta^2}}$$

FIGURE 3. Solving for time dilation in motion and its relation to the apparent time of the stationary observer on Earth.

$$\Delta t = \left(\frac{2\,d}{c}\right)\frac{1}{\sqrt{1-\beta^2}}$$

Since $2d/c$ is equal to Δt_o, the time of one whole tick for the earth observer, we can relate the time for one tick in the spacecraft to the time for one tick on earth by the following equation



time for one tick = $\Delta t_o = 2d/c$

$$\Delta t = \Delta t_o \frac{1}{\sqrt{1-\beta^2}}$$

and since $\frac{1}{\sqrt{1-\beta^2}}$ can also be defined as γ

$$\Delta t = \Delta t_o\ \gamma$$

Therefore, the space clock's complete tick, according to the Earth observer, is equal to the earth clock's complete tick multiplied by γ

FIGURE 4 Finalization of the time dilation equation

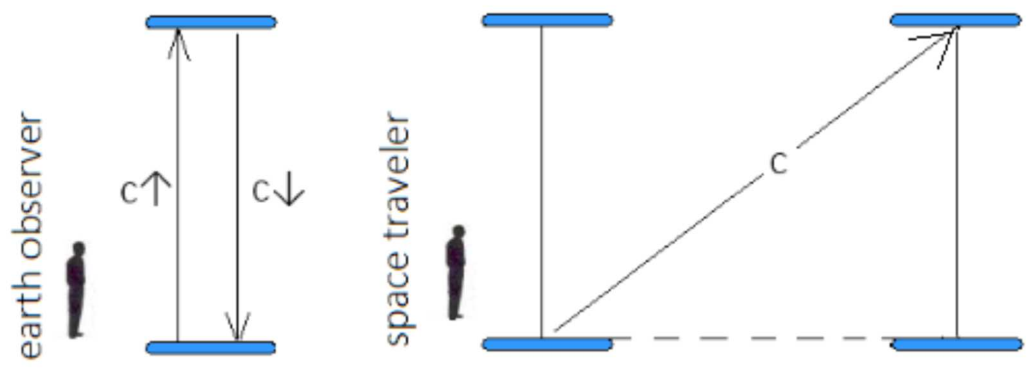
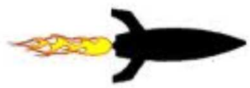


FIGURE 5 Summarization of time dilation



Twin in space

Twin on earth

If we arbitrarily set $\vec{v}$, the spacecraft's velocity as 87% of the speed of light (0.87 c),we are able to see this equation demonstrate time dilation

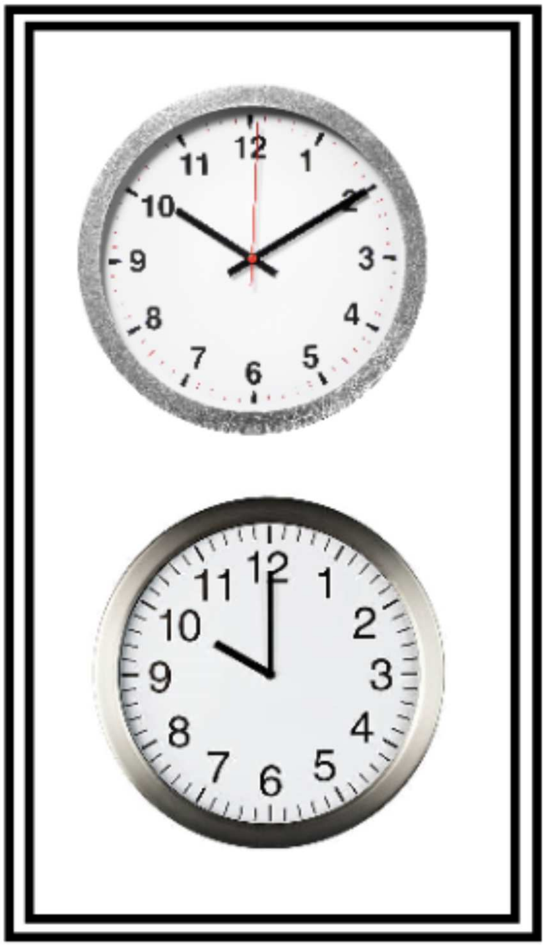
$$\Delta t = \Delta t_o \ \gamma$$

$$\Delta t = \Delta t_o \ \frac{1}{\sqrt{1-\beta^2}}$$

$$\Delta t = \Delta t_o \ \frac{1}{\sqrt{1-\frac{(0.87\ c)^2}{c^2}}}$$

$$\Delta t = \Delta t_o \times 2$$

FIGURE 6 The Twins' Paradox



source of gravity

$$\Delta t' = \Delta t \sqrt{1 - \frac{2GM}{rc^2}}$$

FIGURE 7 Formula for gravitational time dilation

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Figures 1-6 Time clock adapted from Geocities Physics World Light Clock http://www.geocities.ws/physics_world/sr/light_clock.htm

Figures 1-6 Drawing of observer and spacecraft adapted from Einsten's Weird World of Relativistic Time Dilation https://futurism.com/einsteins-weird-world-of-relativistic-time-dilation/

Figure 7 Gravitational Time Dilation formula adapted from ffden-2.phys.uaf.edu Gravitational Time Dilation http://ffden2.phys.uaf.edu/webproj/211_fall_2014/Jackson_Page/jackson_page/page4.html