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SPECIAL THEORY OF RELATIVITY

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Abstract:
The special relativity is applied in special cases. The theory is mostly used in the discussion of high energy, astronomical; distance, and ultra-fast speed, all without the complexity of gravity. In 1905, Einstein added gravity to his theories when he published his paper on general relativity. The discovery and implementation of the special theory of relativity brought a drastic change in science. It completely changes the contemporary idea of time along with space.

Keywords: special, astronomical, ultra-fast

Introduction

Special theory of relativity is one of the most important theories in the field of physic. Special relativity describes the relationship between energy and mass. The theory further states that a small amount of mass can be transposable with a huge amount of energy. It is defined by the famous equation E=mc2.

The special relativity is applied in special cases. The theory is mostly used in the discussion of high energy, astronomical; distance, and ultra-fast speed, all without the complexity of gravity. In 1905, Einstein added gravity to his theories when he published his paper on general relativity. The discovery and implementation of the special theory of relativity brought a drastic change in science. It completely changes the contemporary idea of time along with space.

Discussion on Special Theory of Relativity

In 1905, Albert Einstein combined the idea that experiments performed at a constant speed will give the same results as experiments that are stationary, with the idea that the speed of light will remain constant from both perspectives.[1] The first assumption is a result of Galileo's relativity (. The second assumption comes from the Michelson-Morley experiment.

Spacetime

In 1907 and 1908, the Polish-German mathematician Hermann Minkowski showed that special relativity is best described using the concept of a four-dimensional spacetime[6]. This unites the time dimension with the three spatial dimensions we observe.

Previous to this, the universe was described as an infinite three-dimensional space, with three spatial dimensions - *x*, *y*, and *z* - creating a cube-like, 'flat', space (as shown in Figure 7.7). This is known as Euclidean geometry, after ancient Greek mathematician Euclid. Objects could then be described by four coordinates: the three spatial coordinates and time (*t*). Newton described space and time as being absolute, which means that they are a background in which things take place. Here, the coordinate system is not affected by the objects it describes.

Minkowski showed that the coordinate system that describes an object's location in spacetime does not have to be flat. He described spacetime as a 4-dimensional manifold. A manifold is a surface that looks flat from one perspective but may actually be curved. The surface of the Earth, for example, appears flat when we walk on it, but we know that the Earth is actually a sphere, and so only appears flat from a limited perspective. The locations of objects in spacetime are still described by four coordinates.

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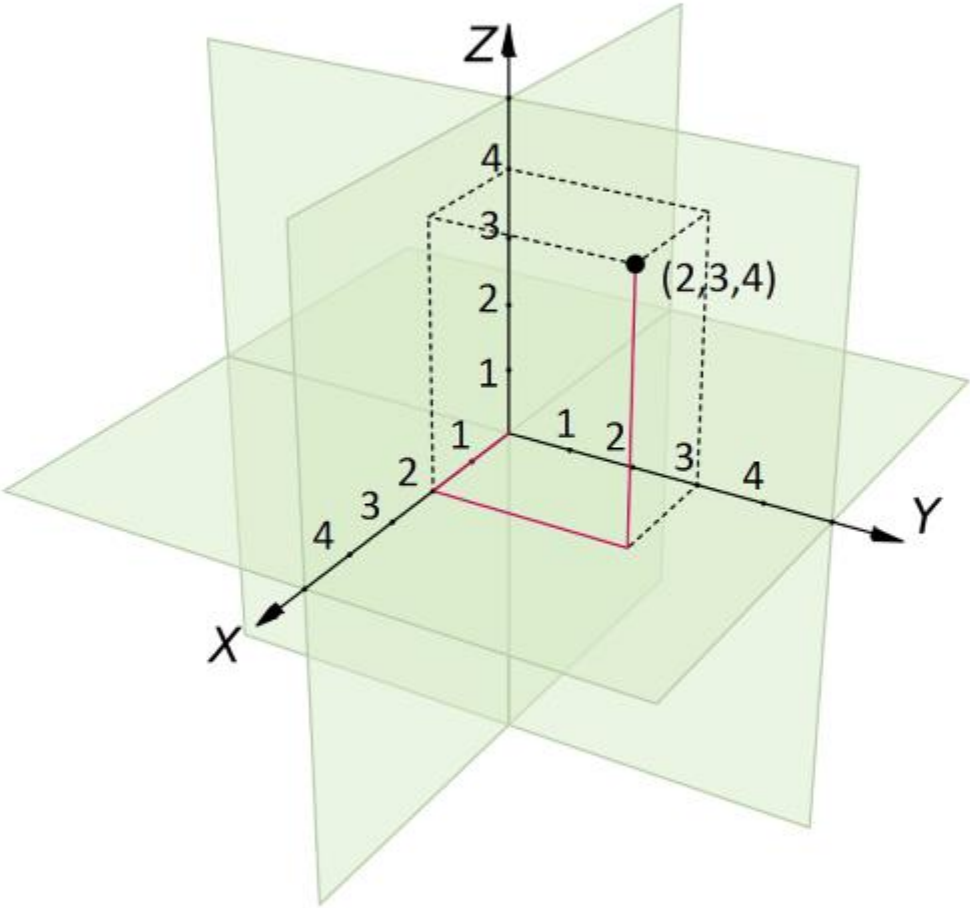
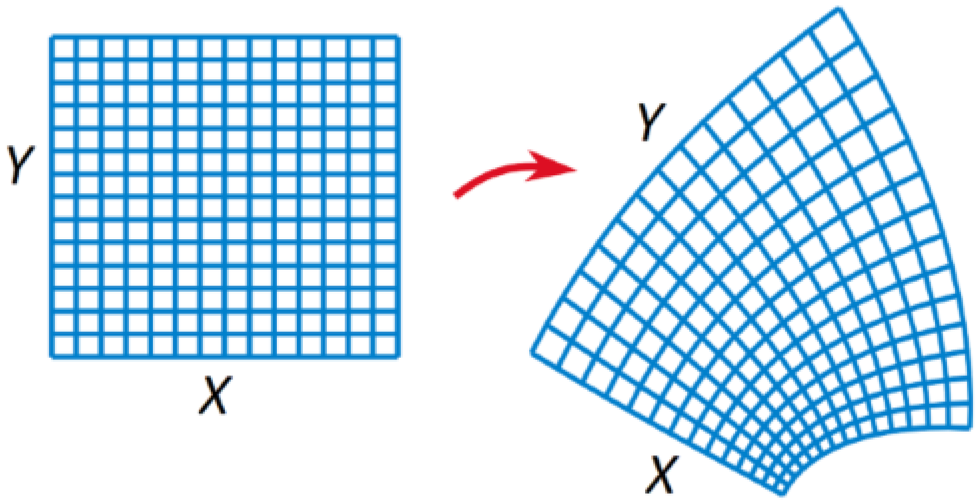


In Newtonian physics, space could be described using a Cartesian coordinate system in three dimensions.



In special relativity, spacetime is thought to be flat and Cartesian coordinates are used, however in general relativity this is not the case, and there is no one unique coordinate system that must be used. In Minkowski's spacetime, the 'distance' between two events can be described as a 'spacelike', 'timelike', or ' lightlike' interval.

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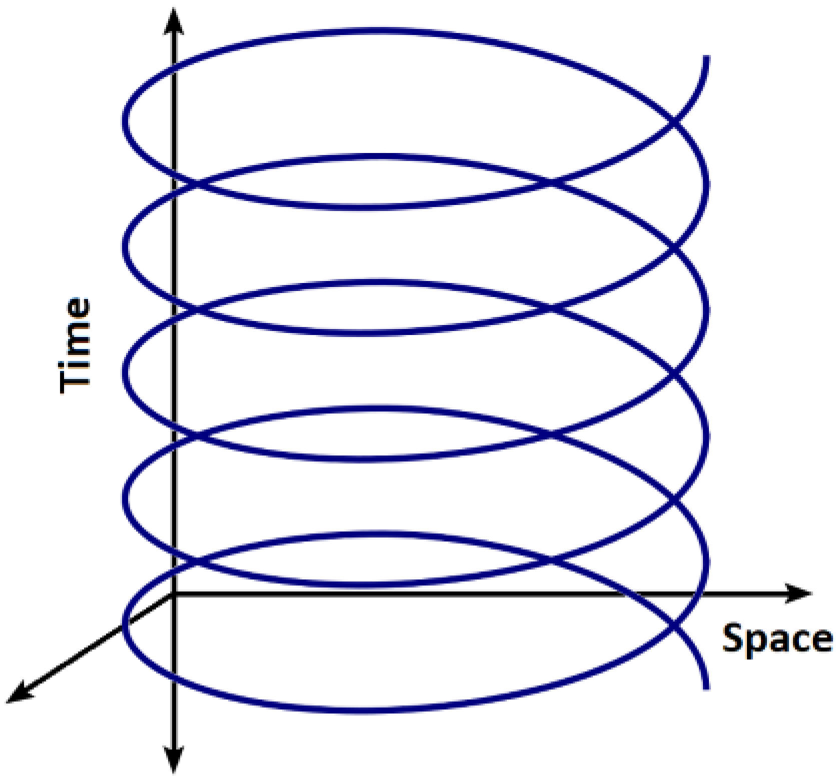
Spacelike intervals
If two events appear simultaneous to someone that's not accelerating with respect to the events, then they are said to be separated by a spacelike interval.

Timelike intervals
If two events describe the same object in different locations, then they are said to be separated by a timelike interval. If all of the past, present, and future events that happen to a single object are placed on a plot of space against time (as shown in Figure 7.9), then the line connecting them all is referred to as a 'worldline', and two events on a worldline are always connected by timelike intervals.



Lightlike intervals
If a ray of light could travel between two events, then they are said to be separated by a lightlike interval. Plots of space against time produces cone shapes, known as light cones, for objects travelling at the speed of light (as shown in Figure 7.10). This is because in special relativity, unlike Newtonian physics, there's a universal speed limit; things cannot happen instantaneously. An event in spacetime can only affect the areas it can physically reach, given that information cannot travel faster than the speed of light.
Light reaches further regions of space over time, and this means the future light cone gets wider as time goes on. The past light cone gets wider the further you look back in time because you see further back in time the further you look out into space. This is because light takes a long time to reach us, and so to see something as it was a long time ago, the light must originate from far away. We cannot be affected by anything that is too far away for its light to reach us.

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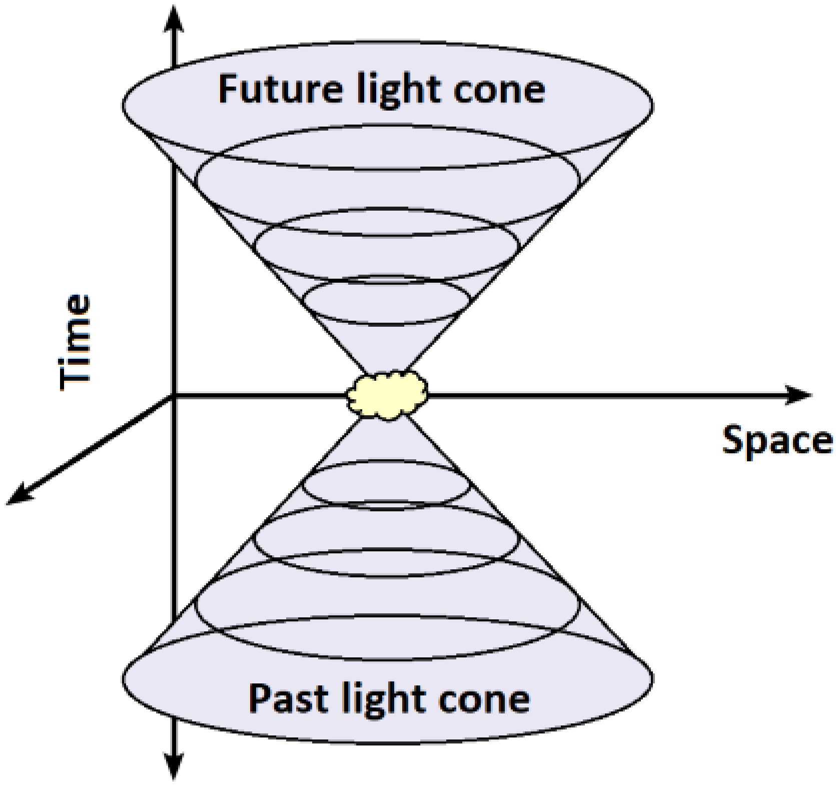
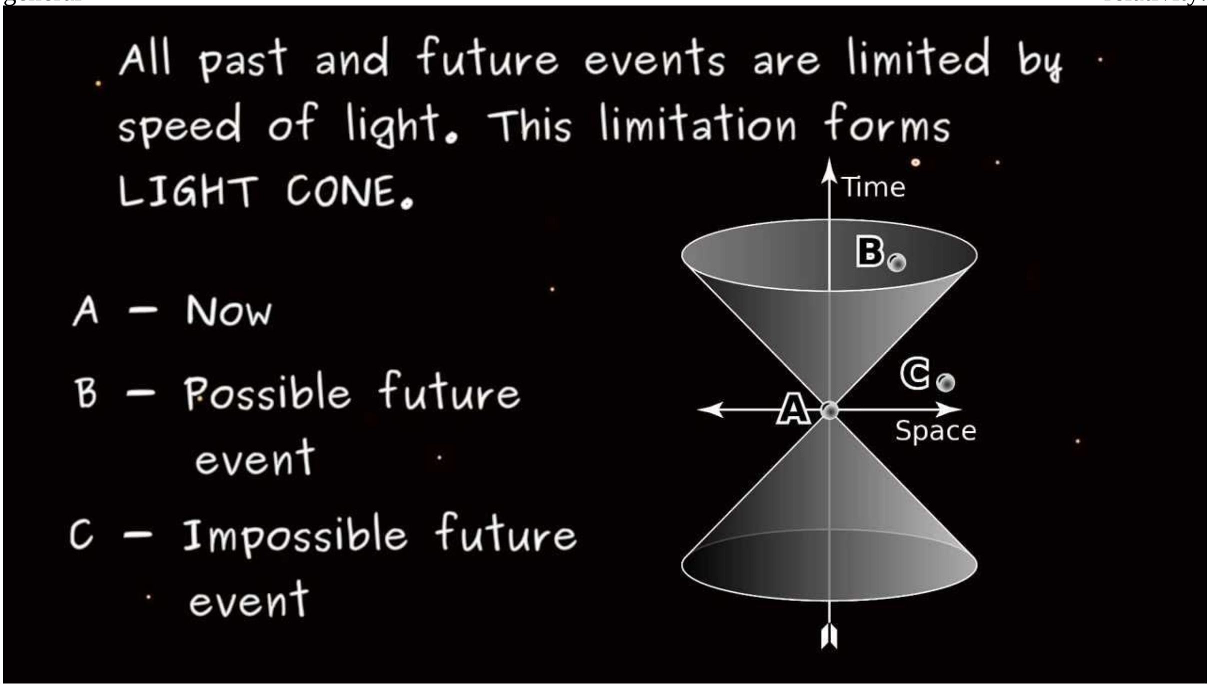


Special relativity was still not compatible with Newton's law of universal gravitation because objects accelerate under gravity, and special relativity only tends to apply to objects that are moving at a constant velocity. The concept of mass and its effect on spacetime were better understood when Einstein reconciled his theory of special relativity with Newton's law of universal gravitation. He finally achieved this in 1916, with his theory of general relativity.



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In 1632, Galileo Galilei showed that no experiment can distinguish if you are moving at a constant speed or velocity or if you are stationary without involving an external source, like a window to look out of.[2] This means that there's no such thing as absolute speed or velocity, and something can only be said to be moving at a constant velocity relative to something else. In the same way, something can only be said to be stationary relative to something else.
Galileo also showed that speeds and velocities are additive. This means that if someone runs at speed *u'* across the deck of a ship moving at speed *v*, then the speed measured by someone on the shore (*u*) would be,

$u = v + u'$

If a beam of light were to move across the ship at speed *c*, the person on the shore should measure the speed to be $u = v + c$. In the same way, a person on Earth should measure the speed of light to be $u = v + c$, where *v* is the velocity of the Earth when it is moving towards the Sun.
In 1887, Albert Michelson and Edward Morley[3] measured the speed of light from the Sun while the Earth was moving in two different directions and found no difference (although the velocity was different because you can tell when light is moving towards or away from you, this did not affect the light's speed). This was completely unexpected and showed that speeds and velocities are not additive, as Galileo had thought.
Special relativity shows that,

$u = v + u' \boxed{1 + (vu'/c^2)}$

The **speed of light is 299,792,458 m/s** = 1,079,252,849 km/h. This means that if you are travelling on a ship at 5 km/h and run at 10 km/h. A person on the shore would measure your velocity to be about 15 km/h.

$u = 5 + 10 \boxed{1 + (5\times10 / 1{,}079{,}252{,}849^2)}$

$= 15 \boxed{1 + (50 / 1{,}079{,}252{,}849^2)}$

$= 15 \boxed{1.00000000000000004}$

$= 14.9999999999999994$ km/h

If you run at 10 km/h (2.8 m/s) on a spacecraft travelling at 90% of the speed of light (269,813,212.2 m/s), then someone on Earth would measure your velocity to be slightly more than 90% of the speed of light but less than 269,813,212.2 m/s + 2.8 m/s.

$u = 269{,}813{,}212.2 + 2.8 \boxed{1 + (269{,}813{,}212.2\times2.8 / 299{,}792{,}458^2)}$

$= 269813212.7$ m/s

However, if you shone a light from a spacecraft travelling at 90% of the speed of light, then someone on the shore would still measure the light's velocity to be the speed of light.

$u = 269{,}813{,}212.2 + 299{,}792{,}458 \boxed{1 + (269{,}813{,}212.2 / 299{,}792{,}458)}$

$= 569{,}605{,}670.2 \boxed{1.9}$

$= 299{,}792{,}458$ m/s

If the spacecraft was travelling at the speed of light,

$u = c + c \boxed{1 + (c^2/c^2)} = 2c \boxed{2} = c$

Special relativity

If two people who are moving in different directions both measure the speed of light to be the same, then either of the two properties that speed relies on - time or distance - must differ between observers. Einstein's theory of special relativity shows that both of these parameters can vary according to perspective. Special relativity, like Galileo's relativity, applies to objects in an inertial reference frame - this means that it applies to objects

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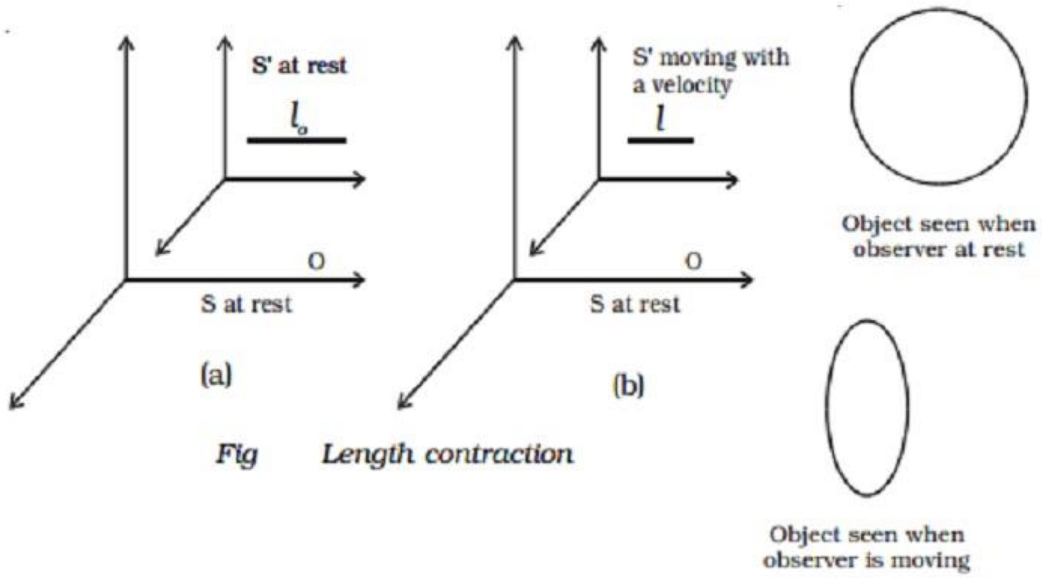

Fig Length contraction

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thatare not accelerating.

(px,py,px,E) are components of a 4-vector which has same Lorentz transformation

$px' = \gamma\,(px + uE/c^2)$ u = velocity of transform

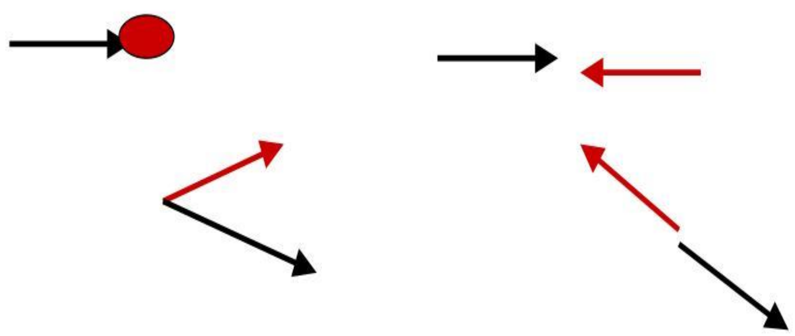
$py' = py$ between frames is in

$pz' = pz$ x-direction. If do px' → px

$E' = \gamma\,(E + upx)$ "+" → "-" Use common sense

also let $c = 1$

Frame 1 Frame 2 (cm)



Before and after scatter

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The proper time Δt_0 is the time interval between two events as measured by an observer who sees the events occur at the same place. Let the "proper" frame move with velocity *v* w.r.t. another frame.

Time interval in moving frame: $\Delta t = \gamma \Delta t_0$

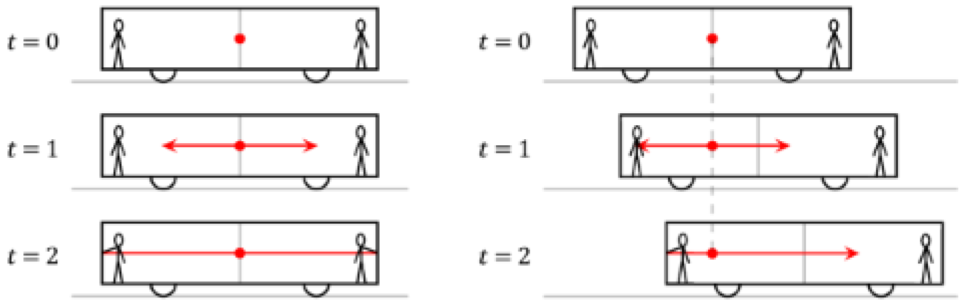
where $$\gamma = \frac{1}{\sqrt{1 - v^2 / c^2}}$$

The relativity of simultaneity

The first consequence of special relativity is known as the relativity of simultaneity. This shows that events that appear simultaneous in one reference frame, might not do so in another.

If, for example, we place a light source between two observers that emits a beam of light in each direction, then the observers will think that the beams were emitted simultaneously if they reach each observer at the same time.

If the observers are moving, however, then the beams will not reach both observers at the same time, and so they may conclude that they were not emitted simultaneously. Galileo's relativity shows that both views are correct. This means that what we perceive as the present only corresponds to what is occurring simultaneously to us, in our reference frame.



Time dilation

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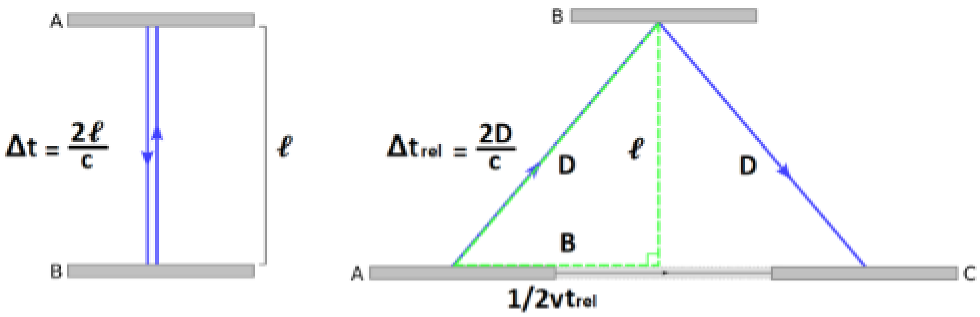
The second consequence of special relativity is time dilation. This states that for someone in an inertial reference frame, moving clocks appear to run slower. This means that the time between ticks is longer.
This can be illustrated by imagining that we bounce a beam of light from two mirrors and observe it from both perspectives, one where the mirrors are stationary with respect to the observer and one where the mirrors are moving .



If the clock is stationary with respect to the observer, the light will travel vertically up and down, defined here as one tick. Assuming $v = d\,\boxed{\Delta t}$, where the distance is twice the length of the clock (ℓ).

$\Delta t = d\,\boxed{v} = 2\ell\,\boxed{c}$

The time we measure between events that are stationary with respect to someone in an inertial reference frame is known as 'proper' time, or rest time (t), and this is an invariant, which means that this value does not change, and could be calculated from any perspective. The time we measure between events that are moving with respect us is sometimes called relativistic time (t_{rel}).
If the clock is moving with respect to the observer, the mirrors will appear to be moving, and so the light will have to travel further between ticks. The distance is now equal to D.

$\Delta t_{rel} = d\,\boxed{v} = 2D\,\boxed{c}$ (7.8

Using the Pythagorean theorem, $D^2 = \ell^2 + B^2$.

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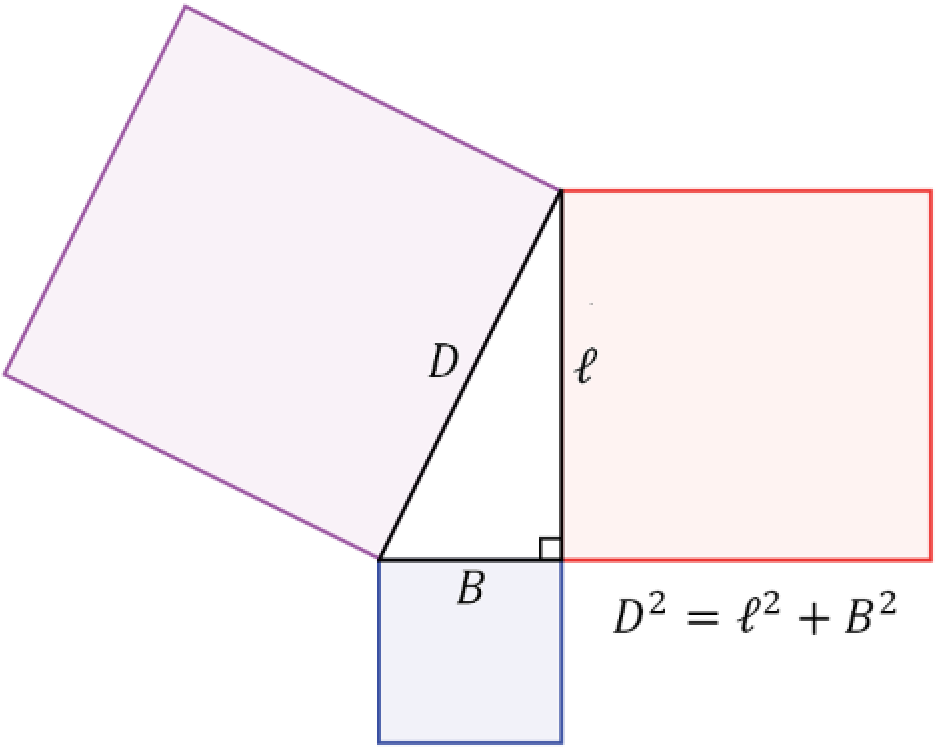

The Pythagorean theorem states that the square of the longest side of a right-angled triangle is equal to the sum of the squares of the other two sides.

B is equal to half the distance the mirror moves between ticks, since $d = v\Delta t_{\text{rel}}$, $B = v\,\Delta t_{\text{rel}}/2$.

This gives $D^2 = \ell^2 + (v\Delta t_{\text{rel}}/2)^2$, which is the same as $D = \sqrt{\ell^2 + (v\Delta t_{\text{rel}}/2)^2}$, and $\Delta t_{\text{rel}} = 2D/c$ so that $D = c\Delta t_{\text{rel}}/2$.

This means $\sqrt{\ell^2 + (v\Delta t_{\text{rel}}/2)^2} = c\Delta t_{\text{rel}}/2$, which can be rearranged to show,

$$\Delta t_{\text{rel}} = \Delta t/\sqrt{(1 - v^2/c^2)} \quad (7.9)$$

This means,

$$\Delta t_{rel} = \gamma\Delta t \quad (7.10)$$

where,

$$\gamma = 1/\sqrt{(1 - v^2/c^2)} \quad (7.11)$$

γ is known as the Lorentz factor, as it's derived from the work of the Dutch physicist Hendrik Lorentz. γ cannot be less than one, and so Δt_{rel} is always larger than Δt. This is because it takes longer to travel a longer distance at the same velocity. If the time between ticks is longer, then the clock appears to be running slower; moving objects appear to be slowed in time.

The time between heartbeats is also slower, and so from the perspective of a stationary person, a moving person appears to be living their life at a slower rate. Conversely, from the perspective of the moving person, the stationary person seems to live like their life as if it is being fast-forwarded. If they travelled fast enough, then they would see the stationary person age before their eyes.

The Earth can be considered an approximately inertial reference frame because the effects of its accelerationare slight. This means that if a person leaves Earth and travels in a rocket at a constant velocity, then they will age

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more slowly than someone that stays on Earth. If they have a twin, then they will be younger than them when they return. This effect is greater the faster they travel.

Δt = time between ticks of a clock on Earth = 1 s,

v = velocity of moving person = 99% the speed of light = 296,794,533 m/s, and

c = 299,792,458 m/s.

Δt_{rel} = $\gamma\Delta t = \Delta t \sqrt{(1 - v^2\ cv^2)}$

= $1 \sqrt{(1 - 296{,}794{,}533^2\ 299{,}792{,}458^2)}$ = 7 s

This means that from the perspective of someone on Earth, it takes seven seconds for the astronaut's clock to tick once; the astronaut's actions appear to have

Δt = 6 months = 15,768,000 s,

v = velocity of moving person = 8 km/s = 8000 m/s, and

c = 299,792,458 m/s.

Δt_{rel} = $\gamma\Delta t = \Delta t \sqrt{(1 - v^2\ c^2)}$

= $15{,}768{,}000 \sqrt{(1 - 8000^2\ 299{,}792{,}458^2)}$

= 15,768,000.0056 s

$\Delta t_{rel} - \Delta t$ = 0.0056 s.

Time dilation has a greater effect the higher the velocity and the longer the time spent at that velocity.

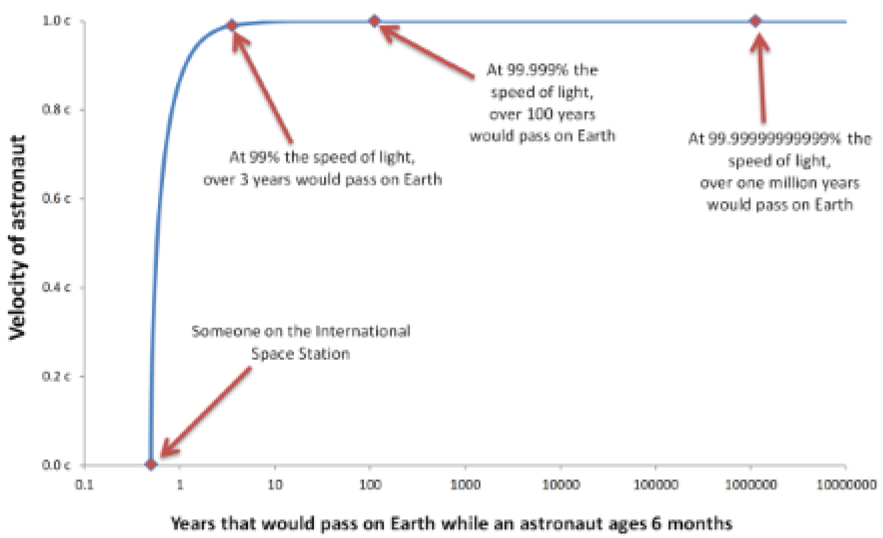
Δt = 6 months = 15,768,000 s,

v = velocity of moving person = 296,794,533 m/s, and

c = 299,792,458 m/s.

Δt_{rel} = $15{,}768{,}000 \sqrt{(1 - 296{,}794{,}533^2\ 299{,}792{,}458^2)}$

= 111,852,947 s = 3.54 years.



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The time that people experience on Earth while an astronaut travels for 6 months at a range of velocities.

The twin paradox asks why the astronaut can consider themselves to be moving and the Earth to be stationary, when Galileo's relativity shows that there's no such thing as absolute velocity. Why can't the astronaut consider themselves to be stationary while the Earth moves away at tremendous speeds?
The answer is acceleration. Galileo's relativity applies to inertial - that is non-accelerating - reference frames. The fact that the astronaut must have accelerated before getting to such a high speed means that they know they are the one that is moving.

Length contraction

The third consequence of special relativity is length contraction. Einstein showed that an object will appear to be shorter in its direction of motion if we measure it while it's moving relative to us.
The length that we measure when we are stationary with respect to an object is known as the 'proper' length, or rest length. This is also an invariant. The length we measure if the object is moving with respect to us (ℓ_{rel}) is sometimes referred to as the relativistic length.
In the case of an astronaut travelling at 99% the speed of light (as discussed in Section 7.2.3), people on Earth measure 3.54 years to have passed before 6 months passes for the astronaut; $\Delta t = 0.5$ years and $\Delta t_{rel} = 3.54$ years.
If the speed of light is the same from both perspectives, then they will each appear to have travelled different distances. From the perspective of someone on Earth, the astronaut travels for 0.5 years at 99% the speed of light. This means they will appear to cover a distance - or length - of about 0.5 light-years.

$$\begin{aligned} \ell_{rel} &= v\Delta t \\ &= 296{,}794{,}533 \times (0.5 \times 60 \times 60 \times 24 \times 365.25) \\ &= 4.68\times10^{15} \text{ m} \\ &= 0.5 \text{ light-years} \end{aligned}$$

During this time, 3.54 years pass on Earth, and so the length would otherwise be about 3.5 light-years.

$$\begin{aligned} \ell &= v\Delta t_{rel} \\ &= 296{,}794{,}533 \times (3.54 \times 60 \times 60 \times 24 \times 365.25) \\ &= 3.32\times10^{16} \text{ m} \\ &= 3.5 \text{ light-years} \end{aligned}$$

This means that moving things appear to be shorter in their direction of motion.

$$\ell_{rel} = v\Delta t$$

The special Theory of Relativity is a very important concept in physic. It changes the way of thinking of space, time. and despite the light source, the speed of light within a vacuum is similar to any other space. Special relativity exposes the result of the equivalence of mass-energy, length contraction, the relativity of simultaneity, and a universal speed limit (Sumardani, Putri & Sumardani, 2020).
The traditional notion of the absolute universal time is replaced by the notion of time and it is dependent on the spatial position and reference frame. In special relativity, the reference frame acts as very important. The time of events can be measured by using the clock. In special relativity which was proposed by Albert Einstein contradicts with the principle of Galilean relativity. This particular theory denotes the body (either in the uniform motion within a straight line or at rest) for following the particular principle of inertia. As opined by Antonov (2020), special relativity can be applied to those objects that move in uniform motion with each other. The speed of the light in tree space can be determined by this theory but at the same time mass and energy cannot be easily changed as the speed of light is a huge number.

Special relativity is generally applied in all aspects of physical phenomena and it happens without the presence of gravity

The application of the special theory of relativity

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The special theory of relativity is the most famous and important scientific theory of the twenty century. The GPS satellites that possess an atomic clock run faster than the clocks of the earth's surface. According to Park (2018), it is because these GPS satellites are located far from the gravitation of the earth. The other application of special relativity can be found in electromagnets, GPS navigation. The theory is essential for the process of GPS navigation

The meaning of $e=mc^2$

of the well-known and popular theories in physic is e=mc2. It means energy is equivalent to the product of mass and square of the speed of light. It can be also said that mass (m) and energy (e), are replaceable. The equation needed to be squared by itself to be larger. A little amount of mass consists of a huge amount of energy (Feng & Huang, 2020). This is a phenomenal discovery in physics. It completely changes the conventional idea of space and also time.

Time dilation

Time dilation refers to the slowing of the time when it is observed by one observer compared with another. It depends on the position and relative motion of the observer within a gravitational field. Two types of time dilation exist. One is based on the difference in the relative velocity and the other is created by the effect of gravity. As opined by Barukčić (2019), the time dilation generally contradicts with withy the concept of the absolute time.

Time is relative. Time duration occurs due to motion and gravity. The spatial coordinates cannot explain the location of a particular individual in the universe but it also depends on time coordinates

Laws of transformation of space and time

Law of space and time states that time can be created by space. Einstein initiated the idea of time as a fourth dimension. As proposed by Wang (2021), it means that these two components are inextricably linked.

Conclusion

Special relativity holds high significance in the ground of physics. The theory is important in understanding and calculating the high-velocity affairs. The idea of time, as well as space, is totally transformed by the introduction of the special theory of relativity. The gravitational theory also gave a new dimension and scientists were able to gather more information.

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