A few relativistic calculation examples.

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Example 1

Suppose we shoot a clock with a tremendous speed to Mars and back at the same speed. Mars is at that moment at **10 light minutes = 10 x 60 x 300,000 km = 180 million km** away from us (back and forth **360 million km, 20 light minutes**).

According to an observer on earth, the clock takes **40 minutes** to return. What is the state of the clock when it is set to **0:00:00** on departure?

Answer:

$$t_{clock}=\sqrt{t_o^2-t_s^2}=\sqrt{40^2-20^2}=34.64\,min=00:34:38.$$ (see HERE)

Example 2:

According to an observer, two missiles fly towards each other. Missile 1 flies according to the observer at a speed of **0.6 c**, missile 2 at a speed of **0.4 c**. At what speed do the missiles see each other approaching? (see HERE)

For missile 1 applies:

$$v_e=\frac{c}{\sqrt{1/0{,}6^2-1}}=0.75\,c$$

For missile 2 applies:

$$v_e=\frac{c}{\sqrt{1/0{,}4^2-1}}=0.4363\,c$$

Sum of both= 1,1864 c

$$v_i=\frac{c}{\sqrt{(c/v_e)^2+1}}=\frac{c}{\sqrt{1/1{,}1864^2+1}}=0.7646\,c$$

So the two missiles see each other approaching with a speed of **0.7646 c**.

Example 3:

What is the kinetic energy of a particle with a speed of **0.99 c**?

$$v_e=\frac{c}{\sqrt{1/99^2-1}}=7.018\,c$$

$$E_k=mc\sqrt{c^2+v_e^2}-mc^2$$

$$E_k=mc^2\sqrt{1+7.018^2}-mc^2=6.089\,mc^2$$

Example 4:

In the Large Hadron Collider (LHC) near Geneva, protons are accelerated in a ring-shaped tunnel with a circumference of **27 km** to a speed of **0.999,999,964 c**.

What is the required average field strength of the magnetic field to keep the protons in their orbit?

An electrically charged particle traverses a (part of a) circular trajectory in a magnetic field, where the radius is determined by $r=\frac{mv_e}{Bq}$

=> $B=\frac{mv_e}{rq}$

m = the mass of the proton = $1.672,62*10^{-27}kg$
q = the charge of the proton = $1.6*10^{-19}C$
r = the radius of the traversed circle = $4,297.2\,m$
$\mathbf{v_i}$ = the speed of the proton = $0.999,999,964\,c$

$$v_e=\frac{c}{\sqrt{(c/v_i)^2-1}}=3,726.78\,c$$

$$B=\frac{1.672,62*10^{-27}*3.726,78*10^3*3*10^8}{4.297,2*10^3*1.6*10^{-19}}=2.72\,T$$

In order to keep the protons in the circular path, the LHC uses about twelve hundred 15 meter long superconducting magnets with a field strength of 8.36 Tesla.

Example 5:

How big is the centrifugal force on a proton in the Large Hadron Collider (LHC) that has to be compensated by the Lorentz force to keep the proton in its orbit. The LHC has a circumference of **27 km** and the proton has a speed of **0.999,999,964 c**.

The outward force which a revolving mass m exerts at a distance r from a center is given by:

$$F_m=\frac{mv_e^2}{r}$$

m = the mass of the proton = $1.672,62*10^{-27}kg$
r = the radius of the traversed circle = $4,297.2\,m$
$\mathbf{v_i}$ = the speed of the proton = $0.999,999,964\,c$

$$v_e=\frac{c}{\sqrt{(c/v_i)^2-1}}=3,726.78\,c$$

$$F_m=\frac{1.672,62*10^{-27}*(3,726.78\,c)^2}{4,297.2}=4.865,4*10^{-7}\,N$$

Example 6:

With a spaceship a clock is shot into space with a constant acceleration. An observer stays behind.
The clock is set to 00:00:00 at the moment of departure.
The acceleration is $1000\, m/s^2$.

At what distance from the observer, according to that observer, does the ship reach a speed of 0,4 c (v_i) and what is the state of the clock at that moment?

$$v_e = \frac{c}{\sqrt{(c/v_i)^2 - 1}} = 0.4364\, c$$

t_e is the state of the clock .

$$t_e = \frac{v_e}{a} = \frac{0.4364\, c}{1000} = 130{,}931\, seconds = 36:22:11$$

$$s = \frac{v_e * t_e}{2} = \frac{a * t_e^2}{2} = \frac{1000 * 130{,}930^2}{2} = 8.5714 * 10^{12} m = 8.5714 * 10^9 km = 28{,}571\, light\, seconds$$

which is almost equal to $8\, light\, hours$.

Example 7:

What is the difference, after a hundred years, of a clock on a 100 m high tower with a clock on the ground?

Answer:

The acceleration at the surface of the earth (and at a hundred meters height) is equal to $10\, m/s^2$, what is equivalent to a time gradient of (one second is equal to $3 * 10^8 m$)
$10\, m/(3 * 10^8 m)^2 = 1.1111 * 10^{-16} per\, meter$.

100 years is equal to $100 * 365 * 24 * 3600\, s = 3.1536 * 10^9 s$

The time difference is
$height * time - gradient * 100\ years = 100 * 1.1111 * 10^{-16} * 3.1536 * 10^9 = 35.04 * 10^{-6} s$
so just a little more than $35\, \mu s$.

Example 8:

How much does a clock in a satellite at 20,000 km altitude go faster or slower in comparison to a clock on the earth after one revolution?

Answer:

A clock at a certain height runs faster then a clock on earth.

A clock that moves with respect to a clock on earth runs slower.

The acceleration due to the attraction of a mass applies: $g(r)=\frac{GM}{r^2}$

The product of G and M for the earth is known with great accuracy.
For the earth applies: $GM=3{,}986*10^{14}m^3s^{-2}$

For the satellite, the centrifugal force is equal to the gravitational pull of the earth:

$$\frac{mv_e^2}{R_s}=\frac{mGM}{R_s^2} \quad => \quad v_e=\sqrt{\frac{GM}{R_s}}=\sqrt{\frac{3{,}986*10^{14}}{26{,}371*10^6}}=3.887{,}8\,ms^{-1}$$

The circumference of this circular orbit: $C_s=2\pi r=2*3{,}1416*26{,}371*10^6=165{,}694*10^6\,m$

The time of a revolution: $t_{e-revolution}=\frac{165{,}694*10^6}{3.887{,}8}=42.619\,s=11:50:19$

The time difference due to its speed between the clock on earth and the clock in the satellite is: $t_i-t_e=\frac{s}{v_i}-\frac{s}{v_e}=\frac{s(v_e-v_i)}{v_iv_e}=\frac{s(1-v_i/v_e)}{v_i}$

$$v_e=\frac{v_i}{\sqrt{1-v_i^2/c^2}} \quad => \quad t_i-t_e=\frac{s}{v_i}(1-\sqrt{1-v_i^2/c^2})\approx\frac{s\,v_i}{2c^2}$$

The time difference due to its speed after one revolution:

$$t_i-t_e=\frac{165{,}694*10^6*3.887{,}8}{2(3*10^8)^2}=3{,}5788*10^{-6}s$$

If you do not like approaches, you can calculate the result using the Ivy calculator from Google: $t_i-t_e=\frac{s}{v_i}(1-\sqrt{1-\frac{v_i^2}{c^2}})=3{,}5788*10^{-6}s$

In **Example 7**, **g** is approximately a constant. However, that does not apply here. We therefore integrate **g(r)** from $\mathbf{R_0}$ to $\mathbf{R_s}$.

$$g[R_0-R_s]=\int_{R_0}^{R_s}\frac{GM}{r^2}dr=[\frac{GM}{r}]_{R_o}^{R_s}=GM(-\frac{1}{R_s}+\frac{1}{R_0})=GM(\frac{R_0-R_s}{R_sR_0})m^2s^{-2}$$

$$g[R_0-R_s]=3.986*10^{14}(\frac{6.371*10^6-26.371*10^6}{6.371*10^6*26.371*10^6})=-47.450*10^6m^2s^{-2}$$

The time difference of the two clocks due to gravity after one revolution is:

$$\frac{-47{,}45*10^6}{(3*10^8)^2}*42.619=-22{,}47*10^{-6}s$$

The total time difference after one revolution is therefore
$3{,}5788*10^{-6}-22{,}47*10^{-6}=-18{,}89*10^{-6}s$, so almost $-19\,\mu s$

To be continued.

In this article/discussion I will show that it is better for a good understanding of the theory of relativity to take more distance from observation to interpret the observation data. In addition, the theory of relativity can be better understood.

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