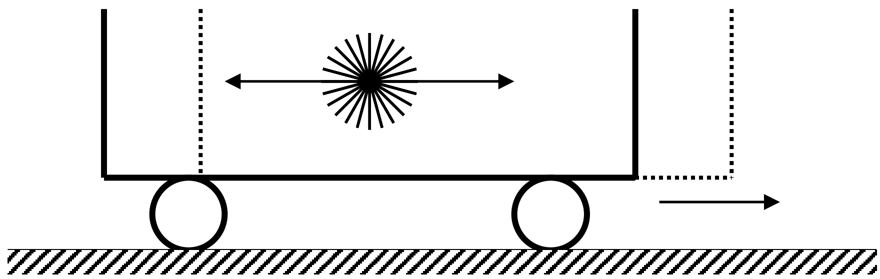
SPECIAL THEORY OF RELATIVITY

1. Basic information

- author – Albert Einstein
- phenomena observed when TWO frames of reference move relative to each other with speed close to the speed of light
- 1905 - special theory of relativity (STR) – the mutual speed of the frames is constant
- 1915 – general theory of relativity (GTR) - the mutual speed of the frames is NOT constant
- What will be observed by an „outer“ and „inner“ observer of the following experiment?



2. Postulates of STR

I. ***The laws of physics are the same in all inertial frames of reference.***

II. ***The speed of light in a free space (vacuum) has the same value in all inertial frames of reference***

Michelson – Morley experiment 1887

http://galileoandeinstein.physics.virginia.edu/more_stuff/flashlets/mmexpt6.htm

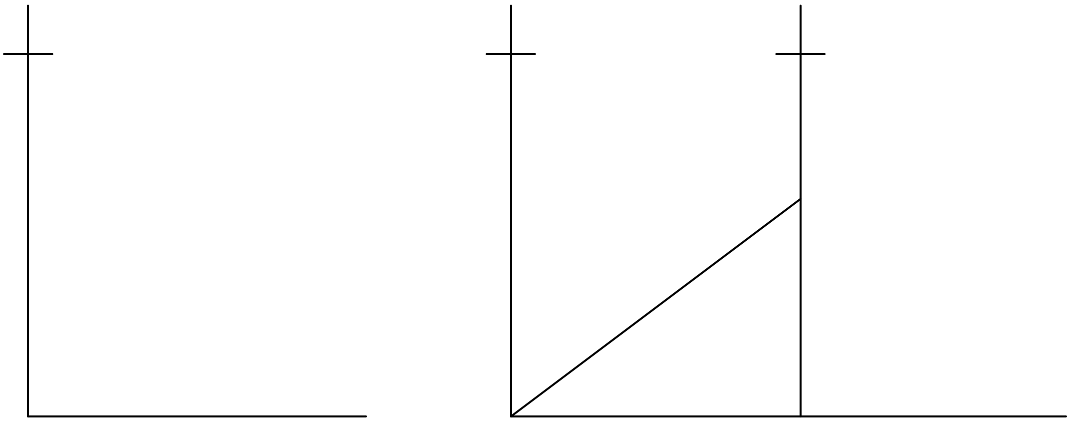
What was the main idea of the experiment?

Did the authors succeed?

a) time dilation

„A moving clock ticks more slowly than a clock at rest"

http://www.anu.edu.au/Physics/qt/Welcome.html



$$c^2\Delta t^2 = c^2\Delta t'^2 + v^2\Delta t^2$$

$$\left(c^2 - v^2\right)\Delta t^2 = c^2\Delta t'^2$$

$$\Delta t^2 = \frac{c^2}{c^2 - v^2}\Delta t'^2 = \frac{1}{1-\frac{v^2}{c^2}}\Delta t'^2$$

$$\Delta t = \frac{\Delta t'}{\sqrt{1-\frac{v^2}{c^2}}}$$

„inner" observer – time interval on a moving clock = in its rest frame

„outer" observer – time interval on a clock at rest = measured between the events in a moving frame

Questions:

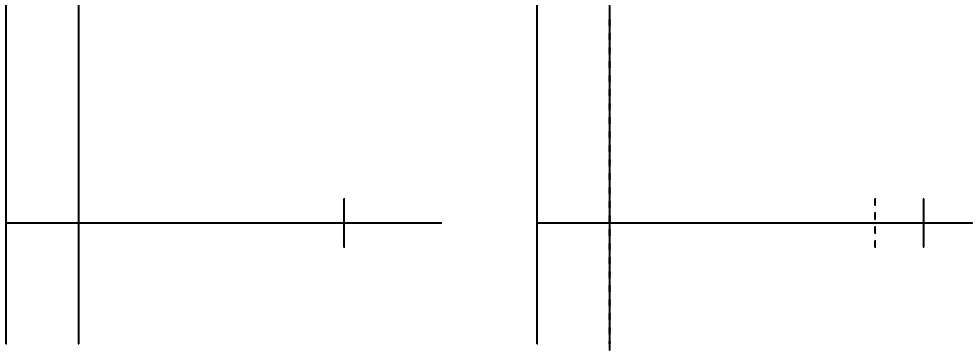
1. Muon paradox (207 m_e, charge $+e$ or $-e$): these particles are created at higher altitudes, their lifetime is about 2.2 µs. As they are detected at sea level, although this should not be possible even when their speed is almost *c.* Resolution – their own lifetime is the same but it differs for us, as they are so fast! Take $v = 0.9\,c$ and calculate what will be the lifetime of muons measured by us.

2. Mesons π^+, $m = 273\,m_e$, lifetime 2.5×10^{-8} s, move relative to us at 0.99 *c*. How far will they move during this time in their frame of reference and relative to us?

b) length contraction

„Faster means shorter“

To measure the distance between the ends of a moving rod at the same instant is impossible – what happens at the same time in one frame of reference does not do so in another – moving frame of reference (see the first figure – light pulse in a railway truck)



for an observer moving with the frame $K^{/}$ the time taken to travel $OZO^{/}$ is

$$t^{/} = \frac{2l_0}{c}$$

for an observer in frame K :

$$|OZ| : ct_1 = vt_1 + l$$

$$|ZO^{/}| : ct_2 = l - vt_2$$

total time $t = t_1 + t_2 = \frac{l}{c-v} + \frac{l}{c+v} = \frac{2lc}{c^2 - v^2} \rangle t^{/}$

time obeys relativity, so:

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

hence

$$l = l_0 \sqrt{1 - \frac{v^2}{c^2}}$$

rest frame (l_0)
outer observer (l)

http://www.physicsclassroom.com/mmedia/specrel/lc.html

http://www.physics.ucdavis.edu/Classes/NonclassicalPhysics/animations.html

c) relativity of mass and momentum

„Rest mass is least“

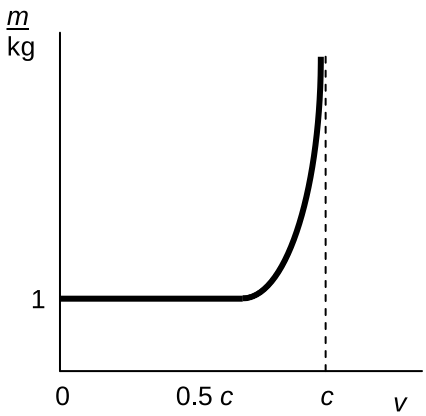
2[nd] N.L.: $F_R = ma$ if m = const

$\Delta E_k = W$ done by F_R - the object could accelerate to infinity, but energy is conserved even at relativity and when the speed of the object rises, the force needed to accelerate it rises too – not possible to accelerate to reach *c*

$$m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

rest mass (m_0)

mass for the outer observer (m)

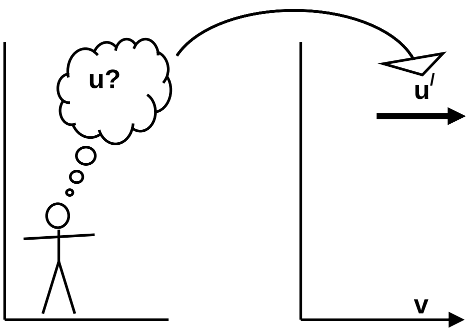


$\vec{p} = m\vec{v}$ even in relativity

$$\vec{p} = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}\vec{v}$$

d) adding speeds

„Maximum speed in any frame of reference is c“



for $v \ll c$ $u = u' + v$

for $v \approx c$: $$u = \frac{u' + v}{1 + \frac{u'v}{c^2}}$$

derive what happens when $u' = c$:

e) equivalence of mass and energy

When mass of object changes by Δm, it corresponds to the energy change of ΔE .

$$\Delta E = \Delta mc^2$$

Example – binding energy of a nucleus:

The mass of any nucleus is always ....than the sum of masses of separated nucleons.

This is due to energy .... in forming the nucleus. When we want to split the nucleus to get the nucleons again, we have to .... the same amount of energy.

choose: bigger/smaller, supplied/released, supply/release

3. Summary

- no basic = rest frame of reference
- *c* – maximum speed with which 2 objects or information can pass, other quantities differ in each frame!
- GENERAL RELATIVITY
- space and time is formed by mass and energy distribution – the shortest distance between 2 objects need not be a straight line
- gravity = acceleration
- gravity affects time (GPS set up)
- essential for extreme conditions (black holes, ...)

Questions:

3. Calculate the period and frequency of the „light clock“ of length 5 cm in its a) rest frame, b) in a frame moving at v = 0.7 c

4. A spaceship moves at v = 0.5 c relative to us. If a light pulse is produced in the spaceship, what will be the speed of light measured by us? Prove – derive using the equation.

L7/1-9, 12-13

Answers:

1. 5 µs
2. 7.4 m, 53 m
3. 3.3×10^{-10} s, 3×10^{9} Hz; 4.6×10^{-10} s, 2.16×10^{9} Hz
4. c

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