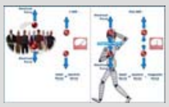
Interesting Web Sites

http://www.spacetimetravel.org/index.html

http://www.phys.unsw.edu.au/einsteinlight/

by Prof. Joe Wolfe of Physics Dept. UNSW


It was assumed that space was filled with "luminiferous Ether", and that this was the "medium" through which light-waves propagated.

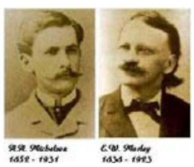
From an observer on Earth, the velocity of light <u>should</u> depend on velocity of the medium (the velocity of the "ether wind" passing Earth).

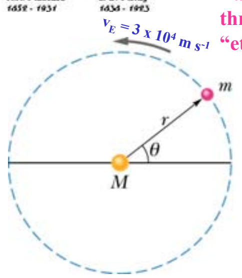
Does it???

Michelson and Morley attempted to find out.

Michelson and Morley's

Attempt to detect the "ether" wind





Earth moves through "ether wind"

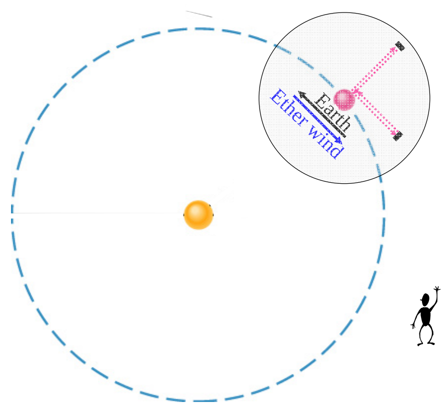
Measured time difference for light "swimming" with and against the wind, and across and back.

$v_{wind} = 3 \times 10^4\ m\ s^{-1}$

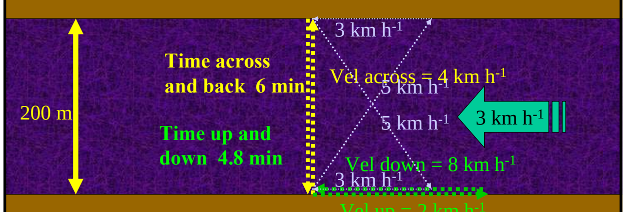
$V_{swimmer} = 3 \times 10^8\ m\ s^{-1}$

Very different velocities

Very hard experiment

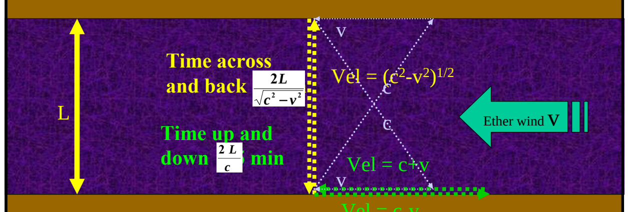


The time for a swimmer to swim across a river and back is longer than to swim up and down stream the same distance.



Swimmers' speed 5 km h^{-1}

Now consider the situation where a beam of light travels out and back across the "ether wind ", or with and against it.



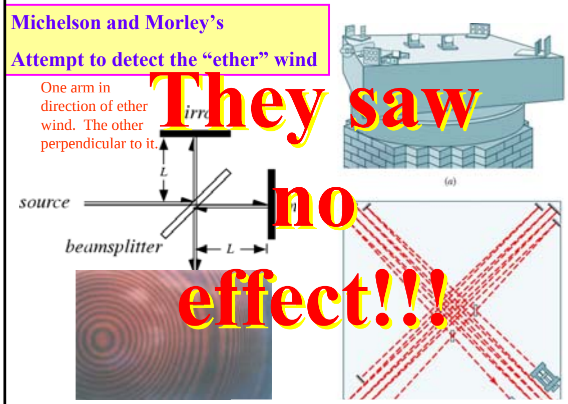
Swimmers' speed c km h^{-1}

Velocity of Earth in orbit (v) = 30 km s^{-1}

Velocity of light (c) = 3.0×10^5 km s^{-1}

Michelson and Morley's

Attempt to detect the "ether" wind



Consequently→ the velocity of light is invariant!

Assumptions of theory

- **The velocity of light in space is invariant.***

  ***That is, it is independent of the velocity of the source or the observer.**

- **The laws of Physics are the same in any inertial system**

An event

To specify an event,

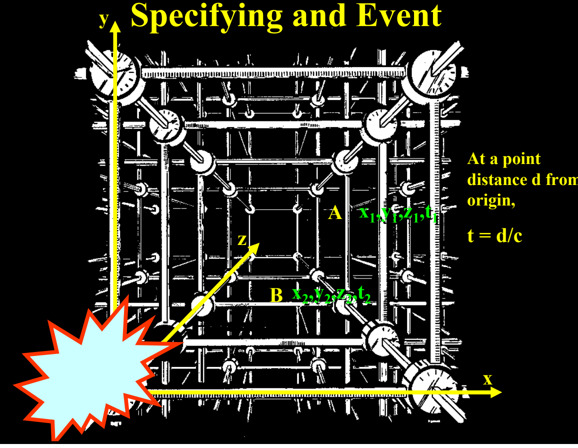
an observer must assign

3 space coordinates (x,y,z)

and a time coordinate (t).

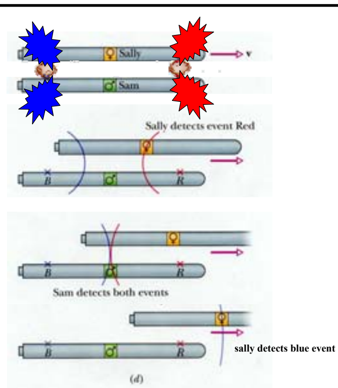
So we need a calibrated reference frame

Specifying and Event



At a point distance d from origin,

t = d/c



Sally says red hit first then Blue

Sam says the events are simultaneous

Who is correct???

Both!!

Simultaneity is not an absolute concept, but a relative one

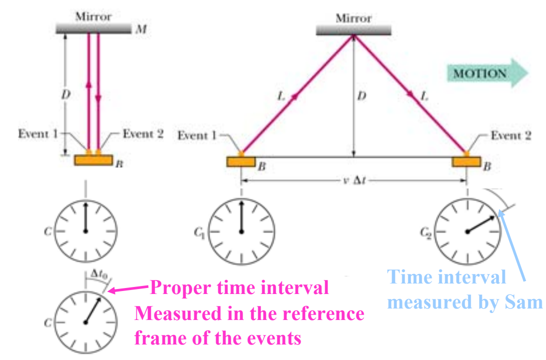
Simultaneity

The order of occurrence of two events, as observed in two different reference frames is not the same.

Simultaneity is relative

Time Dilation

Sally in the train — Sam on the station



Time Dilation

For Sally interval $\Delta t_0 = \frac{2D}{c}$ For Sam interval $\Delta t = \frac{2L}{c}$

$$\Rightarrow D = \frac{\Delta t_0 c}{2}$$

$$L = \sqrt{(\tfrac{1}{2} v\,\Delta t)^2 + D^2} \qquad L = \sqrt{(\tfrac{1}{2} v\,\Delta t)^2 + (\tfrac{1}{2} c\,\Delta t_0)^2}$$

$$\Delta t = \frac{2L}{c} = \frac{2\sqrt{(\tfrac{1}{2} v\,\Delta t)^2 + (\tfrac{1}{2} c\,\Delta t_0)^2}}{c} \Rightarrow \Delta t = \frac{\sqrt{(v\,\Delta t)^2 + (c\,\Delta t_0)^2}}{c}$$

$$c^2\Delta t^2 = v^2\,\Delta t^2 + c^2\,\Delta t_0{}^2$$

$$c^2\Delta t^2 - v^2\,\Delta t^2 = c^2\,\Delta t_0{}^2$$

$$\Delta t^2(c^2 - v^2) = c^2\,\Delta t_0{}^2$$

$$\Delta t^2 = \frac{c^2}{(c^2 - v^2)}\Delta t_0{}^2 = \frac{1}{(1 - \frac{v^2}{c^2})}\Delta t_0{}^2$$

Interval when events are at rest rel to you

Interval when events are moving rel to you

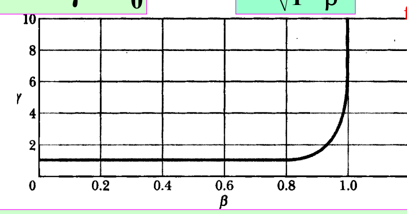
$$\Delta t = \frac{\Delta t_0}{\sqrt{1 - \beta^2}} \qquad \beta = \frac{v}{c}$$

$$\Delta t = \frac{\Delta t_0}{\sqrt{1 - \beta^2}} \quad \text{where} \quad \beta = \frac{v}{c}$$

Sometimes written as

$$\Delta t = \gamma \Delta t_0 \quad \text{where} \quad \gamma = \frac{1}{\sqrt{1 - \beta^2}}$$

γ is known as the Lorentz factor



If we are travelling at a relative velocity v, I will measure the time interval between two events in your world as longer than you do.

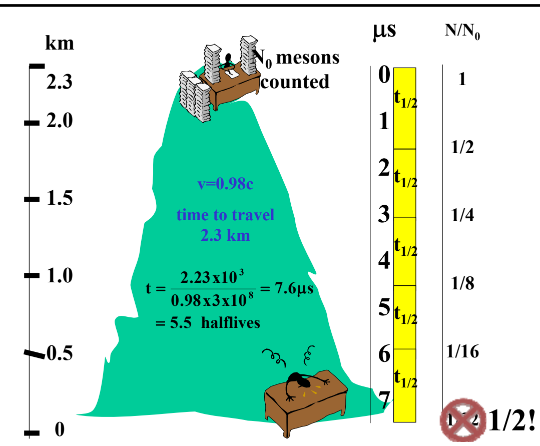
μ–mesons are made in the upper atmosphere by cosmic rays.

A μ–meson is an unstable particle and decays to an electron, with a half-life $T_{1/2}$ = 1.5 μs

1 μs = 10^{-6} s

$$\mu^- \Longrightarrow e + \nu$$

Time (μs)	Number remaining
0 μs	N_0
1.5 μs	1/2 N_0
3.0 μs	1/4 N_0
4.5 μs	1/8 N_0
6.0 μs	1/16 N_0



What has gone wrong???

In a flight time of 7.6 μs expect $N_0/32$ mesons to reach ground → In reality they observed $N_0/2$

We forgot that when the mesons are moving relative to us, their clocks slow down!!!

$$\Delta t = \frac{\Delta t_0}{\sqrt{1-\beta^2}}$$

Δt_0 is the half-life in the meson reference frame. In the Earth ref. frame this time (Δt) is:

$$\Delta t = \frac{1}{\sqrt{1-.98^2}}\Delta t_0 \approx 5\,\Delta t_0 = 7.6\ \mu s$$

So the time from top to bottom (7.6 μs) measured in the Earth ref. frame, is only 1.5 μs (1 half-life) as measured by the μ mesons

Time Intervals

The time interval between two events, as observed in two different reference frames is not the same.

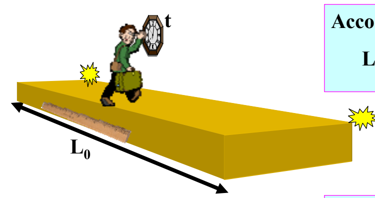
Time intervals are relative

Length Contraction

$$L_0$$

$$L = L_0\sqrt{1-\frac{v^2}{c^2}}$$

Moving rods get shorter



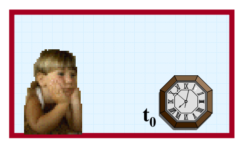
According to Sam

$L_0 = \Delta t\ v$

L_0 = propper length

According to Sally

$L = v\ \Delta t_0$



Why t_0 for Sally and t for Sam??

According to Sally → $L = v\Delta t_0$ equ 1

Length measured in moving frame

According to Sam → $L_0 = v\Delta t$ equ 2

Length measured in rest frame

Divide equ 1 by equ 2 → $\frac{L}{L_0} = \frac{\Delta t_0}{\Delta t}$

But recall $\Delta t = \frac{\Delta t_0}{\sqrt{1-v^2/c^2}}$ So that $\frac{L}{L_0} = \frac{\Delta t_0}{\frac{\Delta t_0}{\sqrt{1-v^2/c^2}}}$

→ $L = L_0\sqrt{1-v^2/c^2}$ or $L = \frac{L_0}{\gamma}$

L is always < L_0

Recall the μ-meson experiment

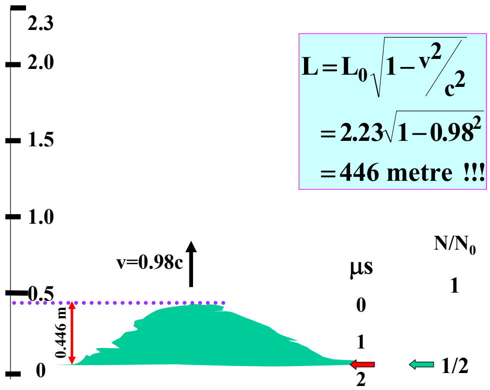
In a flight time of 7.6 μs expect $N_0/32$ mesons (halflife = 1.5 μs) to reach ground → In reality they observed $N_0/2$

We forgot that when the mesons are moving relative to us, their clocks slow down.

$$\Delta t = \frac{\Delta t_0}{\sqrt{1-\beta^2}}$$

So the time from top to bottom (7.6 μs) in the Earth ref. Frame, is only 1.5 μs (1 half-life) as measured by the μ mesons

In the reference frame of the μ-mesons



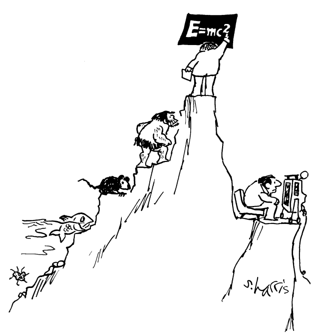
$$L = L_0\sqrt{1-\frac{v^2}{c^2}} = 2.23\sqrt{1-0.98^2} = 446 \text{ metre !!!}$$

Lengths

The distance between two events, as observed in two different reference frames is not the same.

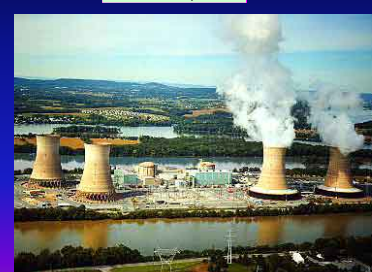
Lengths are relative

Mass-Energy



Mass-Energy

$E=m_0c^2$



Special Relativity says that the **total** energy is

$$E = mc^2$$

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

The inertial mass increases as the velocity increases.

Thus

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

$$E = \gamma\, m_0c^2$$

The relativistic mass (m) is a measure of the total energy.

Einsteinian Mechanics

Time intervals depend on v

$$\Delta t = \frac{\Delta t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

Lengths depend on v

$$L = L_0\sqrt{1-\frac{v^2}{c^2}}$$