Physics 100 – January 22, 2007

Last Time –

Course introduction

- If you missed 1st class see website

http://web.pas.rochester.edu/~manly/class/P100_2007/

- Get syllabus, notes from 1st lecture
- If not getting class emails, let me know
- Sign up for recitation section

https://spider.pas.rochester.edu/signup/PHY100-S07/

Also last time –

Human experience only a tiny fraction of time/length/mass scales in this universe.

* magnet lab powers of ten Java applet

Why should nature conform to human bias?

What is Science?

How does Science differ from other human Endevours that seek to make sense of the world around us?

Science bows before experiment.

How does the mission of Science, combined with the constraint above, dictate the nature of Science?

Science helps us understand and bring order to the world around us.

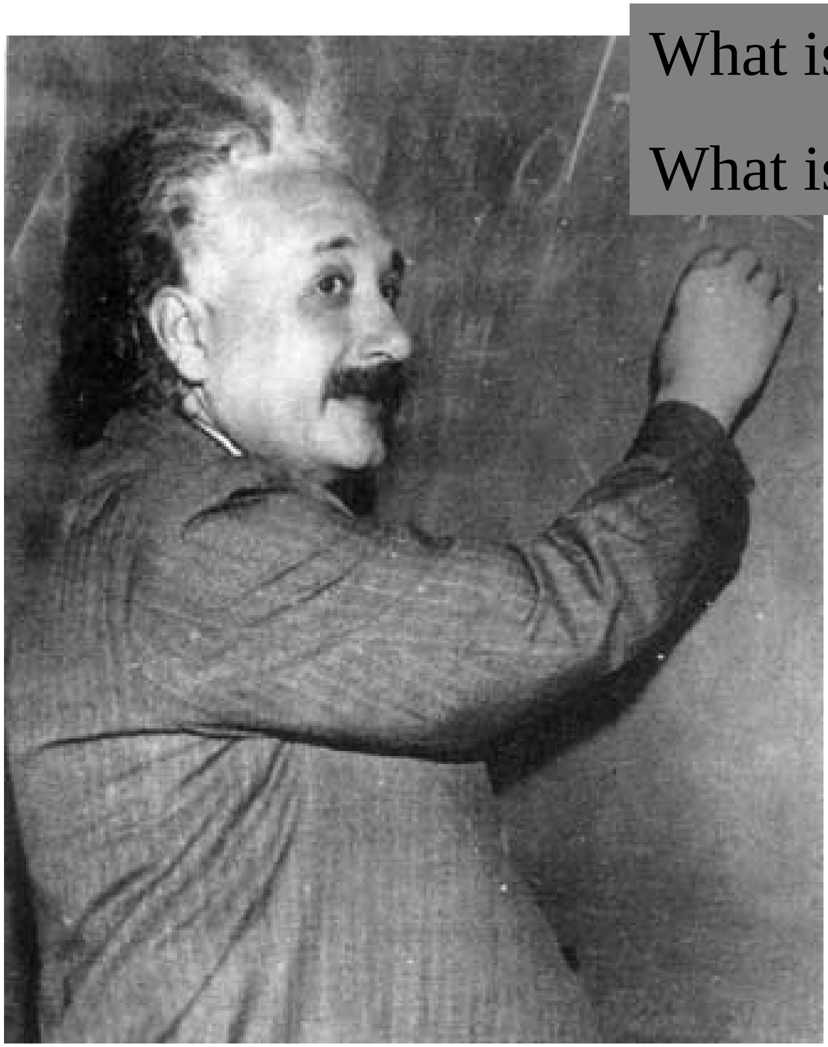
People must convey enough detail about a scientific observation to others that the others can attempt to reproduce the experiment/observation

detail … units, techniques
conditions of measurement

Makes scientific writing very dry/detail oriented as compared to other forms of writing

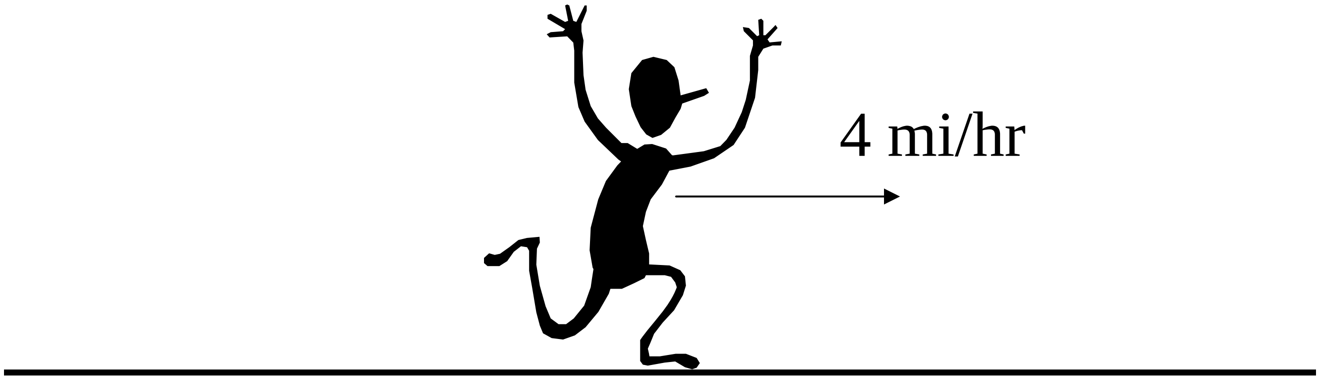
Hard to read unless you are expert

Also all observations incomplete unless provided with measure/estimate of how **good** is the observation → observation plus error estimate

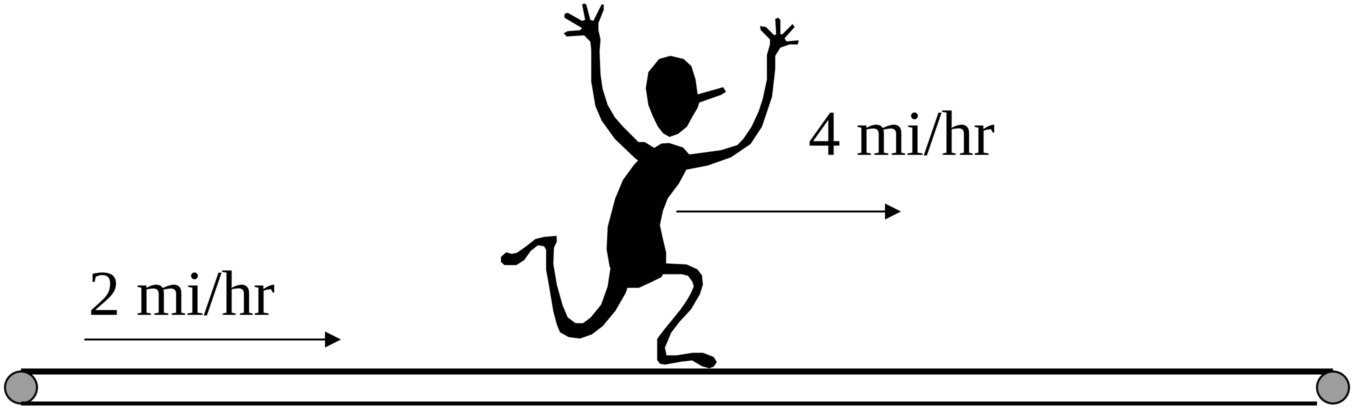


What is time??

What is space??

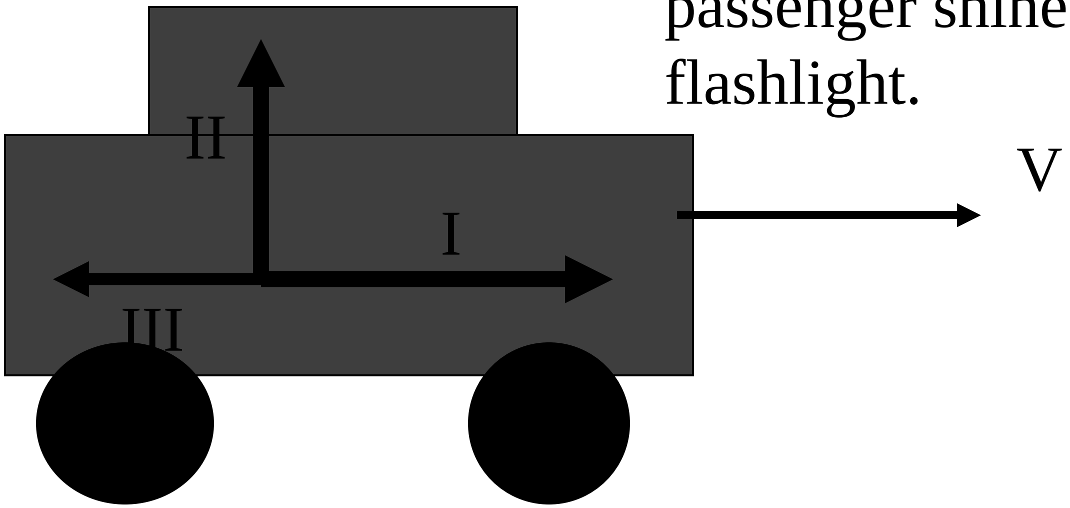


Speed with respect to you is 4 mi/hr

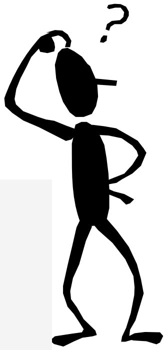


Speed with respect to you is 2 + 4 = 6 mi/hr

The speed of light is greater for beam I, beam II or beam III?



Car moves while passenger shines a flashlight.



Experiment says the speed of light is the same in all directions!!

waves

Photo credit: Andrew Davidhazy

Michelson-Morley experiment

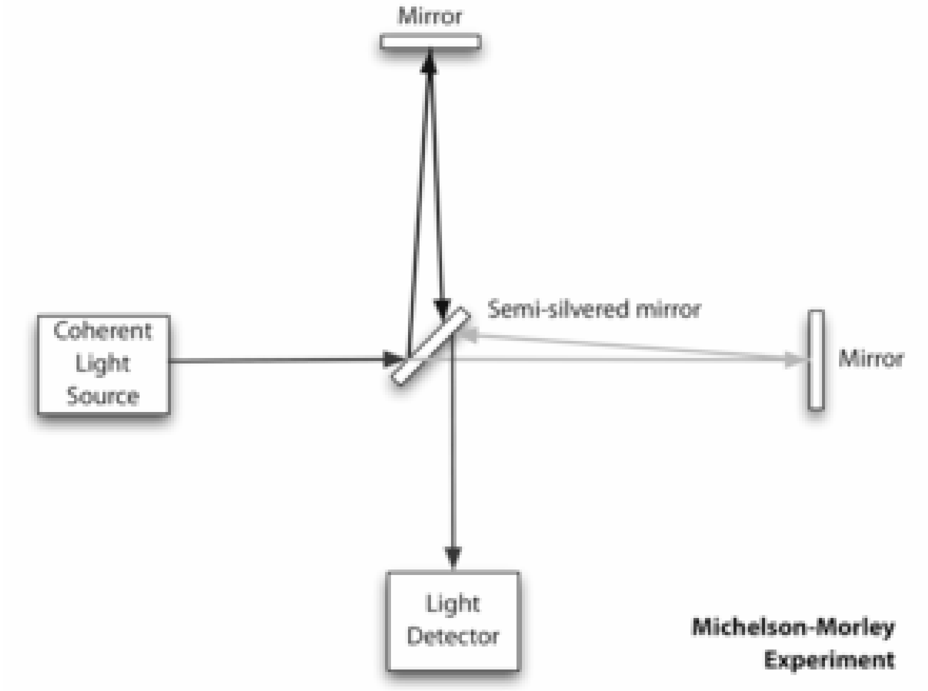
1881 – A.A. Michelson in Berlin

1887 - A.A. Michelson and E.W. Morley in US (Case Western)

1907 Nobel Prize in physics

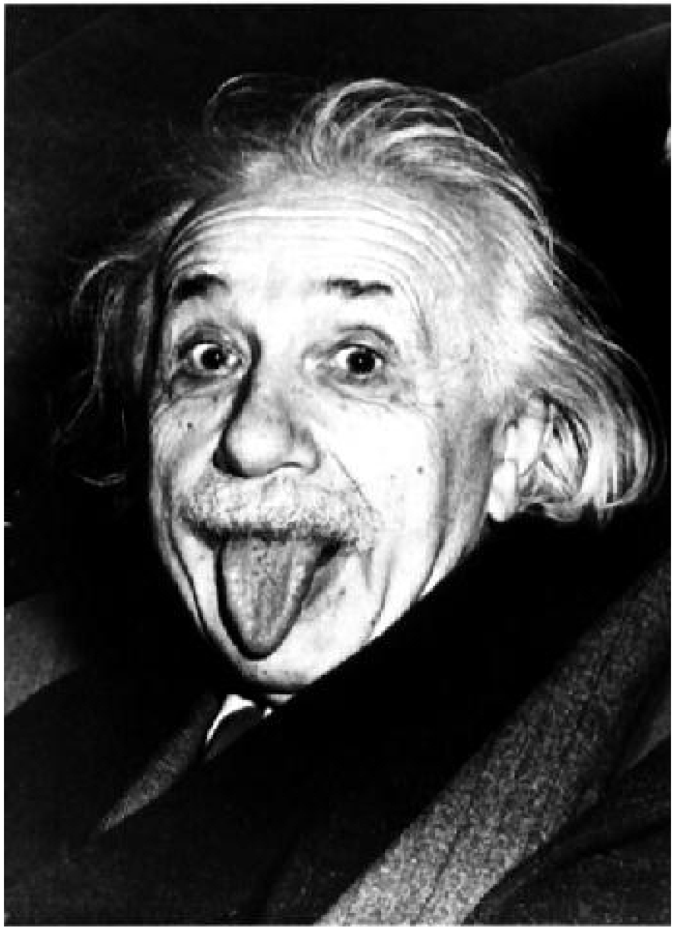
Michelson

Morley



Weird, huh? What does it mean for the real world?

Enter our man Einstein!

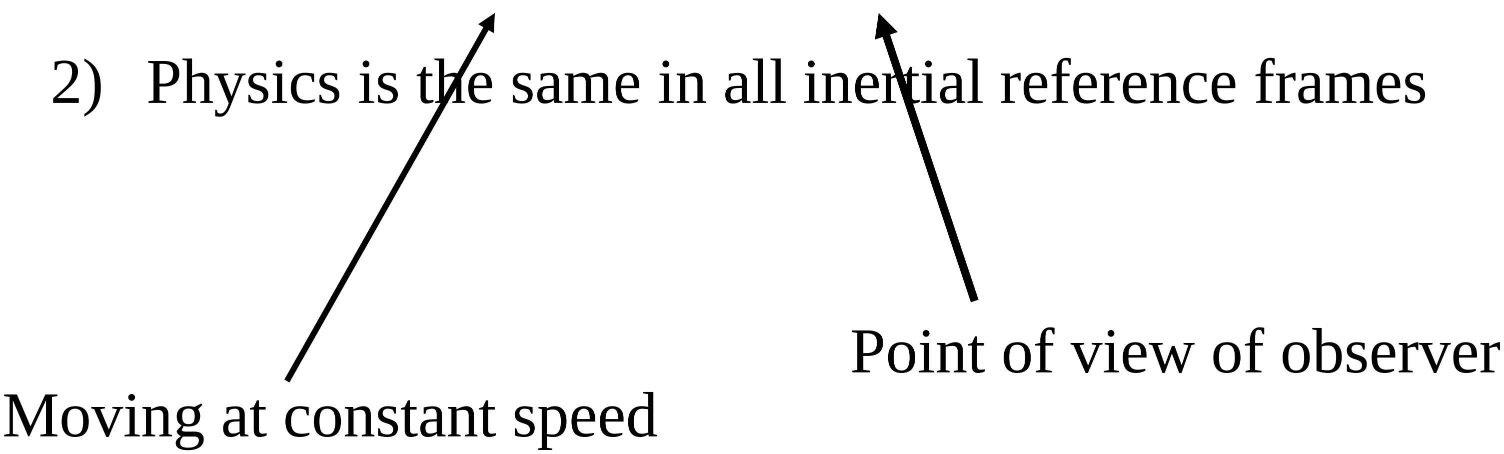


Instead of trying to “save the current paradigm”, Einstein bowed before the experiment.

What if it is true??

Two postulates:

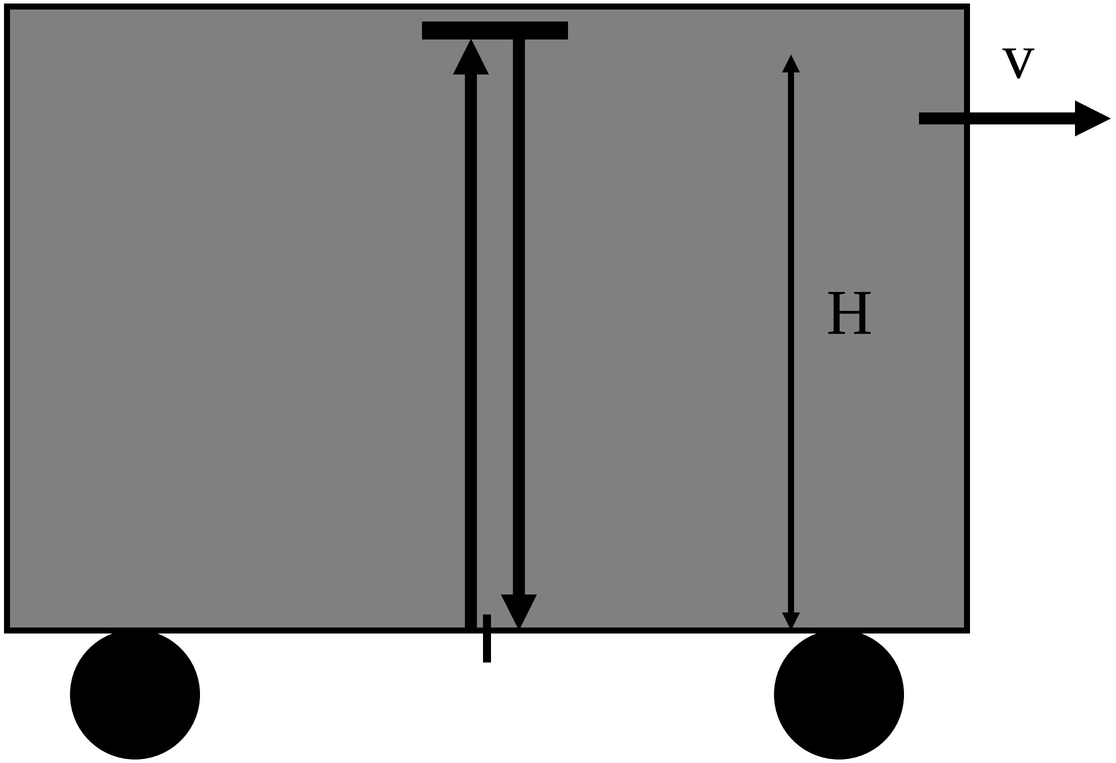
1) Michelson-Morley is correct. Speed of light is the same in all inertial reference frames
2) Physics is the same in all inertial reference frames



Point of view of observer

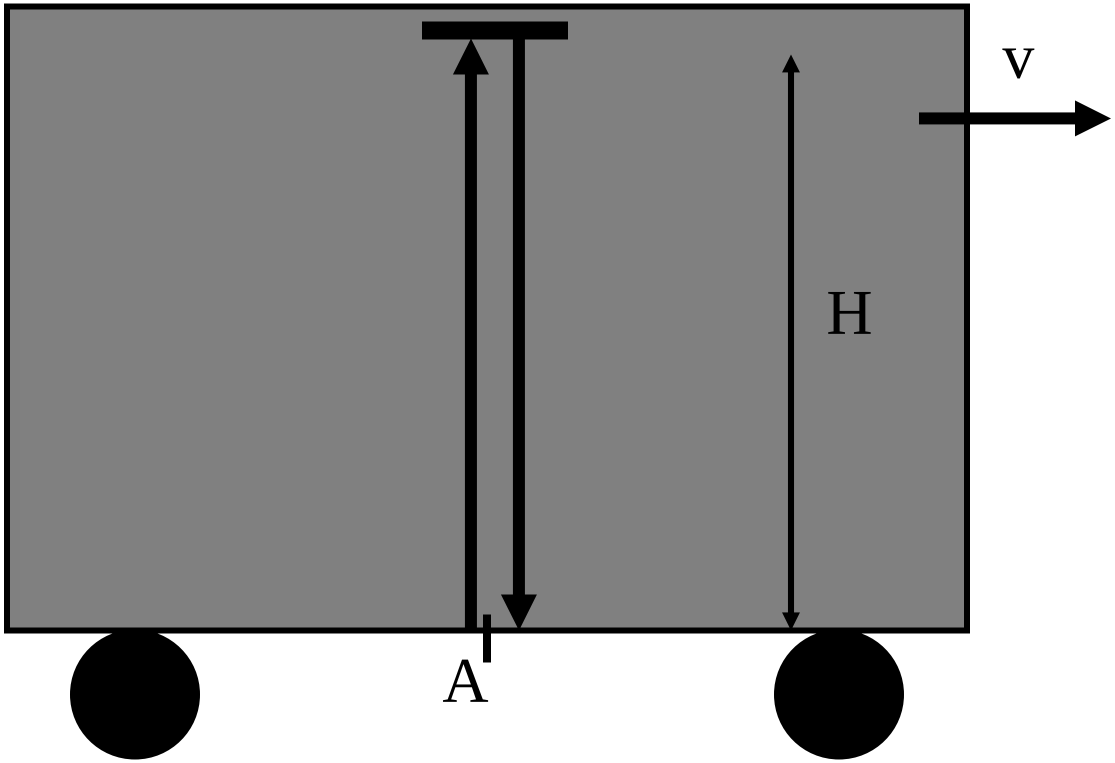
Moving at constant speed

Einstein thought experiment:
Consider a beam of light that is emitted from the floor of a train that bounces off a mirror on the ceiling and returns to the point on the floor where it was emitted.

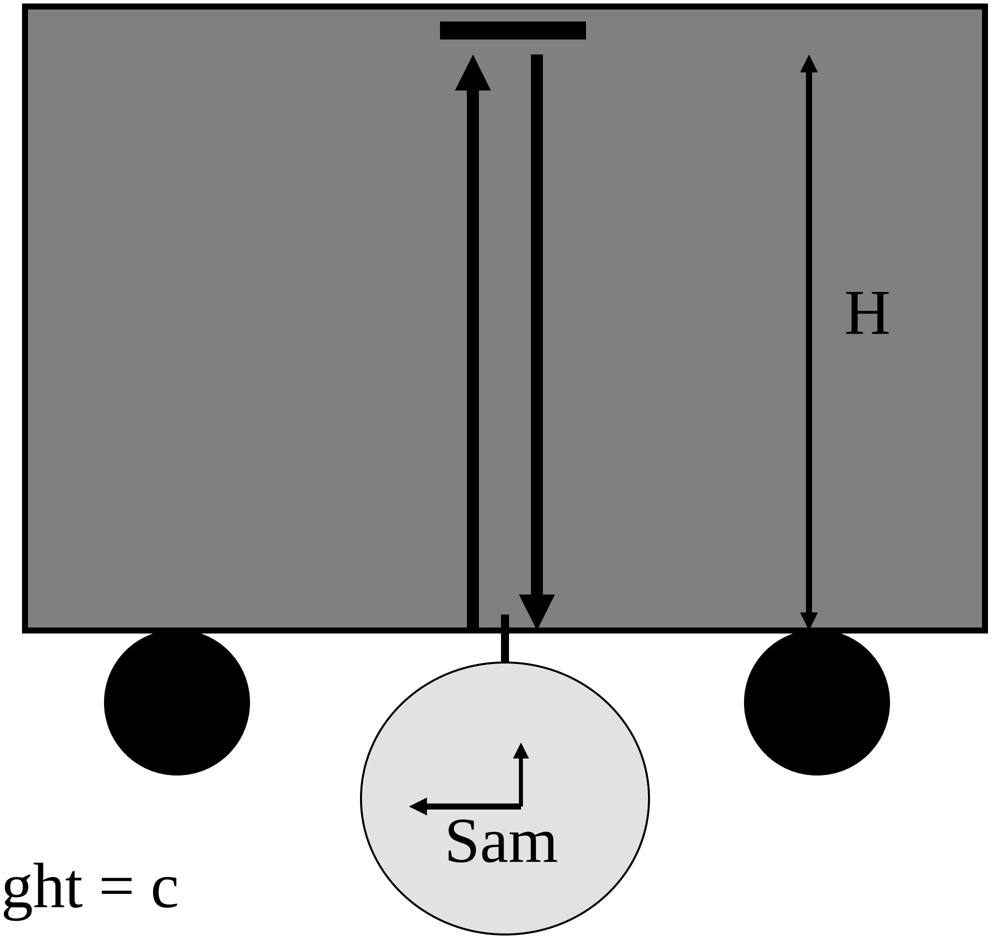


Fact: Light is emitted and detected at point A.

This fact must be true no matter who makes the measurement!!!!



Sam is on the train



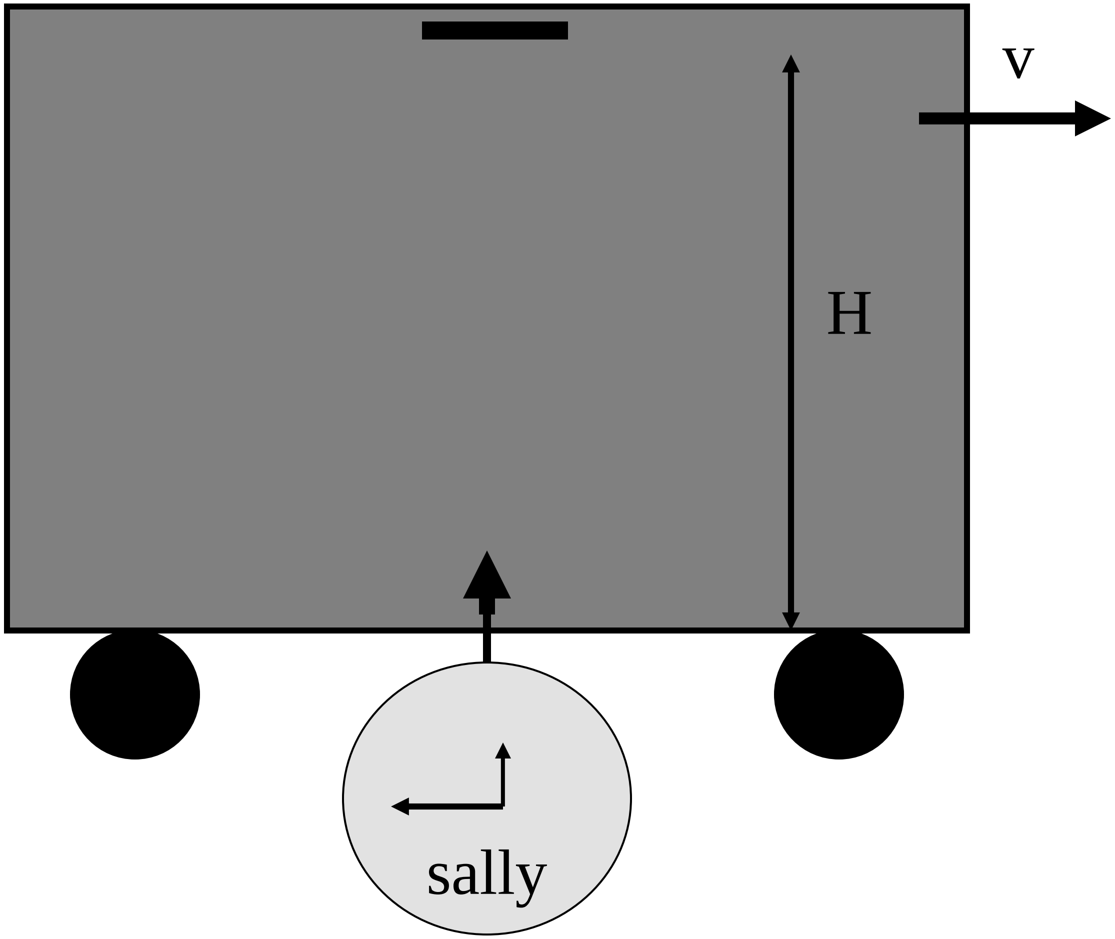
Velocity of light = c

c = distance/time

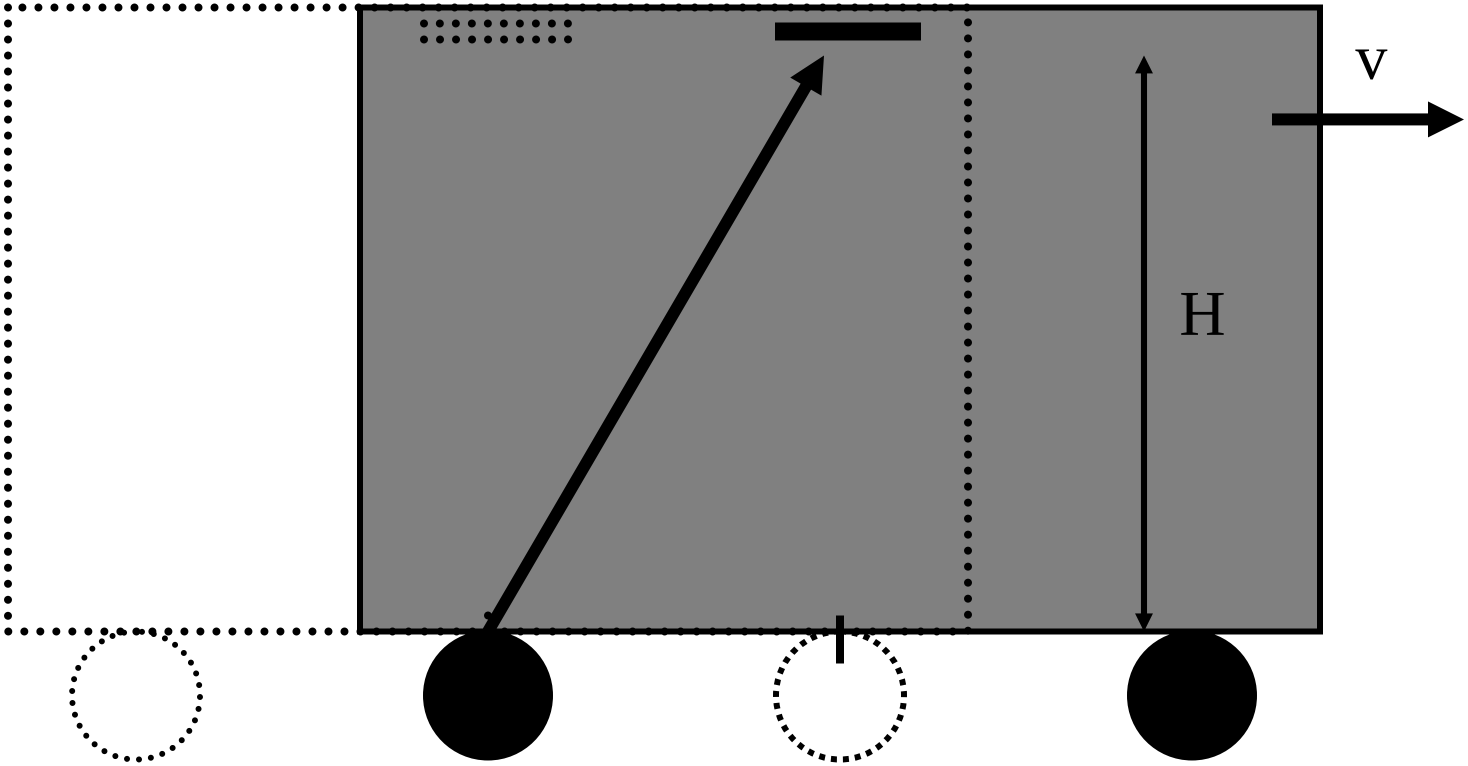
$c = 2H/T_{sam}$

$T_{sam} = 2H/c$

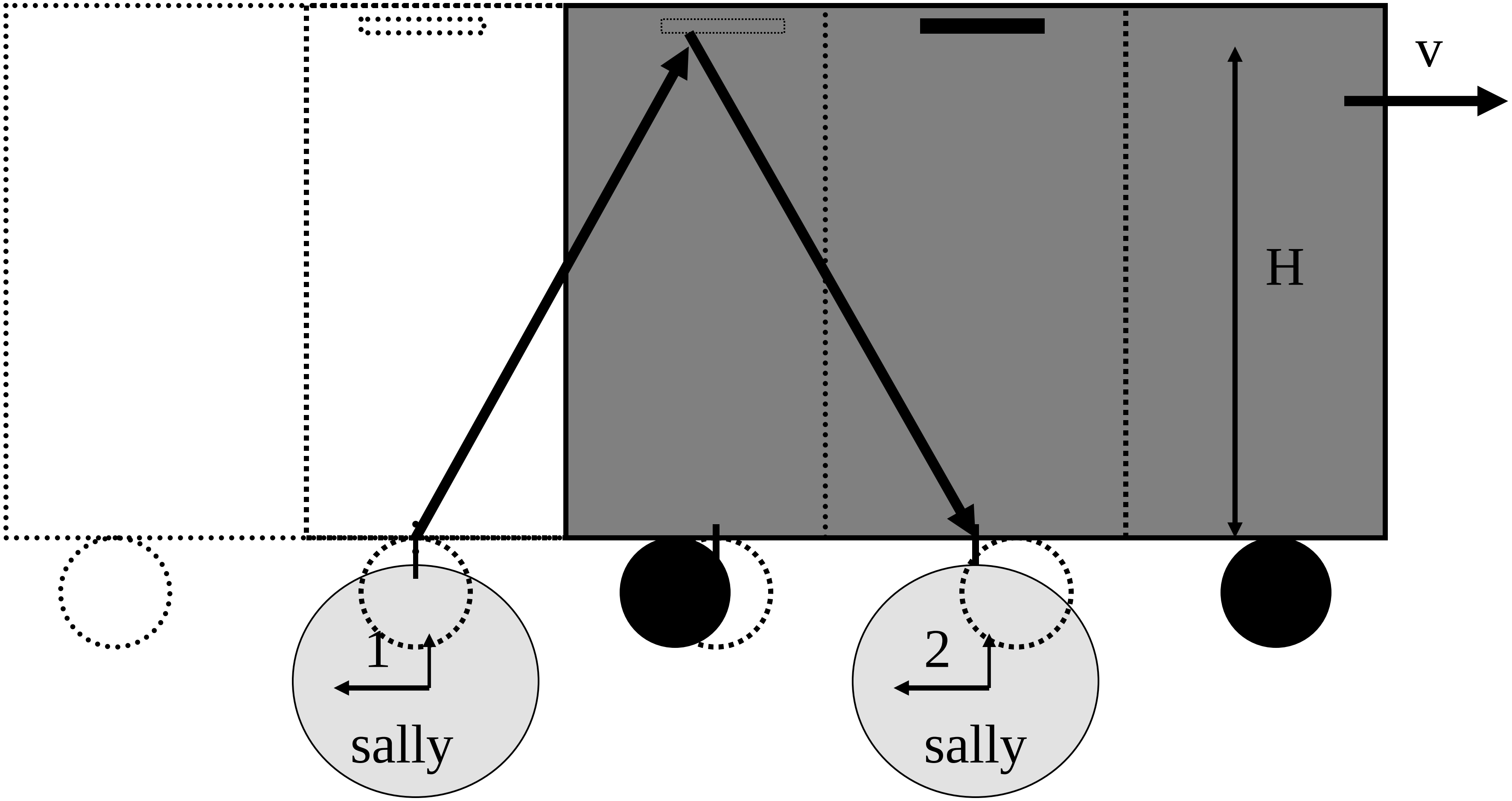
Sally watches the train pass and makes the same measurement.



Light is emitted


v
H

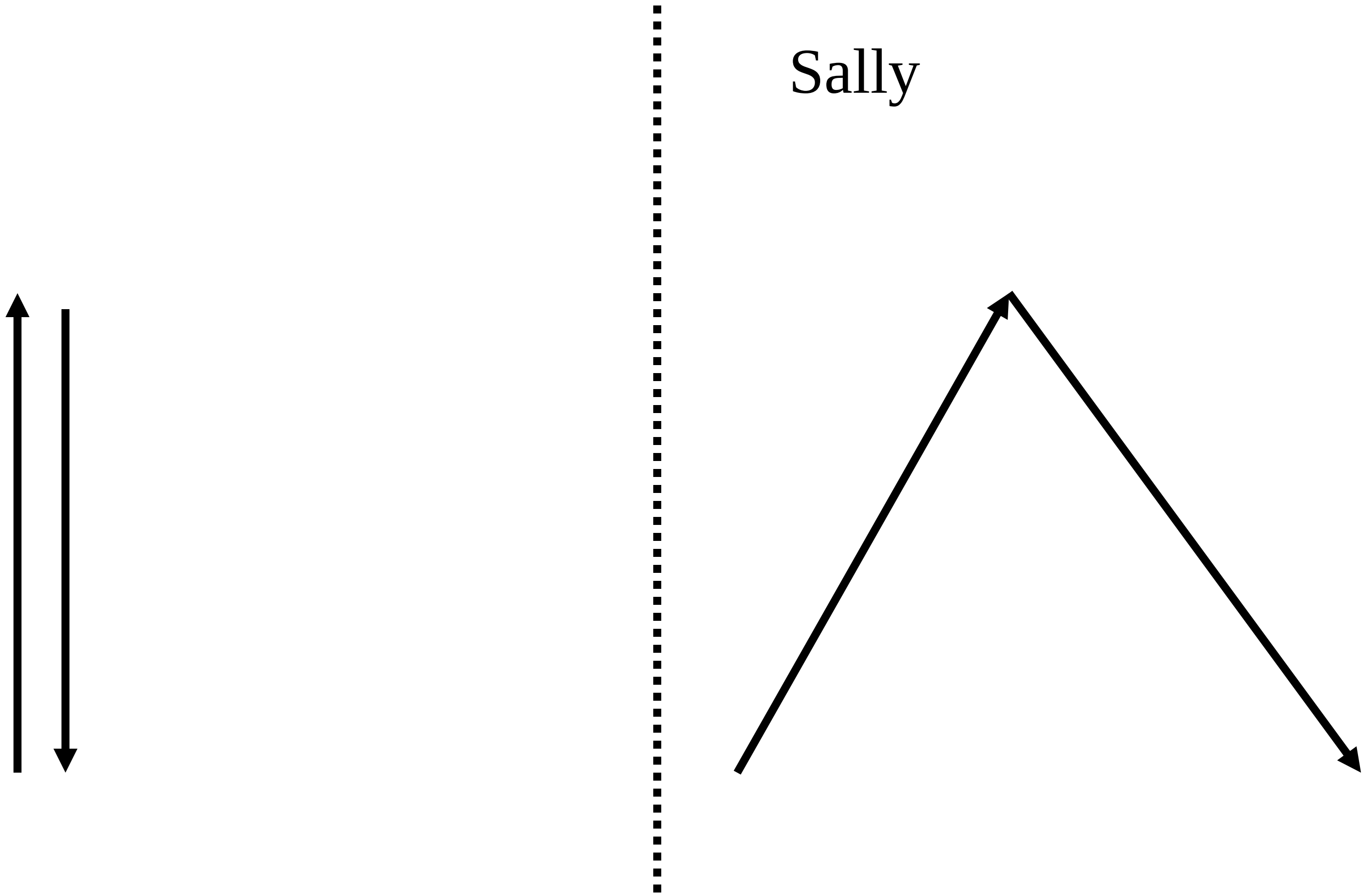
Sally is standing still, so it takes two clocks.



Light is emitted

Light returns

Do train cart demo



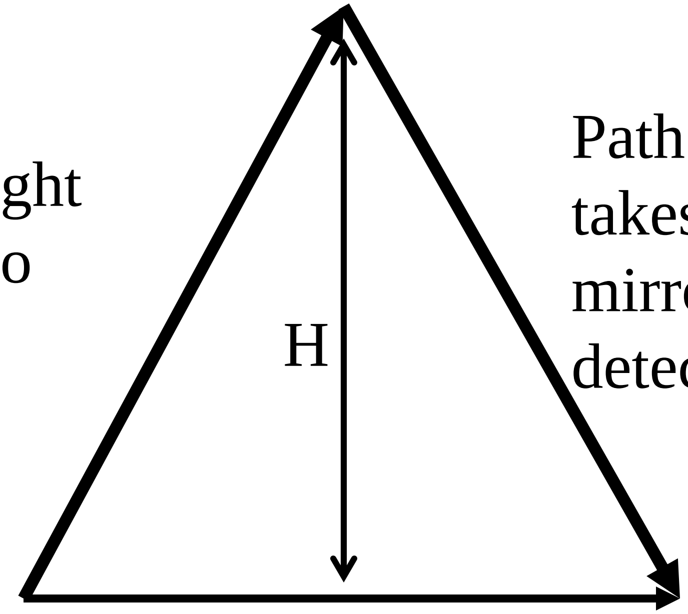
Sam

Sally

Sally sees the light traveling further. If light travels at a constant speed, the same “event” must seem to take longer to Sally than Sam!

Time is relative … not absolute!!

From Sally’s point of view



Path light takes to mirror

Path light takes from mirror to detector

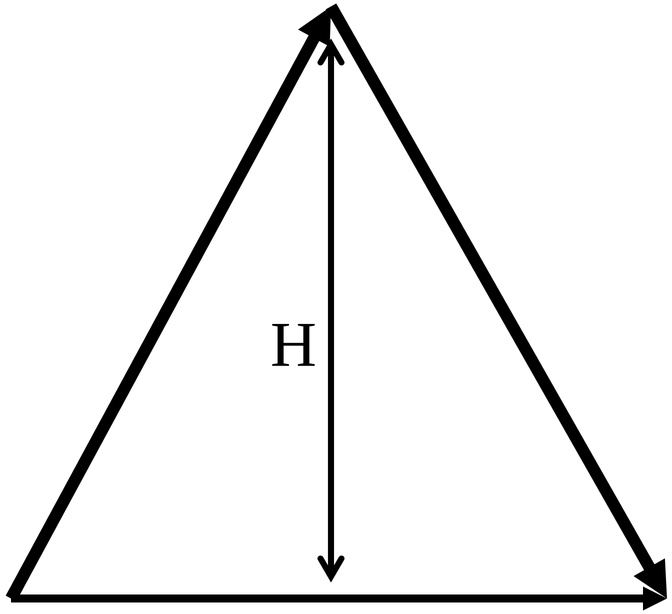
Distance train travels while light is traveling

$= VT_{sally}$

$$\boxed{D = \sqrt{H^2 + (\frac{1}{2} \mathrm{v} T_{sally})^2}}$$

Makes use of Pythagorian theorem

From Sally’s point of view



$$c = \text{distance/time} = 2D/T_{sally}$$

$$T_{sally} = 2D/c$$

Sam (on train)

Sally (on ground)

$2H/T_{sam} = c$

$c = 2D/T_{sally}$

$$c = \frac{2}{T_{sally}}\sqrt{H^2 + (\frac{1}{2}\mathrm{v}T_{sally})^2}$$

$$\frac{2H}{T_{sam}} = \frac{2}{T_{sally}}\sqrt{H^2 + \left(\frac{1}{2}\mathrm{v}T_{sally}\right)^2}$$

$$\left(\frac{2H}{T_{sam}}\right)^2 = \left(\frac{2H}{T_{sally}}\right)^2 + \left(\frac{2}{T_{sally}}\right)^2\left(\frac{1}{2}\mathrm{v}T_{sally}\right)^2$$

$$\left(\frac{2H}{T_{sam}}\right)^2 = \left(\frac{2H}{T_{sally}}\right)^2 + \mathrm{v}^2$$

$$\left(\frac{1}{T_{sam}}\right)^2 = \left(\frac{1}{T_{sally}}\right)^2 + \frac{\mathrm{v}^2}{(2H)^2}$$

Recall 2H/T_{sam} = c or 2H=cT_{sam}

$$\left(\frac{1}{T_{sam}}\right)^2 = \left(\frac{1}{T_{sally}}\right)^2 + \frac{\mathrm{v}^2}{(cT_{sam})^2}$$

$$c^2 = \frac{c^2 T_{sam}^2}{T_{sally}^2} + \mathrm{v}^2 \quad \longrightarrow \quad \boxed{T_{sally} = \left[\frac{1}{\sqrt{1-\left(\frac{\mathrm{v}}{c}\right)^2}}\right] T_{sam}}$$

Sam (on train)

Sally (on ground)

$2H/T_{sam} = c$

$c = 2D/T_{sally}$

$$c = \frac{2}{T_{sally}} \sqrt{H^2 + (\frac{1}{2} vT_{sally})^2}$$

A bit of algebra.

$$T_{sally} = \left[\frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \right] T_{sam}$$

This number is >1.

It becomes larger as

v approaches c.

Think about it!

Sam and Sally measure the time interval for the same event.

The ONLY difference between Sam and Sally is that one is moving with respect to the other.

Yet, $T_{sally} > T_{sam}$

The same event takes a different amount of time depending on your “reference frame”!!

Time is not absolute! It is relative!

$v = 0.98c$

what is lifetime of human on spaceship as seen by observer on Earth?

Let human on spaceship live 70 years as measured by clocks on spaceship

human on spaceship lives normal biological life

$$\Delta t' = \gamma \Delta t$$

relation of times (Δt) as measured in two frames of reference

$$\gamma > 1$$

$$\gamma = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}} = \frac{1}{\sqrt{1-\left(\frac{.98c}{c}\right)^2}} = 2.3$$

How do I know which frame is "primed"?

Trick to remember:

We are discussing relativistic time dilation

Time is shortest in frame where event is at rest. The frame where event is at rest is called the "proper" frame

measured time is longer in any other frame of reference

$$\underset{\Delta t' > \Delta t \text{ because } \gamma > 1}{\Delta t'} = \underset{>1}{\gamma}\,\Delta t \Longrightarrow \overset{\text{Earth}}{\Delta t'} = \overset{2{,}3}{\gamma}\,\overset{70\text{ years}}{\Delta t}$$

$$\Delta t' = \Delta t_{\text{Earth}} = \boxed{161\text{ years}}$$

Δt' > Δt

because γ > 1

— This means Δt is shortest

Δt is proper frame

Proper frame is spaceship because that is where person in question is at rest.

person lives normal life on spaceship
70 years

To observers on earth that time is measured to be 161 years.

Observers on Earth perceive time (incl. biological time) to move slower on spaceship.

Time is Relative