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LAST TIME:

The principle of relativity (Einstein).

$$\boxed{\text{The laws of physics are the same in all inertial reference frames.}}$$

crucial example: Maxwell's Equations for electromagnetism

→ predict waves of $\vec{E}$lectric & magnetic fields traveling at

$$v = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \approx 3 \times 10^8 \, m/s$$

↖ call this c

= LIGHT & other electromagnetic radiation

→ speed is independent of source

P.O.R. ⇒ Maxwell's equations valid in any inertial frame ⇒ $\boxed{\text{speed of light (in vacuum) is } c \text{ in any inertial frame}}$

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→ can't be true with ordinary assumptions about distances & times:

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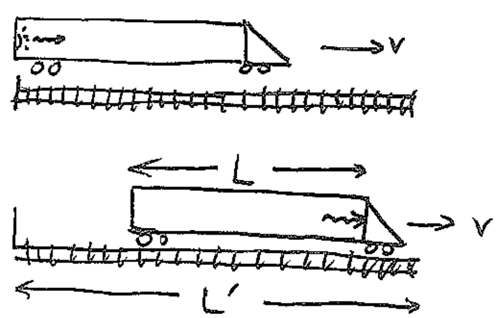
e.g.



$t=0$ light leaves back of train

$t=T$ light reaches front of train.

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

train's frame: $\frac{L}{T}$

track's frame: $\frac{L'}{T}$

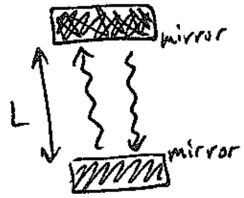
(with conventional assumptions)

cannot both be c!

BUT: experiment shows speed of light IS the same in all frames

OBSERVERS IN DIFFERENT FRAMES CANNOT AGREE ON TIMES & DISTANCES

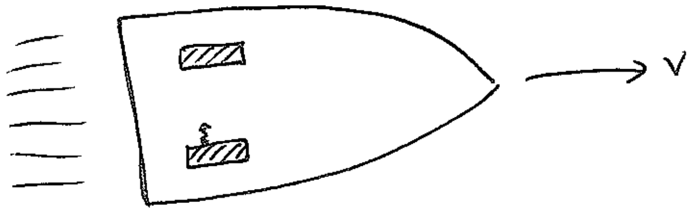
Look at times first:



Light clock: light up & down = one tick

exactly time $\frac{2L}{c}$

What do we see if we observe someone else's light clock in a moving ship?



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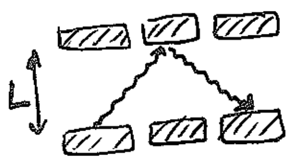


- clock has moved by the time light goes up & down.
- light observed to travel farther than 2L going up & down.
- we observe the light clock to be running slow!

TIME DILATION: moving clocks appear to run slow.

Generally:

$$(\Delta t)_{observed} = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \times (\Delta t)_{proper}$$

$(\Delta t)_{observed}$: time elapsed in observer's frame

$(\Delta t)_{proper}$: time elapsed on moving clock (or any 2 events at SAME PLACE in moving frame)

Experimental evidence:

- accurate clocks on airplanes came back running behind.
- observed decay rates for unstable particles slower if they are moving close to speed of light.

LAST TIME:

P.O.R.

$\Downarrow$

* speed of light is c in all inertial frames of reference *

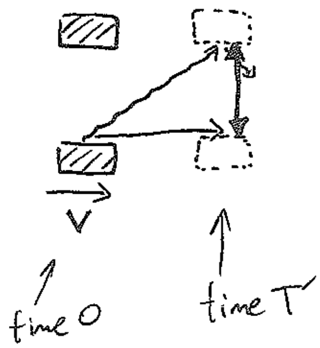
$\Downarrow$

moving clocks observed to run slow $\boxed{\text{TIME DILATION}}$

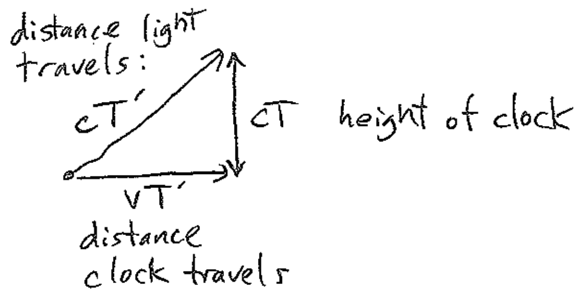
LIGHT CLOCK

define T: time for light to go from bottom to top in frame of clock

height of clock: cT



define T′: observed time for light to reach top of clock moving at speed v.



Pythagoras: $(cT')^2 = (vT')^2 + (cT)^2$

solve for T′: $T' = \dfrac{1}{\sqrt{1-\frac{v^2}{c^2}}}\, T$

Final result:

$$(\Delta t)_{\text{OBSERVED}} = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}(\Delta t)_{\text{PROPER}}$$

time elapsed in observer's frame

call this γ (gamma)

time elapsed on moving clock (or any 2 events AT SAME PLACE in moving frame)

★ $\gamma \approx 1$ for $v \ll c$

★ $\gamma \to \infty$ for $v \to c$: arbitrarily large time dilation possible.

Experimental evidence:

- effects seen directly with accurate clocks on airplanes

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- fast-moving unstable particles decay slower.

★ For two observers in relative motion, each sees the other's clock to run slower ★

→ must be true since only relative motion is important.

A sees B's clock change to 12:01 after As.

B sees A's clock change to 12:01 after Bs.