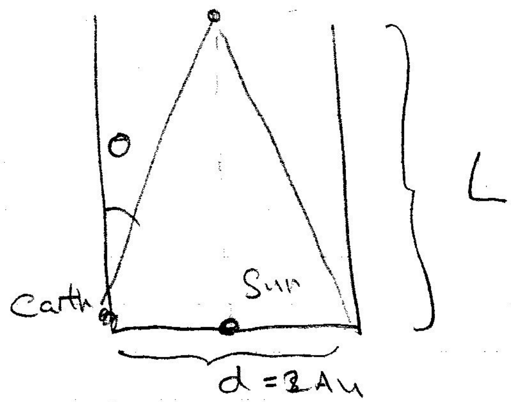
Last Time:

① Measurement of Distances Using Parallax



$$\theta \simeq \frac{d/2}{L}$$

$L = \frac{d/2}{\theta}$ → for $d = 1\,Au$ $L = \frac{1\,Au}{\theta}$

So this can be used to measure distances if angles can be measured precisely

- Used to establish the distance to nearest stars

  α-centauri ~ 4.1y

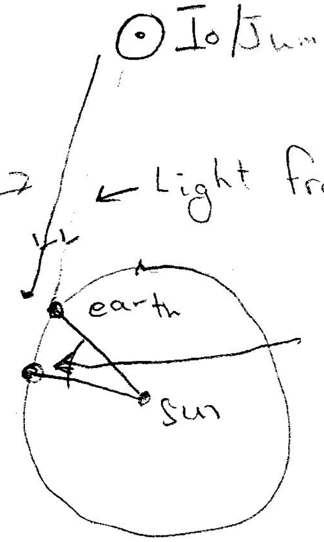
- Currently still used to calibrate known sources (discussed today)

  - Hipparcos sattelite measures distances ⓦ parallax to ~ 300ly

(2) Then we started to discuss the speed of light: (Roemer)

Light from eclipse at 44 h later

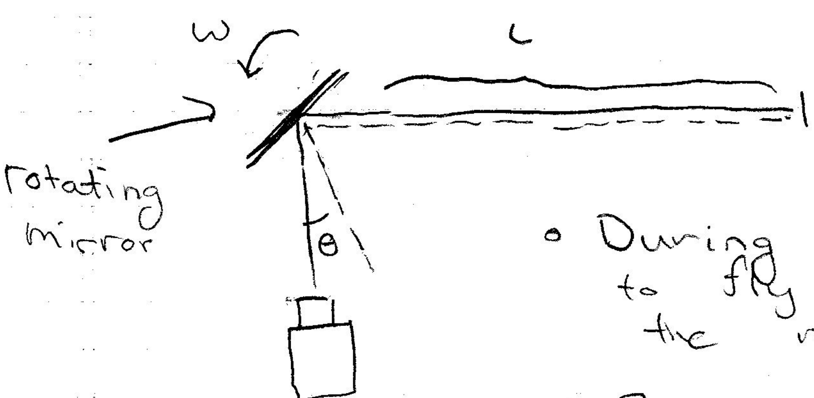
← Light from eclipse at $t=0$



But, the earth has moved to here in 44h so the light arrives late.

So found, $c = (3 \times 10^8\ m/s)$

Then, Later earth based measurements
Fizeau & Foucault ~1862

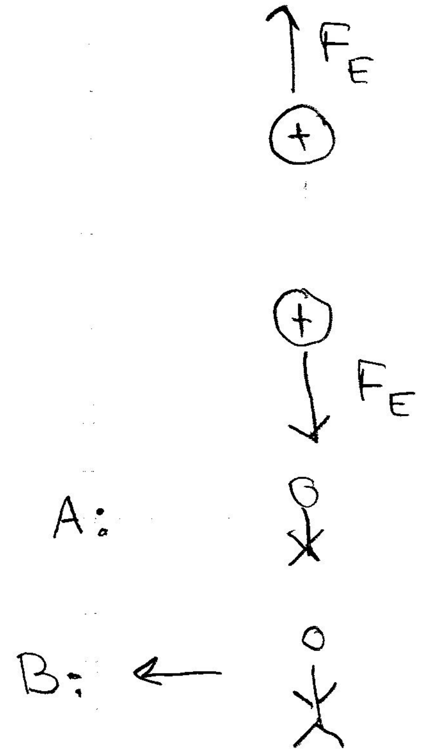


- During the time it takes to fly down and back the mirror rotates
- By measuring the angle, and knowing the distance L, and the rotation rate ω, find c.

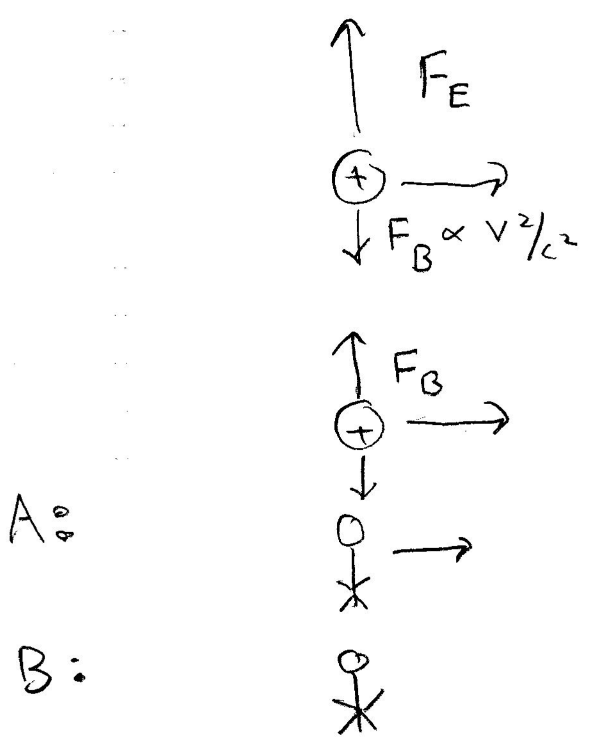
$2.99 \times 10^8\ m/s$

③ Relativity

- A built in property of Electricity and magnetism



This is A's point of view



This is B's point of view.

- According to B the charges are moving and therefore there is a small magnetic attraction

Einstein's Answer -- Both A & B measure different forces, but they also measure different accelerations. The laws of physics are the same for all

$$m \frac{\Delta V_A}{\Delta t_A} = F_A$$

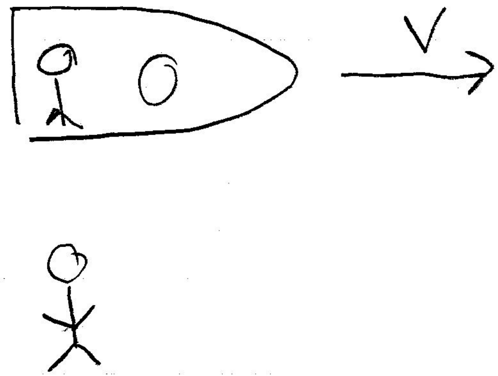
Similarly

$$m \frac{\Delta V_B}{\Delta t_B} = F_B$$

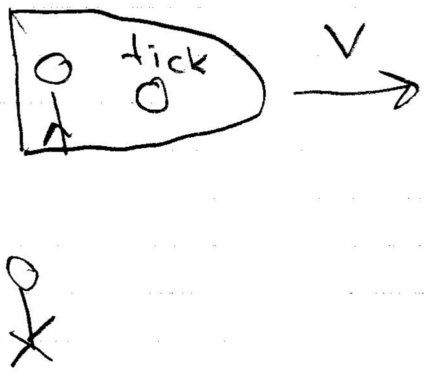
But $F_A \neq F_B$ and similarly $\Delta t_A \neq \Delta t_B$
and similarly $\Delta V_A \neq \Delta V_B$

Have no fear einstein tells you how to relate Δt_A and Δt_B

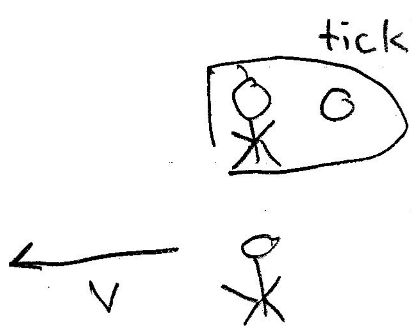
Time Dilation



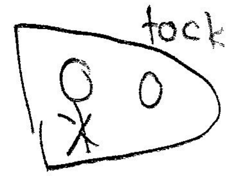
The Ground Observer Sees the clock moving

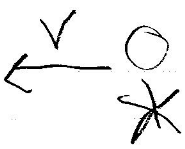


The space ship sees



Then later





- Then according to spaceship the time interval occured at the same point. We call this a proper time interval, call it $\Delta\tau$.
- For the ground observer tick and tock happen at different points and is not a propper time interval, call it Δt.

The relation between Δt and $\Delta\tau$ is

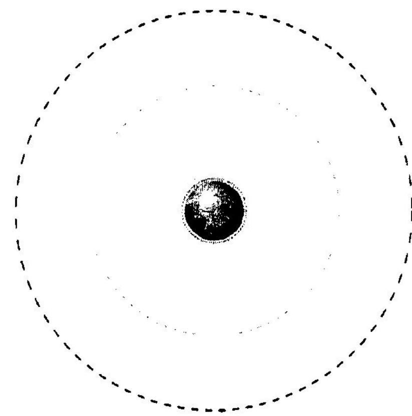
$$\Delta t = \gamma \, \Delta\tau$$

Where

$$\gamma = \frac{1}{(1 - (V/c)^2)^{1/2}}$$

Group work II.

- A clock in a satellite is orbiting $200\ \mathrm{km}$ above the earth in a low earth orbit.The region of low earth orbit is shown below (to scale) as the cyan (or blue) region. (Neglect the differences in gravity between the earth observer and the satellite since the orl is low. We will discuss the the gravitational differences today)



1. Determine the orbital period according using Kepler's Law, $\Delta t_{\mathrm{earth}}$.
2. Determine the speed of the satellite
3. After orbiting once, the clock in the satellite and on earth read different times, which shows a longer elapsed time.
4. Compute

$$\frac{\Delta t_{\mathrm{earth}} - \Delta t_{\mathrm{sat}}}{\Delta t_{\mathrm{earth}}} = 1 - \frac{\Delta t_{\mathrm{earth}}}{\Delta t_{\mathrm{sat}}}$$

5. You will need a lot of digits (about 13) when computing $\gamma = 1/\sqrt{1-(v/c)^2}$. Go to www.wolframalpha.com

Now Lets Review the Material (General Relativity) from two lectures ago.

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① The principle of equivalence (see slides)

② Light is Bent as it goes past a massive Body

$$\Delta\theta \sim \frac{GM}{c^2 R} \Rightarrow \boxed{\Delta\theta = 4\frac{GM}{c^2 R}}$$ exact

In particular for light passing near the sun

$$M = M_\odot \qquad R = R_\odot$$

$\Delta\theta = 1.73$ arcsec -- Measured by the Eddington expedition.

③ If an Object is sufficently massive at a fixed size, then light will not be able to escape from a radius known as the Schwarzchild radius

$$R_{sch} \sim \frac{GM}{c^2} \Rightarrow \boxed{R_{sch} = 2\frac{GM}{c^2}}$$

(4) Due to the finite speed of light Mercury's Elliptic orbit will precess

$$\frac{\Delta\Theta}{\Delta t} \sim 43 \text{ arcsec}/\text{century}$$

(5) In the presence of strong gravitational fields there is gravitational lensing of Light

(6) Today we will add one more test of GR known as the gravitational red-shift.