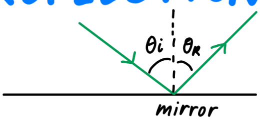
EXAM #3

LIGHT (Vol 3 Chp 1)

- Ray

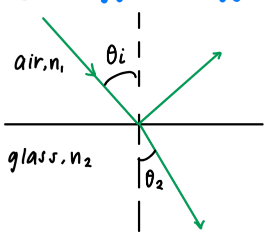
  light moving as a straight line
- medium (something light travels through)
  ex/: lens, fluid, mirror, gas
- c = speed of light $= 2.998 \times 10^{8}$ m/s
  (in a vacuum)
- v = speed of light in medium
  always $v < c$
- index of refraction (n) $\boxed{n = \frac{c}{v}}$

REFLECTION



$\theta_i = \theta_R$

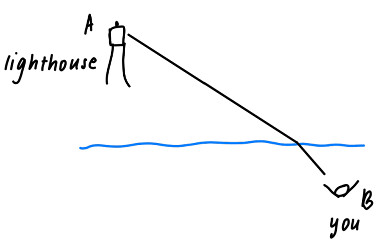
REFRACTION



Snell's Law
$n_1 \sin\theta_1 = n_2 \sin\theta_2$

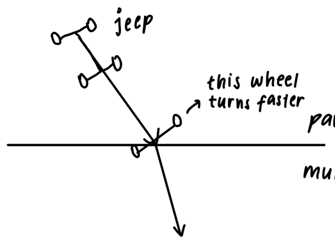
- Why does light change direction?

→

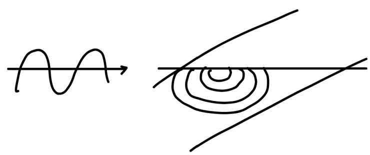


take the path A → B that takes the shortest amount of time.

→ another analogy

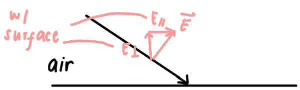


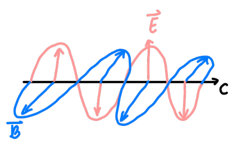
→ Huygen's Principle



* see textbook and take w/ a grain of salt!

→ [real solution!]





$$\nabla \times \vec{E}_{air} = -\frac{\partial B}{\partial t}$$

$$\varepsilon \nabla \vec{E}_{air} = \rho$$

at surface, $\nabla \times \vec{E}_{air} = \nabla \times \vec{E}_{glass}$

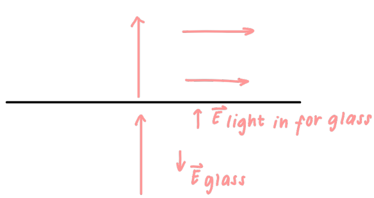
$$\varepsilon_{air} \nabla \vec{E}_{air} = \varepsilon_{glass} \nabla \vec{E}_{glass}$$

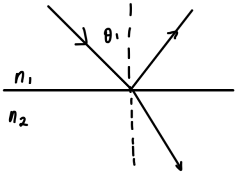
$$E_{glass\parallel} = E_{air\parallel}$$

$$E_{\perp glass} = \frac{\varepsilon_{air}}{\varepsilon_{glass}} E_{\perp air}$$

! Recall PHY-4B ε_0 = permittivity of free space (vacuum)

ε = permittivity of material, measure of how well a material holds energy from an electric field

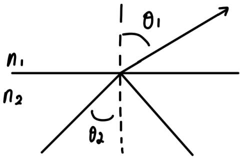


- 

  $n_1 < n_2$

  $\theta_2 < \theta_1$

  * light bends toward normal as it passes into higher index material

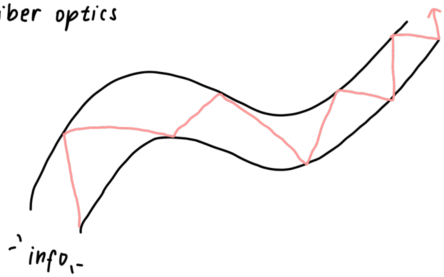
- 

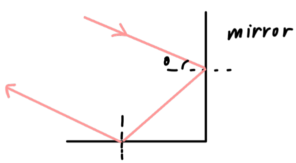
  when $\theta_1 = 90°$, $\theta_2 = \theta_{critical\ angle}$

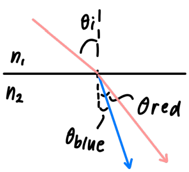
  ↳ total internal reflection

  * bends away from normal going into lower index.

- fiber optics

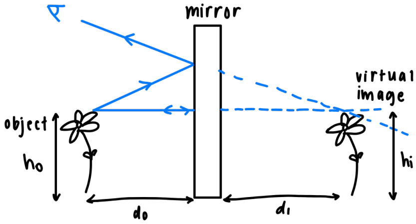
- 

- 

  what if n is wavelength dependent? (for a specific medium)

  $n\uparrow$ as $\lambda\downarrow$ very slightly

GEOMETRIC OPTICS (Vol 2 CHP 2)



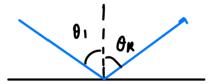
virtual image - appears at the intersection of --- lens

↓

means it's where the ray looks like it's coming from, but no actual light is there.

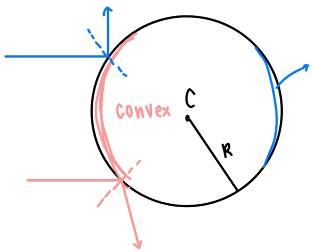
$$d_o = -d_i$$

Recall! Law of reflection

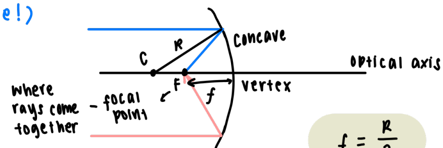


$\theta_1 = \theta_R$

CURVED MIRRORS



concave (! like a cave!)



$$f = \frac{R}{2}$$

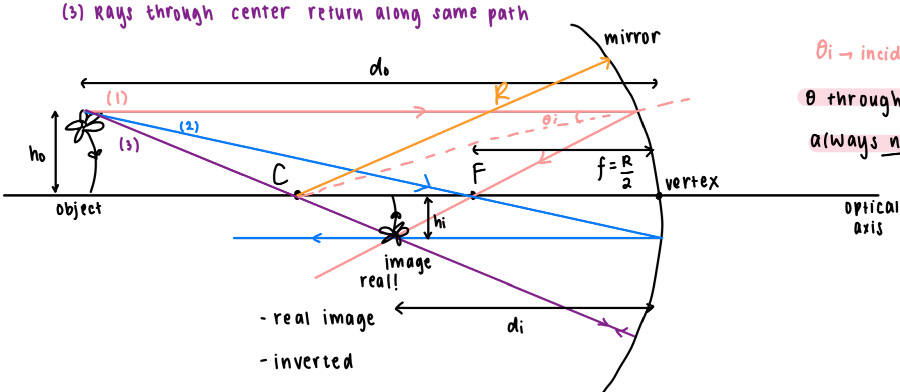
F - focal point

f - focal length

rule: (1) parallel ray goes through focus

(2) Rays through focus go parallel

(3) Rays through center return along same path



θ_i → incident

θ through center always normal!

- real image
- inverted
- de-magnified

mirror equation → $$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

- why does mirror reflect light?

  The moving electric charge (electrons) makes moving electric field, when light comes in, It vibrates the photon w/ the same speed it comes in & reflect it w/ the same amount & speed of the photon that comes in.

- Why use metal / glass?

  It is smooth & protects the reflection.

- $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

  Proof for flat mirror!

  $f = \frac{R}{2}$ and R of flat mirror is ∞

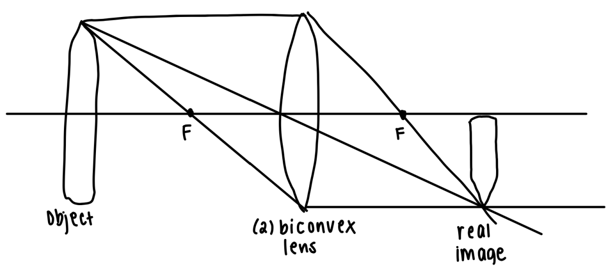
  which means

  $$f = \frac{\infty}{2} = \infty$$
  $$\frac{1}{f} = \frac{1}{\infty} = 0$$
  $$\frac{1}{d_o} = -\frac{1}{d_i}$$ ✓

- difference between lens & mirror:

  lens → light goes through

  mirror → light bounces off.

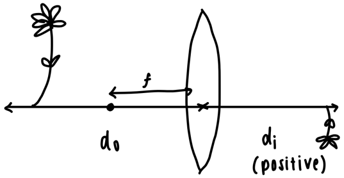
- 

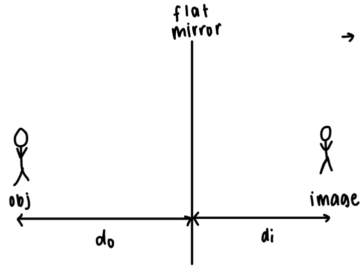
  → when u put object @ focal point, the lines are parallel.

  → when u put object really close to the lens (w/in focal length of a lens), u would see the virtual image behind the object (ex/: magnifying glass)

  → lines diverge

THIN LENS



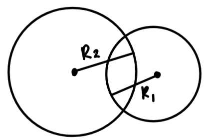


→ images to the right of the mirror d_i is negative (−)

→ for lenses, the material MATTERS A LOT!

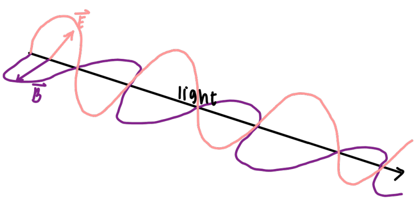
→ if index of refraction is higher, focal length (f) is closer. it bends more (the ray trace)

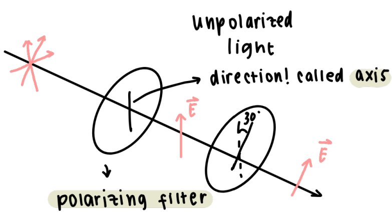
→ lens maker's equation: $\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$



→ our eyes are tuned to be n_2(eye) , n_1(air) perfect ratio to be able to see w/ air surrounding. that's why we can't really see well underwater & need goggles bcs there are air inside.

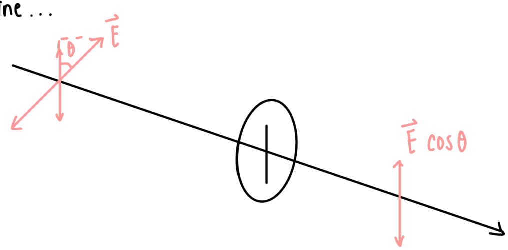
POLARIZATION





if the light falls // , it will go through
" ⊥ , it will be messed up

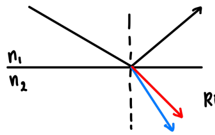
imagine ...



→ if u put 2 polarizers, 90° to each other, light cannot come through

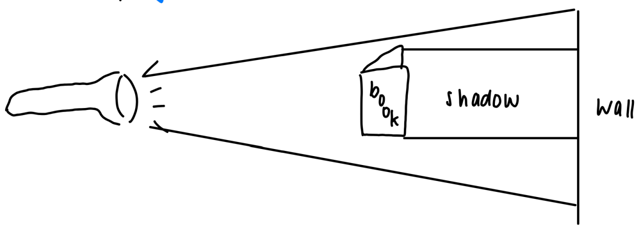
→ if u add another (3rd) polarizer, 90°, light will still not come through but if u put in between & angle it, L.G.T.

WAVE NATURE OF LIGHT



— blue light bends more

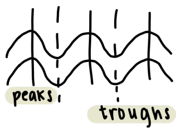
Refraction : deals w/ light changing medium



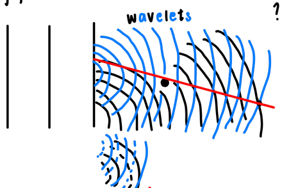
! treat light as a particle

- laser HAS the same wavelength as a strand of hair.

in phase



- Huygen's Principle



? Recall: 2 speakers

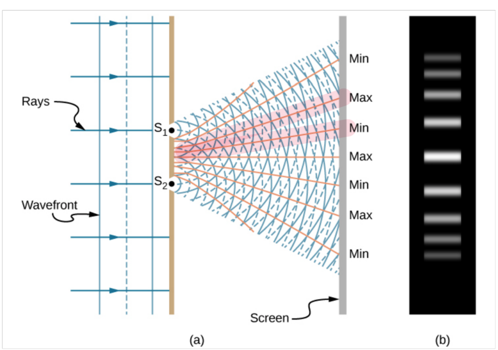
→ they will produce min/max

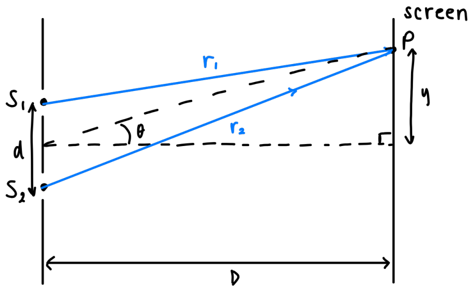
they intersect and
if — & — interfere
it's constructive troughs/peaks

↘ if different lines intersect : destructive

max - all —— or all - - - - -

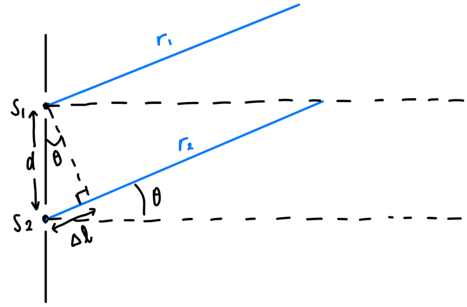
min - —— + - - -



- 

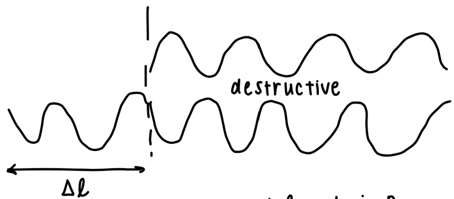
approximate

$D >> d$

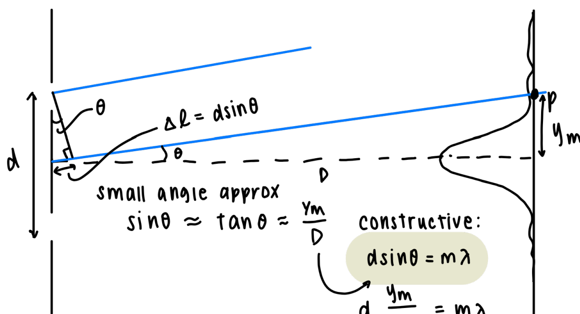


$\Delta \ell = m\lambda$ constructive

$\Delta \ell = (m + \frac{1}{2})\lambda$ destructive



$\Delta \ell = d \sin\theta$

- 

small angle approx

$\sin\theta \approx \tan\theta \approx \frac{y_m}{D}$

constructive:

$d\sin\theta = m\lambda$

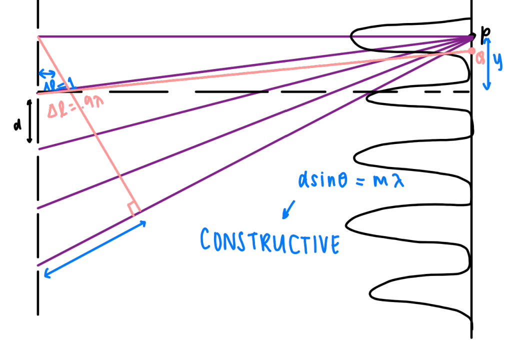
$d\,\frac{y_m}{D} = m\lambda$

$d = \frac{m\lambda D}{y_m}$

interference pattern

- ray will always go $\perp$ to the wavelength

MULTIPLE SLIT

- 

constructive interference

* sharper peaks

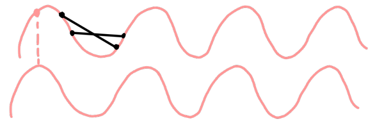
the more slits u have, the finer the light will become

at point P : constructive

→ when you pass monochromatic light through a diffraction = ??

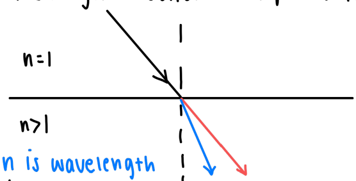
→ when you pass white light through a diffraction = multiple colors come out.

at point a



- Diffraction
  - light interferes as it passes through slits

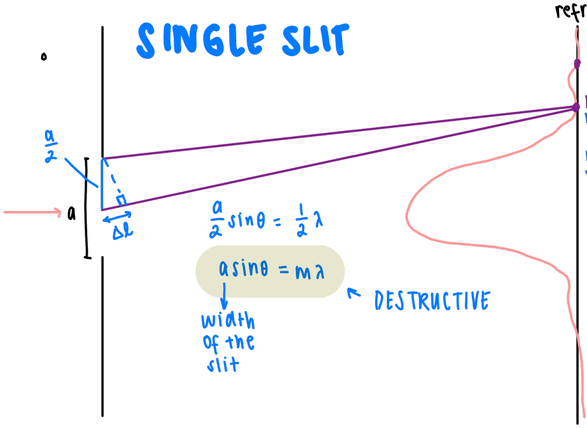
Refraction
- Light changes direction as it passes through a substance



n is wavelength dependent

index of refraction

- **SINGLE SLIT**



$\frac{a}{2}\sin\theta = \frac{1}{2}\lambda$

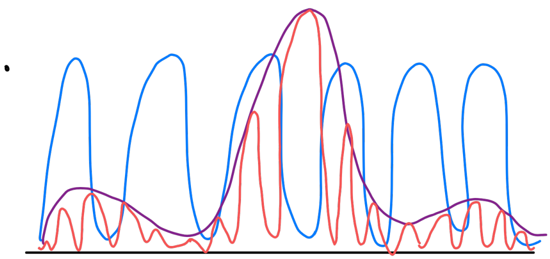
$a\sin\theta = m\lambda$ ← DESTRUCTIVE

a: width of the slit

m is the "order" of the destructive interference

as it passes through single sit, there will be infinite little sources of light passing through.

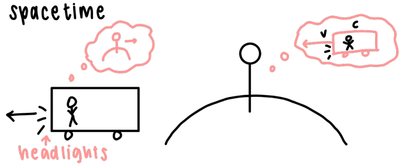
→ find where they are destructive interfering



multiple slit interference (d)
diffraction pattern through slit (a)

RELATIVITY

→ spacetime



who's moving?

disagree : they say the other one's moving

agree : - relative speed

- feel stationary because NO acceleration

- the laws of physics apply

→ "WRT" : with respect to

→ measure c (speed of light) = 3×10^8 m/s

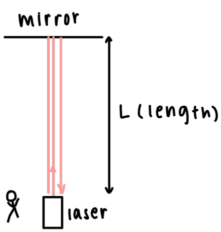
→ Newton says c + v is possible

→ Now, we have the technology to measure $c = 3 \times 10^8$ m/s
↓
constant, everyone agrees

→ in E&M, $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$ $\left[speed = \frac{distance}{time} \right]$

→ reference frame : in the ex/, it is the box where the people feel stationary.

→



for person who is stationary.

"tau"

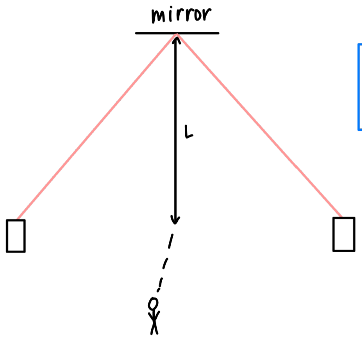
$$\boxed{\Delta\tau = \frac{2L}{c}}$$

↓ (proper time)
time light travels, measured by observer stationary WRT laser

[Δτ : proper time]

→ time interval between events that occur in same location

→ if moving (ex/: train moving)



dilated time

$$\boxed{\Delta t = \frac{2L}{\sqrt{c^2 - v^2}}}$$

→ $c\Delta\tau = 2L = \Delta t\sqrt{c^2 - v^2}$

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

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

define Lorentz Factor

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

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

→ as γ ↑ , the Δt has to ↓

so, the person stationary outside watching the whole experiment happen, sees the other person in the train moves in slow-mo.

→ as you approach speed of light (γ ↑), Δt ↓ longer

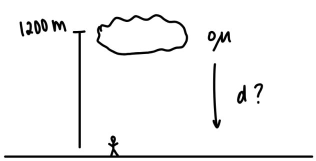
↳ people will view you moving so slow

you will see the people moving slow as well.

→ ex/: muon μ = mu μon

$\Delta\tau$ = proper time

Δt = dilated time



$\approx 2.2\mu s$

assume : $v = c = 3\times10^8 \frac{m}{s}$

classical mechanics

$d = vt$

$= (3\times10^8 \frac{m}{s})(2.2\times10^{-6} s) = 660m$

Lo = proper length

→ distance measured by an observer at rest WRT both end points.

→ assume : $v = 0.9c$

$$\gamma = \frac{1}{\sqrt{1-0.9^2}} = 2.29$$

outside observer (stationary) will see time dilated by a ratio of 2.29

dilated time
how long does observer on Earth see the μon live?

$$\Delta t = \gamma \underbrace{\Delta \tau}_{\text{lifetime of } \mu\text{on, WRT the } \mu\text{on itself}}$$

$$= (2.29)(2.2 \times 10^{-6} s) = 5 \times 10^{-6} s$$

∴ the travel time of the μon is longer (what the observer see)

↓

events in the reference frame

↓

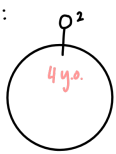
μon aging (life expectancy) longer

the μon still feels the same v & time

$$d = v\Delta t = (0.9)(3 \times 10^{-6}\ m/s)(5 \times 10^{-6} s)$$

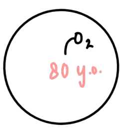
$$= 1350m$$

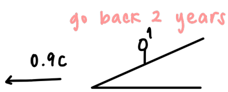
→ ex/:



2 see 1 aging in slow-mo

analysis doesn't work until acceleration is done





1 see 2 very much older

since acceleration is not in the stationary reference frame

[continuation of the analysis]

μon's POV

$\Delta \tau = 2.2 \times 10^{-6} s$ (proper time)

$v = 0.9c$

$L = v\Delta\tau$

$= (0.9)(3 \times 10^{8}\ m/s)(2.2 \times 10^{-6} s)$

$= 594\ m$

∴ μon sees the Earth is compressed, distance it travels get compressed & the person gets shorter

→ they have to agree in v (speed), so

since $v = \frac{\text{distance}}{\text{time}}$, ← needs to change if one change

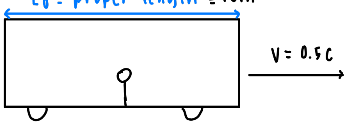
→ the closer you are to the speed of light, then what's gonna happen to you is like the ~~you~~.

→ you see people shorter since they are condensed.

→ people see you go in slow-mo.

[another example ...]

L_0 = proper length = 10m



$$L = (10m)\sqrt{1-(0.5)^2} < 10m$$

the person sees the train squished, shorter

* both people agree on v

$$v = \frac{L_0}{\Delta t} = \frac{L}{\Delta \tau}$$

[recall $\Delta t = \gamma \Delta \tau$]

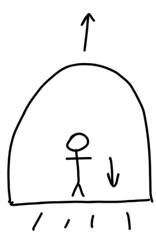
$$\frac{L_0}{\gamma \cancel{\Delta \tau}} = \frac{L}{\cancel{\Delta \tau}}$$

$$L = \frac{L_0}{\gamma}$$ [recall $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$]

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

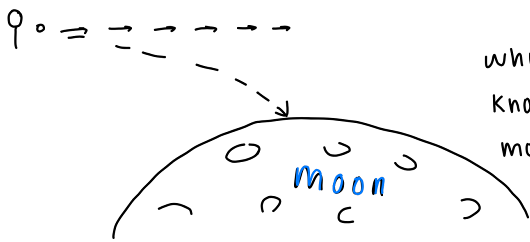
length of the object in moving frame

EQUIVALENCE PRINCIPLE



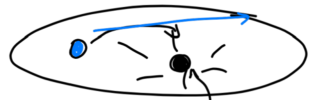
both persons are experiencing the same laws of physics, but the CAUSE is different!

→ acceleration due to gravity is equivalent to acceleration due to motion.



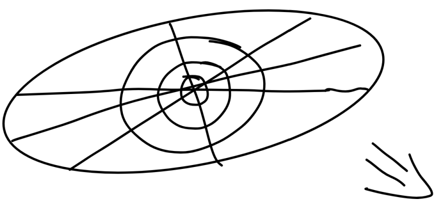
why does the mass know to fall to the moon/gravitational source?

think of trampoline base

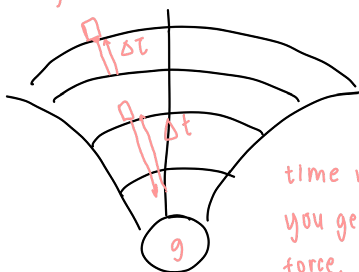


if we put mass

the ball will want to go straight but it is attracted to the dip and continue to go around it



if we put laser



$\Delta t > \Delta \tau$

time is <u>slower</u> when you get to gravitational force.
faster, further away.