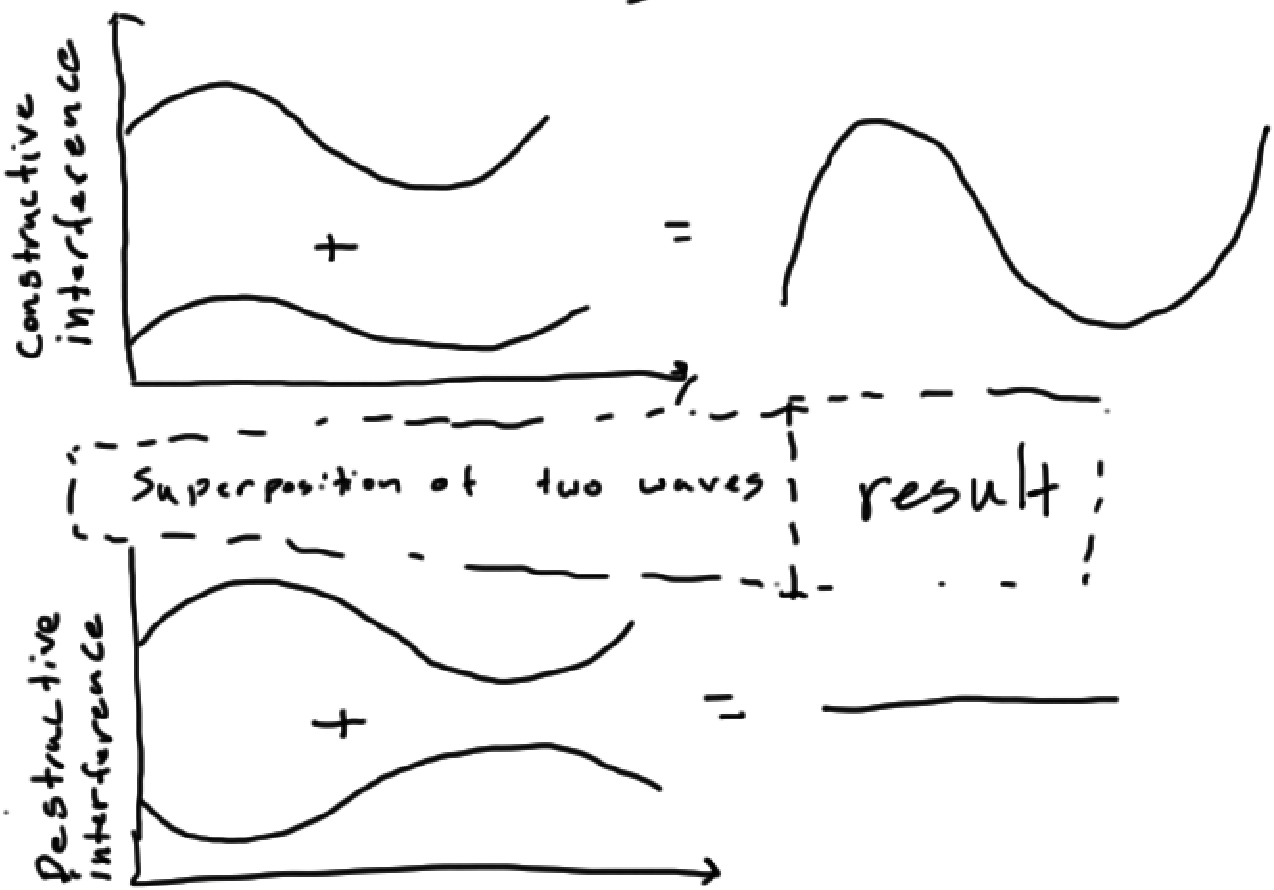
Wave nature of light

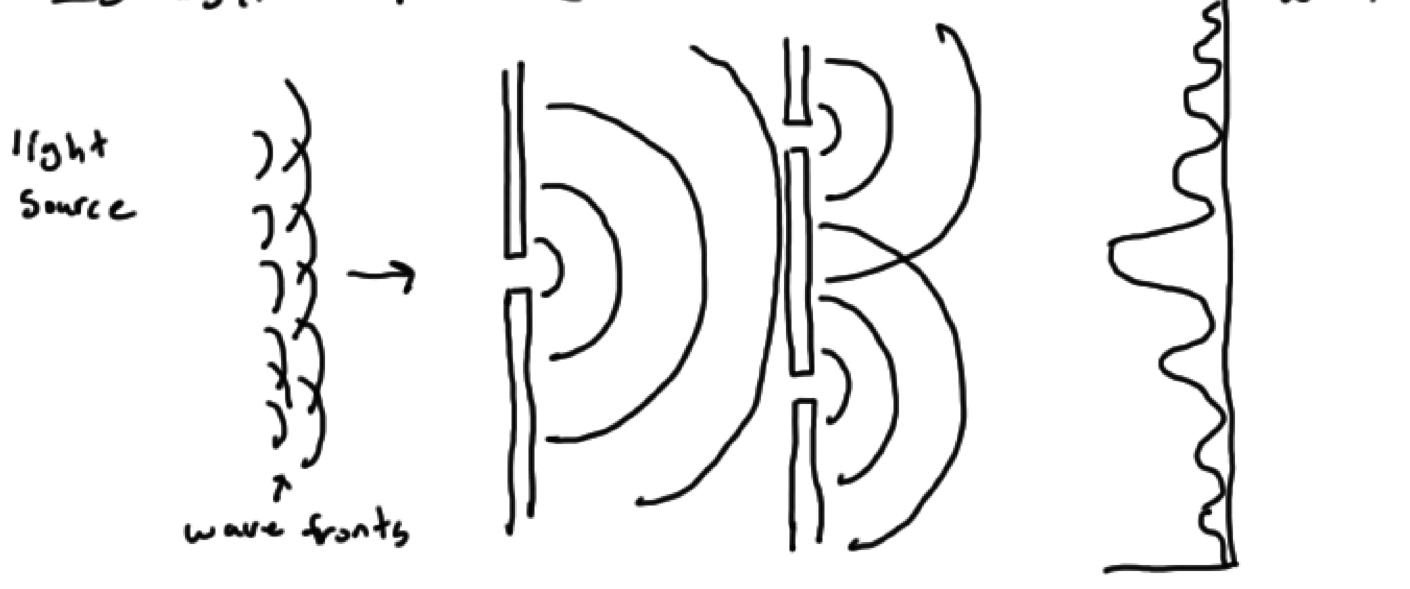
Superposition = adding waves



Simple for Same λ

Young's Double-slit (1801)

Is light a particle or a wave?

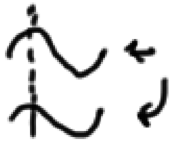


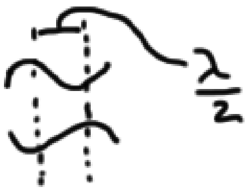
Constructive interference → both waves in phase

Destructive interference → " " out of phase

↑

Can have things between the two as well

 ← this phass $n\lambda$ = 

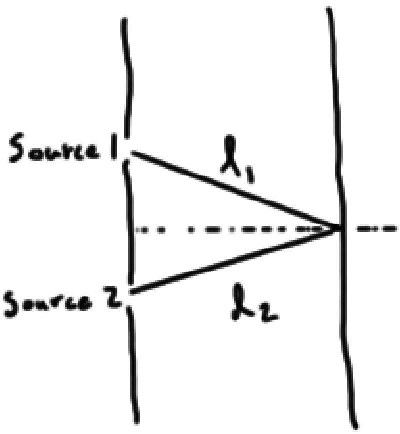


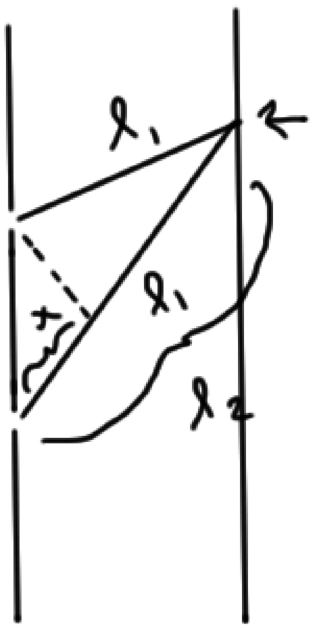
phass $(n+\frac{1}{2})\lambda$ = 

how do wave fronts line up in youngs dbl.-slit?

at center point $l_1 = l_2$

→ constructive





← If this is a bright point $x \approx \lambda$

If its dark

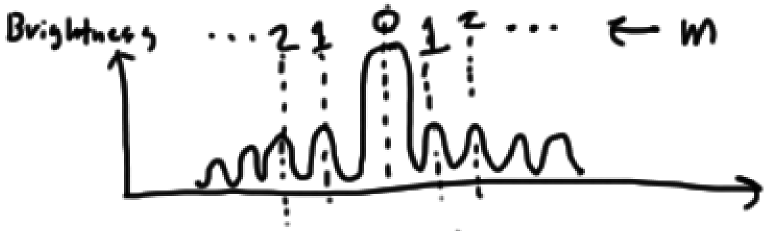
$x \approx \frac{\lambda}{2}$

Bright point

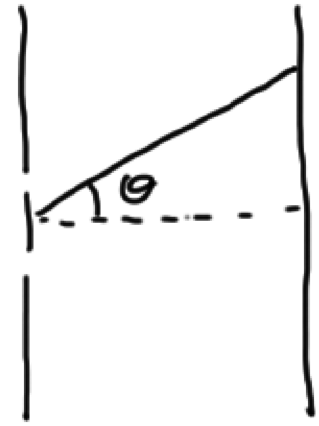
$l_2 \approx l_1 + n\lambda$

Dark point

$l_2 \approx l_1 + (n+\frac{1}{2})\lambda$

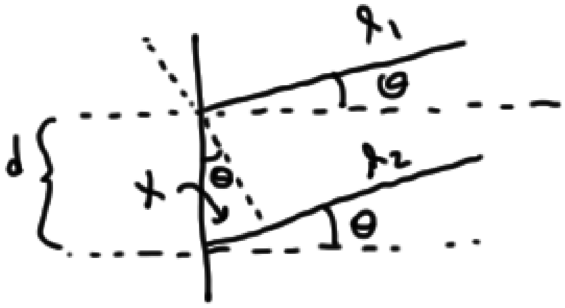


Peaks are all the same distance apart



If the screen is far away

almost parallel



$l_1 = l_2 - x$

$x = d \sin\theta$

Say we are looking for bright place

$x = m\lambda$ so $d\sin\theta = m\lambda$

$\boxed{\sin\theta = m\frac{\lambda}{d}}$ ← the angular position of "bright" is $m\frac{\lambda}{d}$

Jump rigt to dark

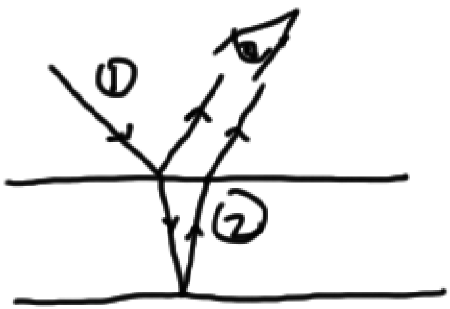
$$\boxed{\sin\theta = \left(m + \frac{1}{2}\right)\frac{\lambda}{d}}$$

In the brigh and dark equations there is a dependence on λ

$\rightarrow$ for different λ the bright and dark places will be different.

<u>Any set of coherent sources will interfere</u>

(Just a conceptual look at) Thin films



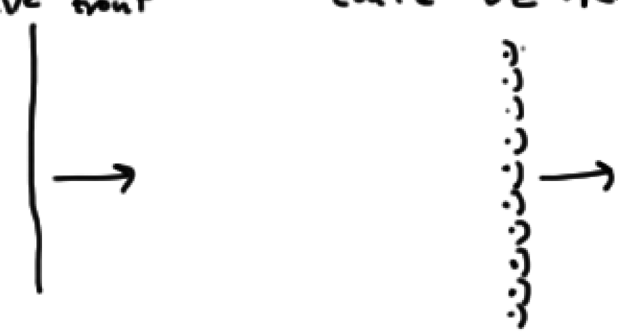
Path 1 has traveld a different distance than path 2.

Depending on the thickness of the film (2nd path length) and the λ the image could be bright or dark.

A soap bubble has many colors because different wavelengths will interfere constructively or destructivly depending on the location of the light source and thikness of the soap at a given point.

Diffraction $\rightarrow$ bending of waves around obsticals.

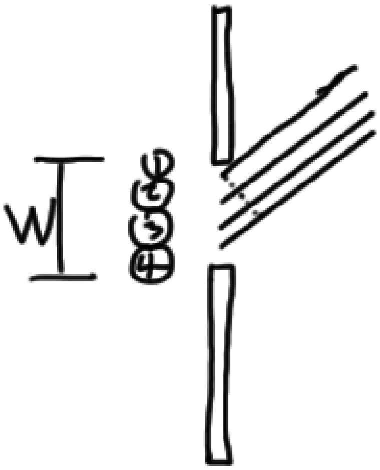
wave front could be viewd as



a bunch of little sources at any given point.

So if we have a Plane wave strike a slit

Do not look like Plane wave.



Produces interference pattern

If 1 & 4 interfere constructively then so do 2 & 3 since the difference between 1 & 4 is the same as the difference between 2 & 3.

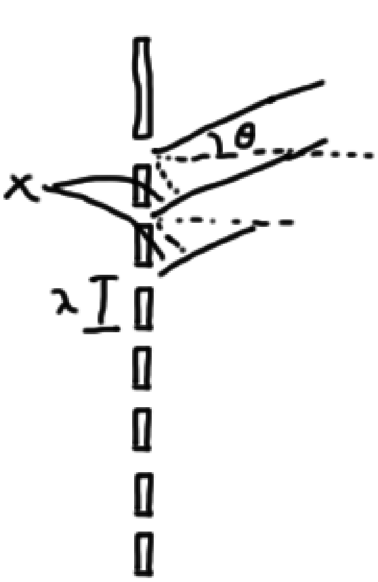
For single slit difraction

Dark $\longrightarrow$ $\sin\theta = m\dfrac{\lambda}{W}$

One last important diffraction example.

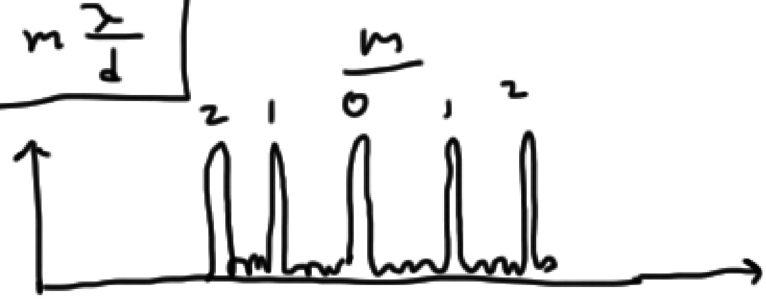
Diffraction grating

similar to single slit. So many slits gives you strong interferece pattern.



$\sin\theta = \dfrac{\lambda}{d}$ ⟵ constructive

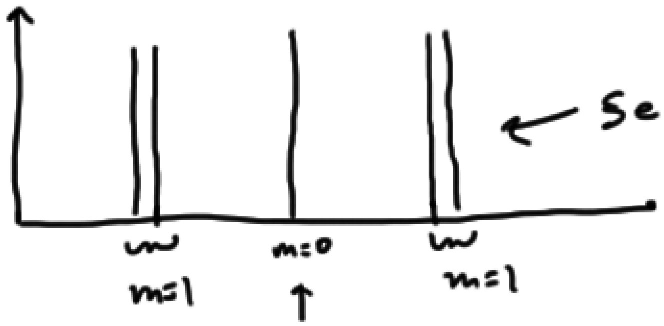
$$\boxed{\sin\theta = m\frac{\lambda}{d}}$$



Diffraction gratings make very narow and sharp peaks.

2 dif. λ on on difraction grating

$\rightarrow$ colors will separate



Seperation depends on $\Delta\lambda$.

both will interfere at m=0

Using this tool we can take some "white" light and determine exactly which mixture of colors are in it.

ex Difraction grating with spacing of

$d = 10^{-6}\,m$

send violet light and red light through

$$\theta_{violet} = \sin^{-1}\left(\frac{\lambda_v}{d}\right) = 24^\circ$$

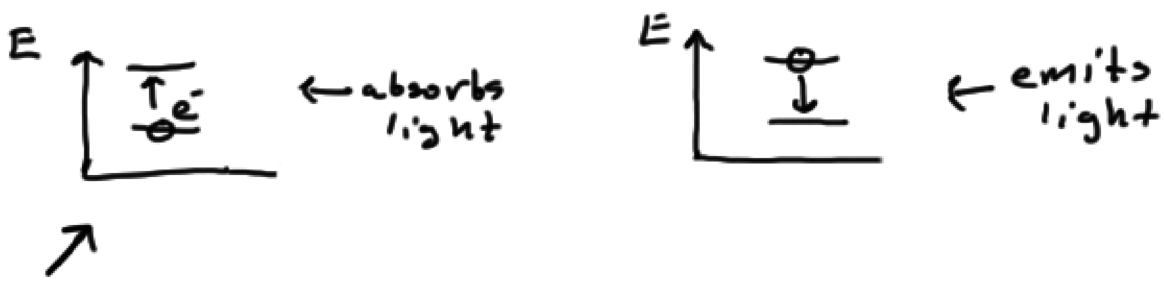
$$\theta_{red} = 41^\circ$$

Atomic spectra

like charge energy levels of an atom are quantized.

light sources will often have specific wavelengths in their spectra which correspond to the nature of the source

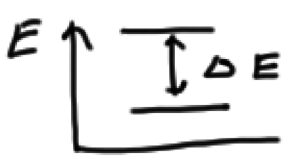
When the electron moves between energy levels it either emits or absorbs light



if the enegy levels are quantized so is the amount of light that can be emitted or absorbed.

One packet of light → Photon

The photons energy is ΔE.



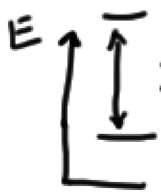
Imagine shaking a rope. It takes more energy to shake it fast.

→ shaking fast → high frequency

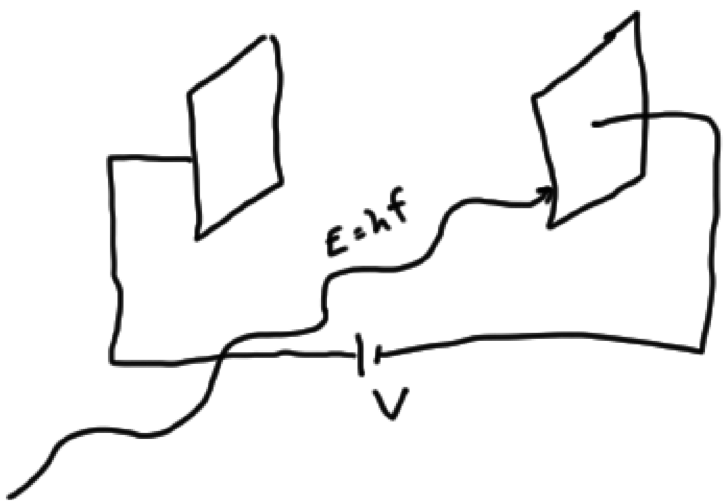
$E_{photon} \propto f$

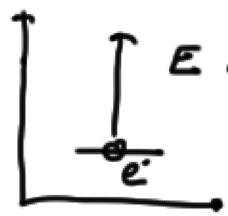
Plack's constant

$\underline{E_{photon} = h f}$



How can we test this idea of quantized light?





E large enough that the electron completely escapes

with light freeing the electrons a current would be measured in the wire.

The least tightly bound electrons will be freed the easiest.

Work function → W_0 → amount of work required to free least tightly bound electrons.

If $E < W_0$ no current is measured.

If $E > W_0$ than the electron picks up some kinetic energy

$$E = hf = KE_e + W_0$$

What is interesting and a little suprising is that if $E < W_0$ than no e are ejected EVEN IF the light is EXTREMLY brigh.

Increasing intensity will increase e^- emitted only if $E > W_0$.

→ will not change KE of e^- emitted.

This contradicts EM wave & classical atom picture. Why wouldnt higher amplitud field rip the e^- off?

→ only f matters.

It is because the classical picture is not complect. We need quantum mechanics to understand

↑

This is also why photo electric effect shows light travels in packets called photons

Einstein 1921 → Nobel Prize.

Special Relativity

Inertial ref. frame → newtons law of inirtia hold.
(not accelerating)

2 people in space traveling at constant velocities are both in inertial ref. frams even if they have non zero velocities with respect to eachother.

Postulates

#1) laws of physics are the same in each inertial ref. frame.

#2) the speed of light is always constant.

#1) Implies absolute velocity does not exsist
→ only realative velocities are meaningfull

Note: acceleration does seem to be absolute though.

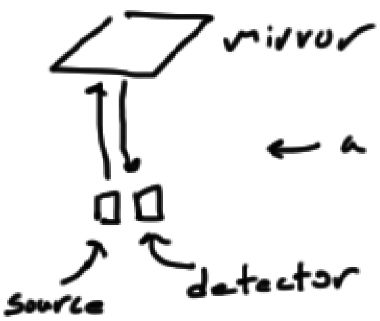
#2) ?? how is this possible??
↓
Time Dialation & length contraction

Usualy

catches ball moving at $V_p + V_b$

DOES NOT FIND SPEED TO BE $c + V_p$

$\boxed{\rightarrow \text{Just } c}$

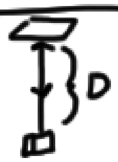


← a special kind of clock

source emits another pulse of light after the detector detects the last one.

Put the clock on a space ship

on the ship



$c \frac{m}{s}$ so $\boxed{\Delta t_{\text{on ship}} = \frac{2D}{c}}$

Lets choose D to be really large so

$\Delta t_s = 1\,s$

on Earth

Person on earth sees light travel a different distance → 2S

Now want Δt_e

$\Delta t_e = \frac{2s}{c}$ express s in terms of things we know.

$s^2 = L^2 + D^2$ $\quad L = (V_{ship})(\Delta t/2)$

$$s^2 = \frac{V_s^2 \Delta t_e^2}{4} + D^2$$

$$\Delta t_e^2 = \frac{4}{c^2}\left(\frac{V_s^2 \Delta t_e^2}{4} + D^2\right) \qquad \Delta t_e^2 - \frac{V_s^2 \Delta t^2}{c^2} = \frac{4D^2}{c^2}$$

$$\Delta t_e^2\left(1 - \frac{V_s^2}{c^2}\right) = \boxed{\frac{4D^2}{c^2}} \rightarrow \text{this is just } \Delta t_s^2$$

$$\Delta t_e^2 = \frac{\Delta t_s^2}{\left(1 - \frac{V_s^2}{c^2}\right)} \qquad \boxed{\Delta t_e = \frac{\Delta t_s}{\sqrt{1 - \frac{V_s^2}{c^2}}}}$$

Since V_s always less than c

$$\frac{V_s^2}{c^2} < 1 \rightarrow 1 - \frac{V_s^2}{c^2} \rightarrow \text{Positive and} < 1$$

$$\boxed{\frac{\Delta t_s}{\text{something} < 1} > \Delta t_s}$$

↑

this means that someone on earth sees time slow down on the ship!

Proper time

time of what? Time it takes for an event to take place.

Proper time is the time interval as measured by a person at rest with respect to the event.

In our last example proper Δt was measured by person on spaceship.

↑
this is important when plugging things into the eqn for time dialation.

The person on ship experiences time normaly

Person on earth sees time slow for person on ship. → this means the person on earth sees the person on the ship experience less time than "usual" over the entire trip.

→ If they both agree on their relative speed to eachothe how is this justified for the person on the ship?

→ Length contraction of traveld distance.

By watching the ship the person on earth measures the distance between earth and the destination to be

$L_0 = V \Delta t$

one of these is known

→ either you time the trip to find L_0 or y know L_0 and know how long the trip will take.

lets say we time the trip

$L_0 = V \underbrace{\Delta t_e}_{\text{known}}$ lets say $V = .95c$

and $\Delta t_e = 4.5$ yrs

so $L_0 = .95c \; 4.5\text{yrs} = 4.3$ light years

but person on ship only feels

$$\Delta t_s = \Delta t_e \sqrt{1 - \frac{V_s^2}{c}} = 4.5\,yr \sqrt{1-(.95)^2}$$

$$\boxed{\Delta t_s = 1.4\,yrs}$$

In order for every one to agree on when he/she shows up the person on ship must have experienced a different length.

we need $1.4\, V_s = L_s$ $1.4(.95c) =$

$$\boxed{L_s = 1.3 \text{ light yr} \quad (1.3 < 4.3 \, !)}$$

This is called length contraction

if $L_o = c\,\Delta t_e$

& $L_s = c\,\Delta t_s = \underbrace{c\,\Delta t_e}_{L_o}\sqrt{1-\frac{v^2}{c^2}}$

then $\boxed{L_s = L_o\sqrt{1-\frac{v^2}{c^2}}}$

this applies to things other than the length traveled by the ship.

ex

what about the ship itself?

Say the ship is 100m long to begin with.

As viewed from earth it is:

$$L = 100\text{m}\sqrt{1-(.95)^2} = \boxed{31.2\text{ m}}$$

Remember proper time

time it takes an event to occure in a frame that is at rest with respect to the event.

Proper length

(inertial)

length of object measured in a ref. frame that is at rest with respect to the object.

Postulate 1 says laws of Physics are the same in all inertial ref frames

→ Lets look at consevation of momentum

$\bar{P} = m\bar{V} \rightarrow P = mV$

↑

this is not conserved for observers moving at a reasonable fraction of the speed of light.

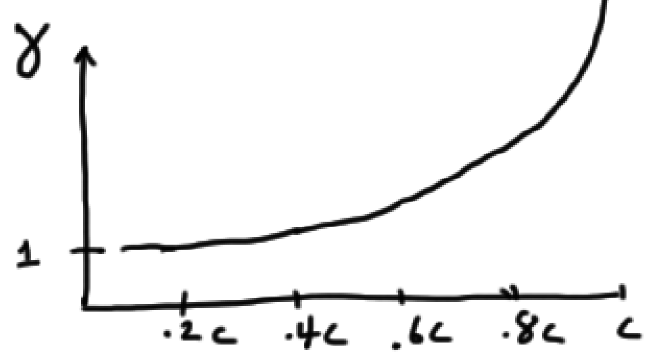
So far we have seen that ideas of space (L) and time (Δt) are those we already knew but modified by a factor of $\sqrt{1-\frac{v^2}{c}}$

$$\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \gamma$$ ← known as the lorentz factor

Indeed we just take

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

this means that for large v the momentum is LARGER than what we would have thought.



Another striking feature of relativity is

$$E_{\text{nergy}} = \frac{mc}{\sqrt{1 - V^2/c^2}} = mc\gamma$$

lets take $V = 0$

$$\boxed{E = mc^2}$$ ← rest energy of an object.

!?!?

This means 1 kg of mass has...

$$E = 1\,\text{kg} \times (3 \times 10^8)^2$$

$$E = 9 \times 10^{16} \approx 10^{17}\ \text{J}$$

100,000,000,000,000,000 J

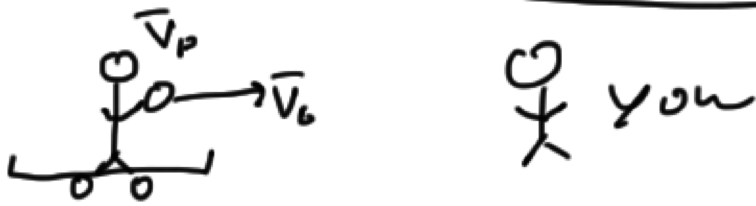
a gun shot $\approx$ 1,000 J

The rest energy is huge! depends on c^2 which is a big number.

golf ball could power a light bulb for 1.7 million years!

Unfair to say this without at least hinting at the way one could actualy harness this energy → say some words on antimatter in class
→ nothing on exam about antimatter.

Relativistic addition of velocities



Lets be careful

$V_{PG} \rightarrow$ vel. of person with respect to ground.

$V_{bG} \rightarrow$ vel. of ball " "

$V_{bp} \rightarrow$ vel. of ball " " person"

If you catch the ball
you would think you would measure

$$V_{measure} = V_{bg} = V_{bp} + V_{pG}$$

but if measured very carefully or if the velocities in the problem are a reasonable fraction of c

then $V_{bg} = V_{bp} + V_{pG} \Rightarrow$ not quit right.

turns out

$$\boxed{V_{bg} = \frac{V_{bp} + V_{pg}}{1 + \frac{V_{bp} V_{pg}}{c^2}}}$$

Consider groud as just another observer that can have any velocity

Just replace

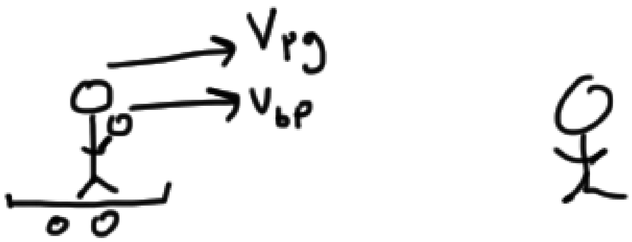
$b \rightarrow$ object A

$p \rightarrow$ object B

$g \rightarrow$ object C

$V_{ij} \rightarrow$ relative V between object i & j

ex



your V relative to the ground is 0.

Lets say $V_{pg} = \frac{1}{2}c$

& $V_{bp} = \frac{3}{4}c$

NO

Old way:

$$V_{bg} = \frac{1}{2}c + \frac{3}{4}c = \frac{5}{4}c$$

greater than c!

New way

$$V_{bg} = \frac{\frac{1}{2}c + \frac{3}{4}c}{1 + \underbrace{\frac{\frac{1}{2}c\,\frac{3}{4}c}{c^2}}_{c\text{'s cancel}}}$$

$$V_{bg} = \frac{\frac{5}{4}c}{1 + \frac{3}{8}} = \frac{5}{4}\,\frac{1}{\left(\frac{8}{8} + \frac{3}{8}\right)}\,c$$

$$= c\,\frac{5}{4}\left(\frac{8}{11}\right) = \boxed{\frac{10}{11}c}$$

smaller than c