



Physics 2D Lecture Slides Lecture 4: Jan 7 2005

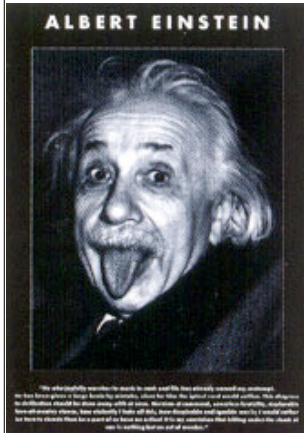
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Announcements



- Pl. review material from 2A, 2B, 2C. Read chapters from your past course text ***Physics for Engineers and Scientists (3rd edition)*** by Wolfson and Pasachoff
 - 16 : Waves
 - 34 : Maxwell's Eqn and Electromagnetic Waves
 - 37: Interference and Diffraction
- Take advantage of Physics Tutorial Center for unlimited drop-in tutoring, see <http://physics.ucsd.edu/students/courses/tutorialcenter/>

Einstein's Special Theory of Relativity



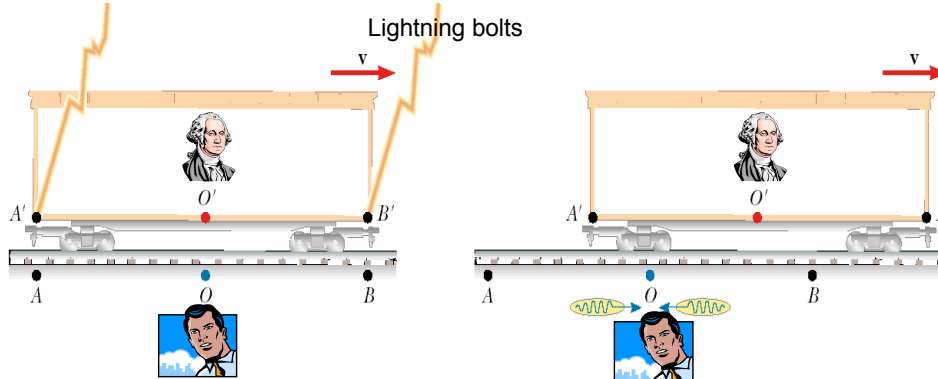
Einstein's Postulates

The laws of physics must be the same in all inertial reference frames

The speed of light in vacuum has the same value $c = 3.0 \times 10^8 \text{ m/s}$, in all inertial frames, regardless of the velocity of the observer or the velocity of the source emitting the light

Consequences of Special Relativity: Simultaneity not Absolute

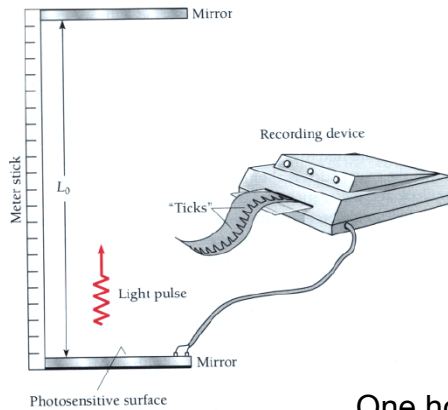
Simultaneity: When two events occur at **same time**, held absolute for Classical Phys



Events that are simultaneous for one Observer are **not simultaneous** for another Observer in relative motion
Simultaneity is not absolute !!

Time interval depends on the Reference frame it is measured in

A Simple Clock Measuring a Time Interval

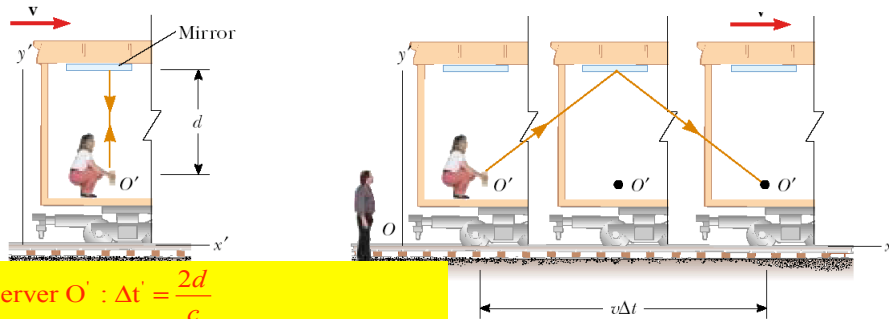


$$t = \int \Delta t$$

One hour = 60 x 1 minute time intervals

Time Dilation and Proper Time

Watching a time interval (between 2 events) with a simple clock



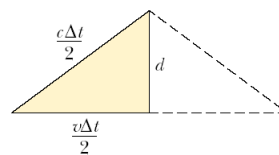
Observer O' : $\Delta t' = \frac{2d}{c}$

Observer O : Apply Pythagoras Theorem

$$\left(\frac{c\Delta t}{2}\right)^2 = (d)^2 + \left(\frac{v\Delta t}{2}\right)^2, \text{ but } d = \left(\frac{c\Delta t'}{2}\right)$$

$$\therefore c^2 (\Delta t)^2 = c^2 (\Delta t')^2 + v^2 (\Delta t)^2$$

$$\therefore \Delta t = \frac{\Delta t'}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} = \gamma \Delta t', \Delta t > \Delta t'$$

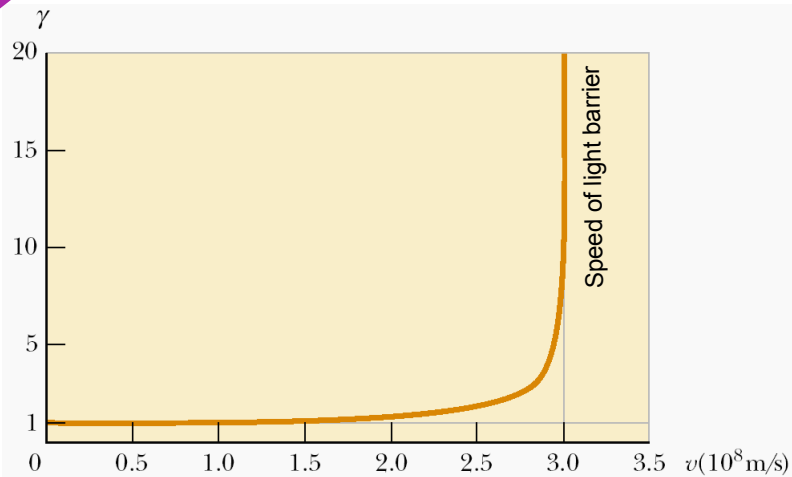


The γ factor

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

as $v \rightarrow 0$, $\gamma \rightarrow 1$

as $v \rightarrow c$, $\gamma \rightarrow \infty$



Pop Quiz !



- What happens when I reverse the clocks being watched ?
 - Sally now watches Sam's clock
 - Sally is moving w.r.t. Sam's clock. Sam is at rest w.r.t the clock.
 - What does she make of time intervals as measured by his clock ?

Measuring Time: Period of a Pendulum

- Period of a pendulum is 3.0 s in the **rest frame** of the pendulum
- What is period of the pendulum as seen by an **observer moving at $v=0.95c$**

Answer:

- Proper time $T' = 3.0s$
- Since motion is relative and time dilation does not distinguish between
 - relative motion $\rightarrow \rightarrow (V)$ from relative motion $\leftarrow \leftarrow (-V)$
- lets reformulate the problem like this (??)
 - A pendulum in a rocket is flying with velocity $V = 0.95c$ past a stationary observer
 - Moving clocks runs slower [w.r.t clock in observer's hand (rest)] by factor γ
 - \rightarrow Period T measured by observer = $\gamma T'$

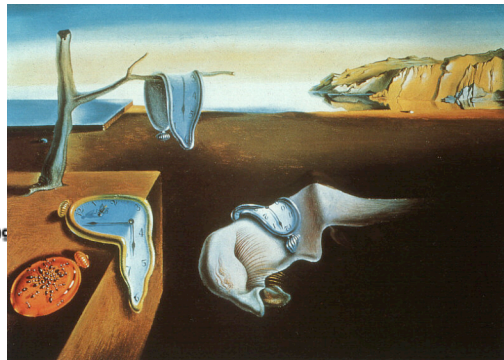
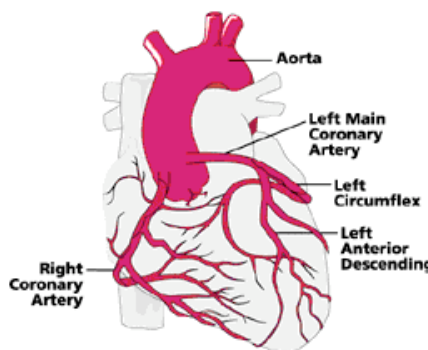
$$\gamma = \frac{1}{\sqrt{1-(v/c)^2}} = \frac{1}{\sqrt{1-(0.95)^2}} = 3.2$$

$$\Rightarrow T = \gamma T' = 3.2 \times 3.0s = 9.6s$$

Moving pendulum slows down \rightarrow takes longer to complete a period

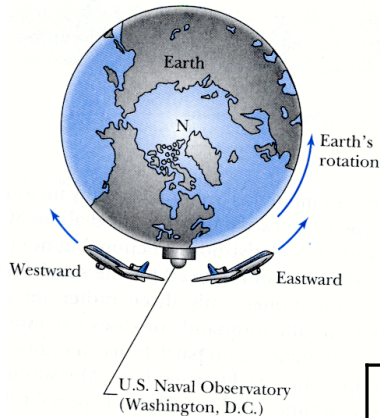
All Measures of Time Slow down from a Moving Observer's Perspective !

- Your heartbeat or your pulse



- Mitosis and Biological growth
- Growth of an inorganic crystal
- ‘...Watching the river flow’
- ...all measures of time interval

Round The World With An Atomic Clock !

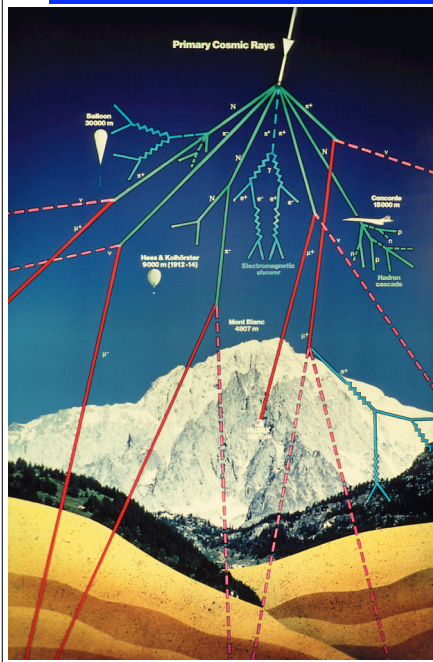


- Atomic Clock : measure time interval for certain atomic level transitions in Cesium atom
- Two planes take off from DC, travel east and west with the atomic clock
 - Eastward trip took 41.2 hrs
 - Westward trip took 48.6
- Atomic clocks compared to similar ones kept in DC
- Need to account for Earth's rotation + GR etc

Travel	Predicted	Measured
Eastward	-40 ± 23 ns	-59 ± 10 ns
Westward	275 ± 21 ns	273 ± 7 ns

Flying clock ticked faster or slower than reference clock. Slow or fast is due to Earth's rotation

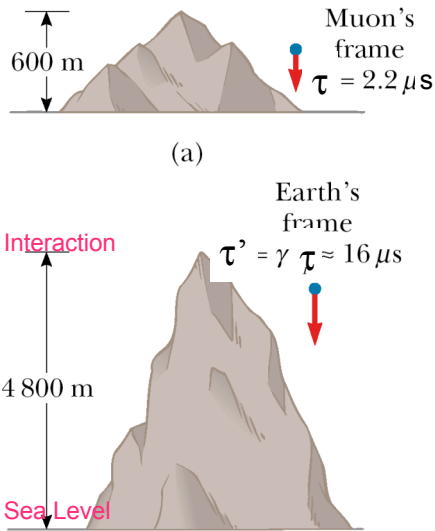
Cosmic Rain !



- Cosmic "rays" are messengers from space
- Produced in violent collisions in the cosmos
- Typical Kinetic energy ~ 100 GeV
- Smash into Earth's outer atmosphere
 - 4700 m from sea level
- Sometimes produce short lived Muons (μ)
- Muon is electron like charged particle
 - ~ 200 times heavier , same charge
 - Lifetime $\tau = 2.2\mu\text{s} = 2.2 \times 10^{-6}$ s
 - Produced with speed $v \approx c$
 - Distance traveled in its lifetime

$$d = c\tau = 650\text{m}$$
 - Yet they seem to reach the surface!!
 - Why => Time Dilation
 - Must pay attention to frames of references involved

Cosmic Rays Are Falling On Earth : Example of Time Dilation



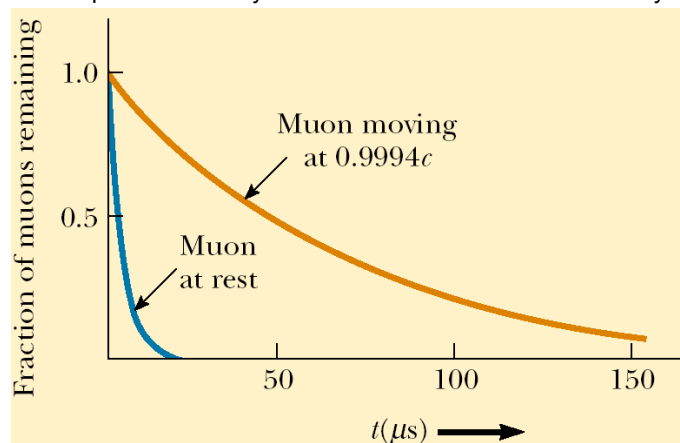
- Consider Two frames of references
 1. You Riding on the Muon Particle
 2. Your twin watching On surface of earth
- Muon Rider has “Proper Time”
 - Time measured by observer moving along with clock
 - $\Delta t' = \tau = 2.2 \mu\text{s}$
 - $D' = v \Delta t' = 650\text{m}$
- Earthling watches a moving clock (muon's) run slower
 - $\Delta t = \gamma \tau$
 - $v = 0.99c, \Rightarrow \gamma = 7.1$
 - $D = v \Delta t = 4700\text{m}$

Muon Decay Distance Distribution

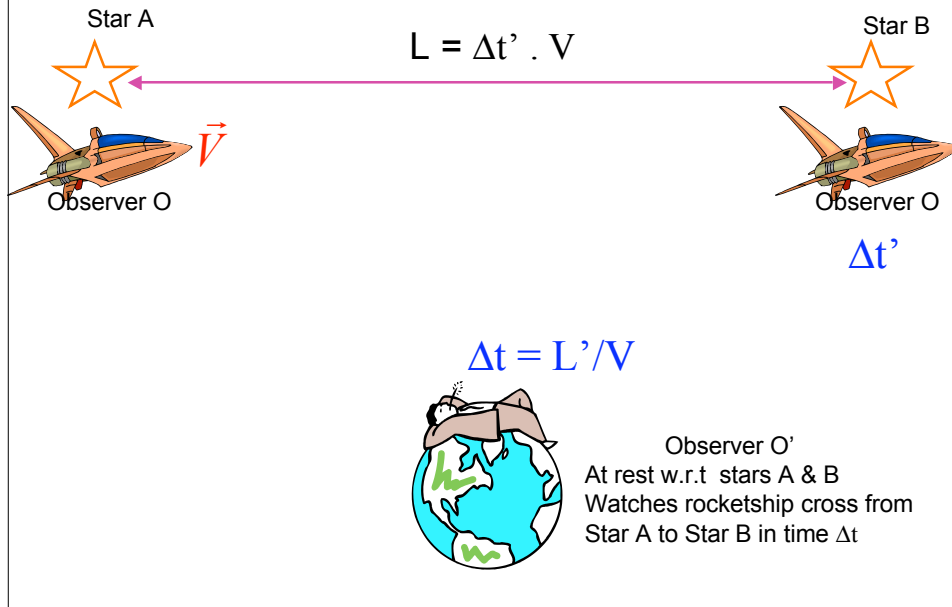
Relative to Observer on Earth Muons have a lifetime

$$t = \gamma \tau = 7.1 \tau$$

Exponential Decay time Distribution : As in Radioactivity



Offsetting Penalty : Length Contraction



Rocketman Vs The Earthling

- Earth Observer saw rocketman take time $\Delta t = (L' / V)$
- Rocketman says he is at rest, Star B moving towards him with speed V from right passed him by in time $\Delta t'$, so

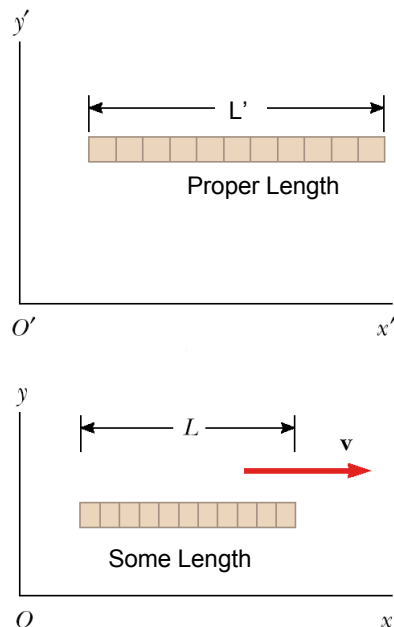
- $L = \Delta t' \cdot V$
- But $\Delta t' = \Delta t / \gamma$ (time dilation)
- $\Rightarrow L = V \cdot (\Delta t / \gamma)$

$= L' / \gamma$

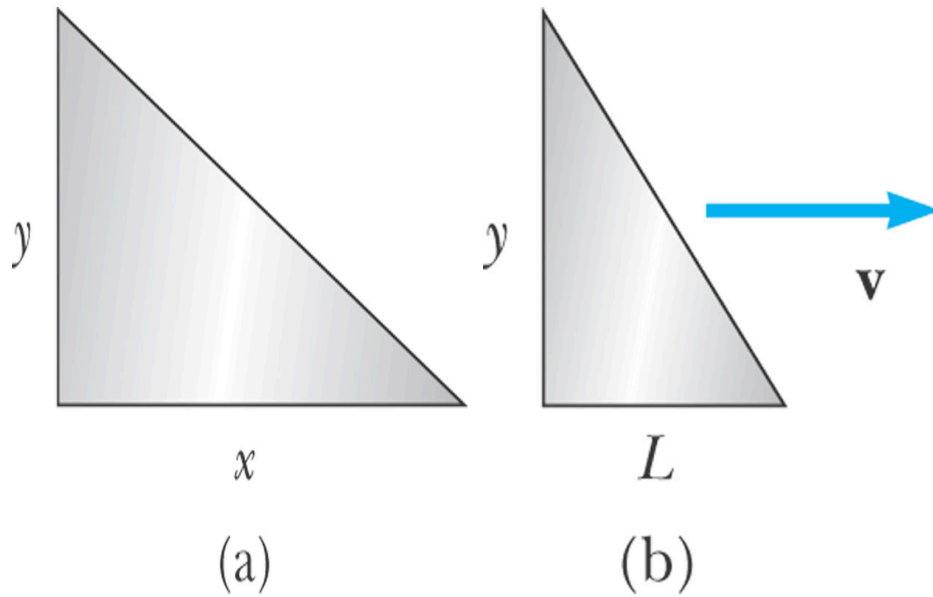
$$L = L' \cdot \sqrt{1 - \frac{V^2}{c^2}}$$

$$L \leq L'$$

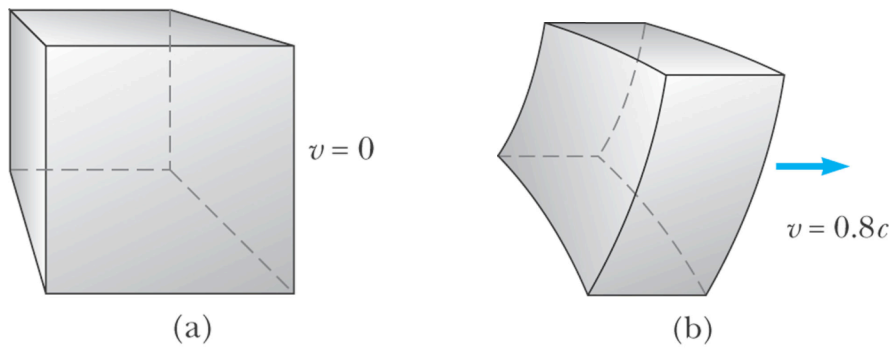
Moving Rods Contract in direction Of relative motion



Perspectives Change Along Direction of Motion



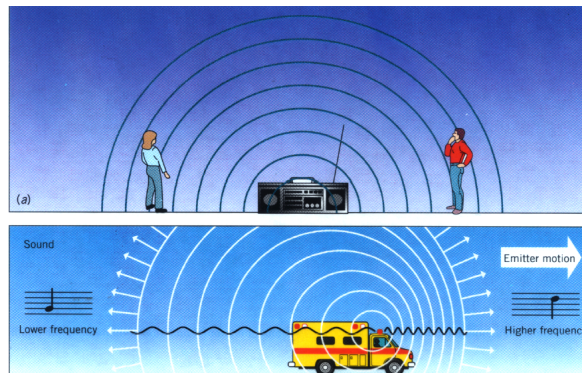
Perspectives Change



Immediate Consequences of Einstein's Postulates: Recap

- Events that are simultaneous for one Observer are **not simultaneous** for another Observer in relative motion
- **Time Dilation** : Clocks in motion relative to an Observer appear to slow down by factor γ
- **Length Contraction** : Lengths of Objects in motion appear to be contracted in the direction of motion by factor γ^{-1}
- **New Definitions** :
 - Proper Time (who measures this ?)
 - Proper Length (who measures this ?)
 - Different clocks for different folks !

Doppler Effect In Sound : Reminder from 2A

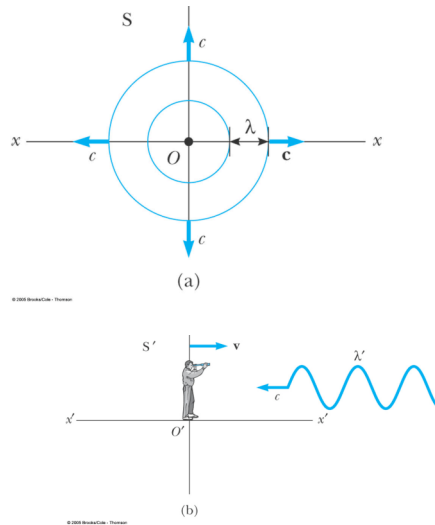


Observed **Frequency** of sound **INCREASES** if emitter moves towards the Observer
Observed **Wavelength** of sound **DECREASES** if emitter moves towards the Observer

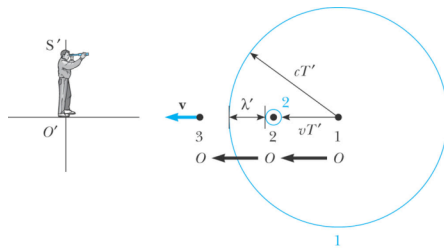
$$v = f \lambda$$

Time Dilation Example: Relativistic Doppler Shift

- Light : velocity $c = f \lambda, f=1/T$
- A source of light S at rest
- Observer S' approaches S with velocity v
- S' measures f' or λ' , $c = f' \lambda'$
- Expect $f' > f$ since more wave crests are being crossed by Observer S' due to its approach direction than if it were at rest w.r.t source S



Relativistic Doppler Shift



Examine two successive wavefronts emitted by S at location 1 and 2

In S' frame, T' = time between two wavefronts

In time T' , the Source moves by cT' w.r.t 1

Meanwhile Light Source moves a distance vT'

Distance between successive wavefront
 $\lambda' = cT' - vT'$

$\lambda' = cT' - vT'$, now use $f = c / \lambda$

$$\Rightarrow f' = \frac{c}{(c-v)T'}, T' = \frac{T}{\sqrt{1 - (v/c)^2}}$$

Substituting for T' , use $f = 1/T$

$$\Rightarrow f' = \frac{\sqrt{1 - (v/c)^2}}{1 - (v/c)}$$

$$\Rightarrow f' = \frac{\sqrt{1 + (v/c)}}{\sqrt{1 - (v/c)}} f$$

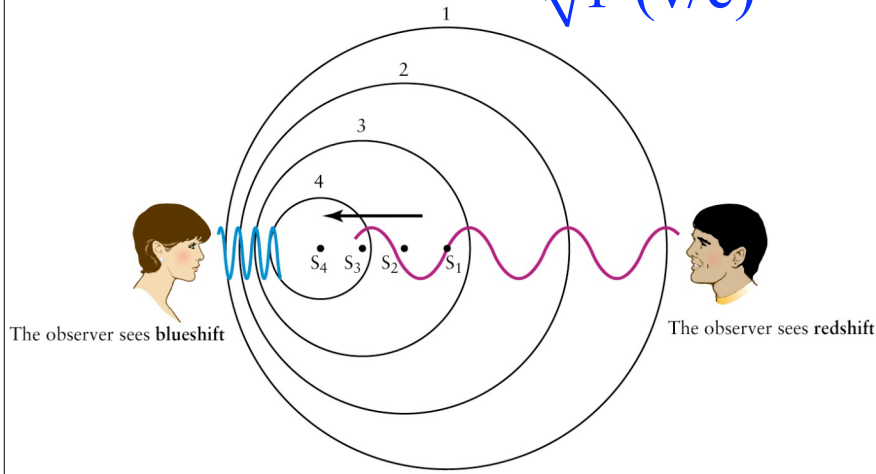
better remembered as:

$$f_{\text{obs}} = \frac{\sqrt{1 + (v/c)}}{\sqrt{1 - (v/c)}} f_{\text{source}}$$

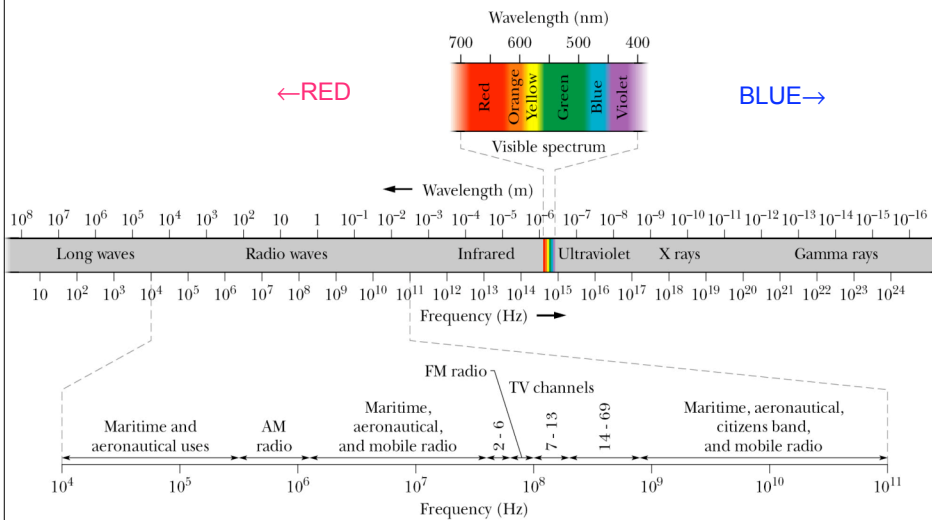
f_{obs} = Freq measured by
 observer approaching
 light source

Relativistic Doppler Shift

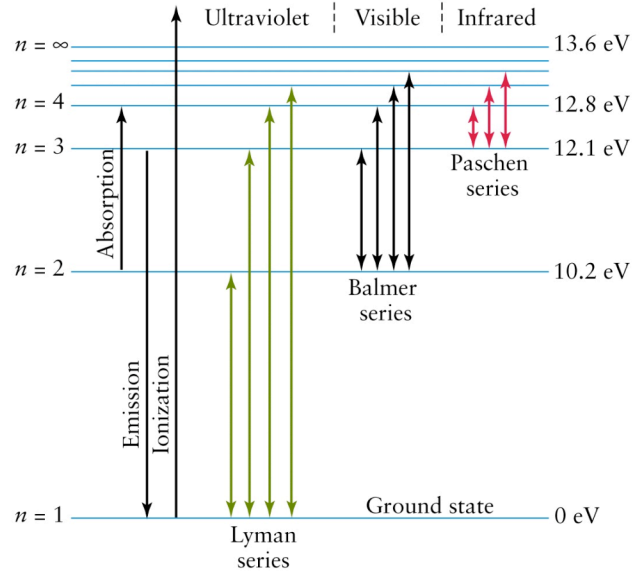
$$f_{\text{obs}} = \frac{\sqrt{1+(v/c)}}{\sqrt{1-(v/c)}} f_{\text{source}}$$



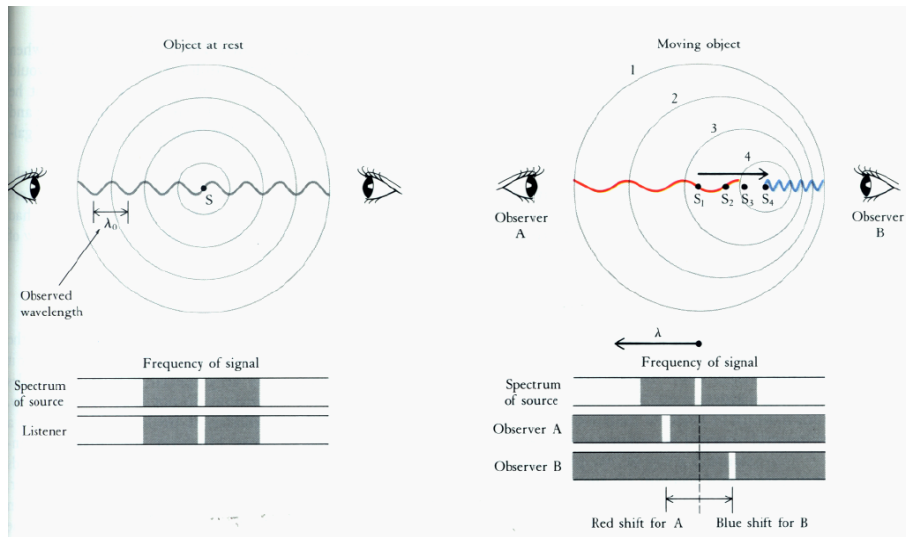
Doppler Shift & Electromagnetic Spectrum



Fingerprint of Elements: Emission & Absorption Spectra

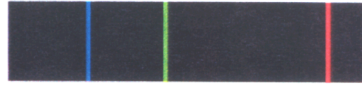


Spectral Lines and Perception of Moving Objects



Doppler Shift in Spectral Lines and Motion of Stellar Objects

Laboratory Spectrum, lines at rest wavelengths



Lines **Redshifted**, Object moving away from me



Larger **Redshift**, object moving away even faster



Lines **blueshifted**, Object moving towards me

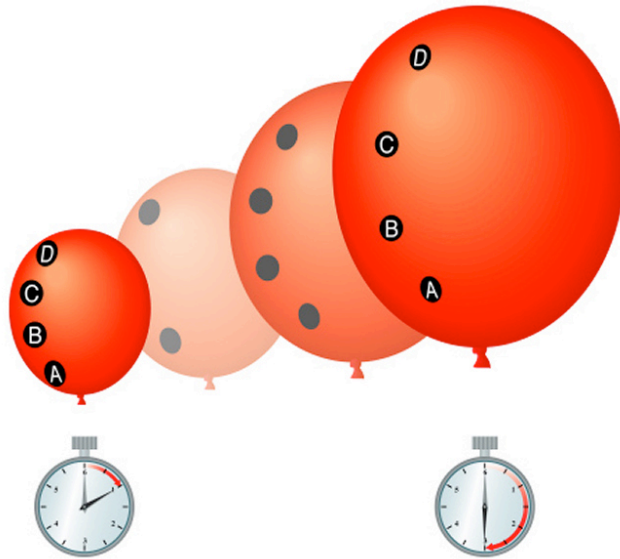


Larger **blueshift**, object approaching me faster



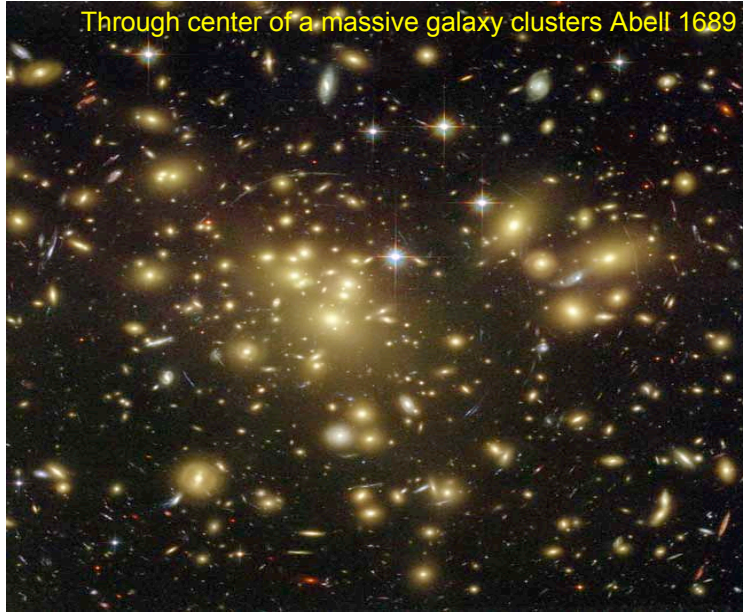
λ →

Cosmological Redshift & Discovery of the Expanding Universe:
[Space itself is Expanding]



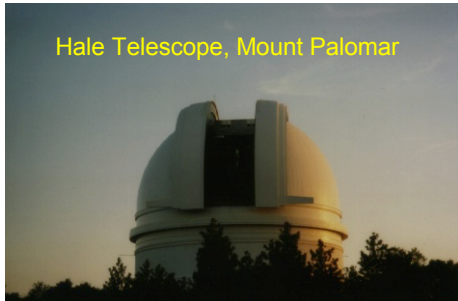
Seeing Distant Galaxies Thru Hubble Telescope

Through center of a massive galaxy clusters Abell 1689



Expanding Universe, Edwin Hubble & Mount Palomar

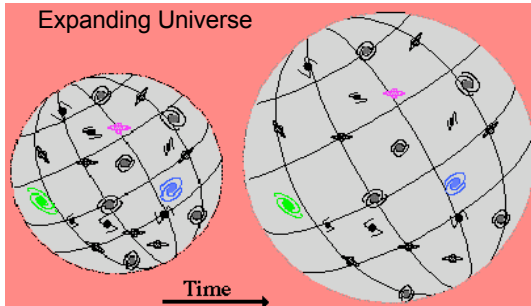
Hale Telescope, Mount Palomar



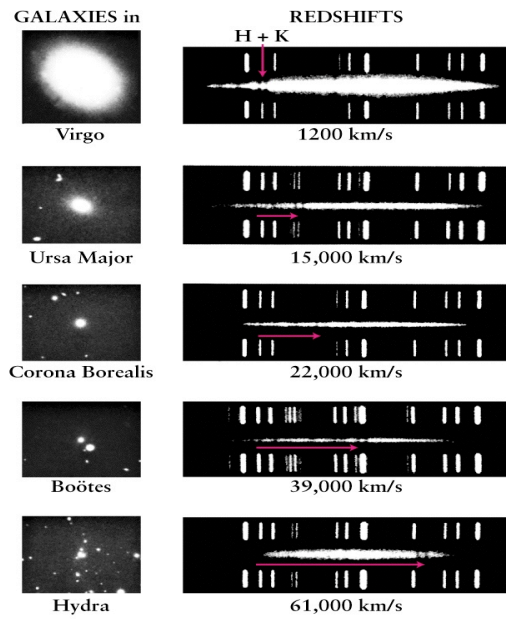
Edwin Hubble 1920



Expanding Universe



Galaxies at different locations in our Universe travel at different velocities



Hubble's Measurement of Recessional Velocity of Galaxies

$V = H d$: Farther things are, faster they go

