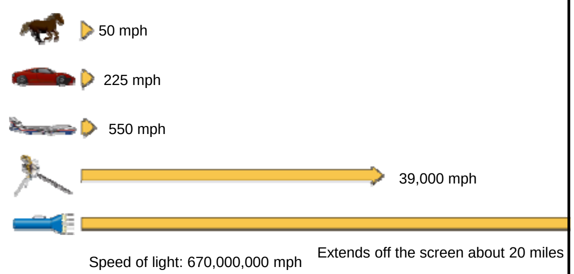
Chapter 7
Motion at High Speed

Did you read chapter 7 before coming to class?

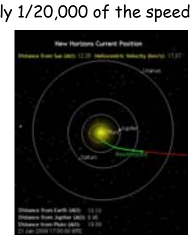
A. Yes
B. No

How fast is "high speed"



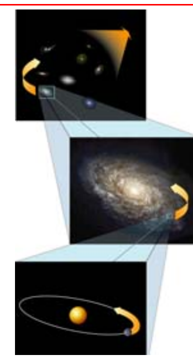
New horizons mission

- Fastest man made object ever at 39,000 mph (largely from a slingshot from Jupiter's gravity)
- Will cover the 3 billion miles to Pluto in just 10 years.
- Still only 1/20,000 of the speed of light



All Motion is relative

- We must define a reference frame in which to measure the motion.
- The idea that all motion is determined relative to its reference frame is called "relativity"
- These ideas have nothing to do with "moral relativity." In fact, Einstein wanted to call the theory the theory of invariance, since it sets up a description of physical systems that is equally valid in all frames of reference.



There are two types of reference frames

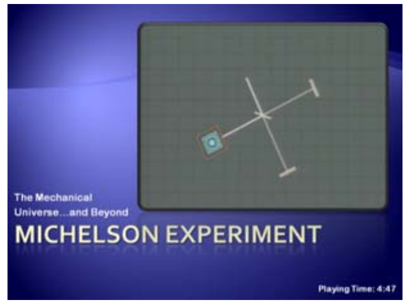
- Inertial reference frames do not accelerate
- Non-inertial reference frames accelerate.
- Could you tell the difference between two inertial frames?
- Could you tell the difference between an inertial frame and a non-inertial frame

When viewed from an inertial reference frame, the motion of another inertial frame is

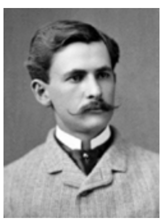
a) Motion in a straight line
b) Motion in a straight line with unchanging speed
c) Motion in a straight line with changing speed
d) Motion in a circle with unchanging speed

Galilean Relativity

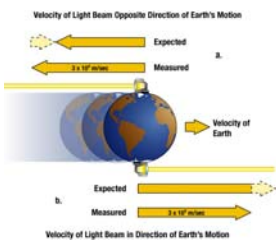
How about light—does it obey Galilean relativity?



Results of the Michelson/Morley experiment.



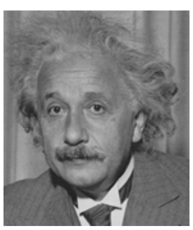
Albert Michelson



Conclusion: Light does not obey Galilean relativity!

Relativity and the Speed of Light

Special Relativity Postulates



1. The laws of nature are the same for all observers who are in uniform motion.
2. The speed of light in empty space is the same for all observers regardless of their motion or the motion of the source of light.

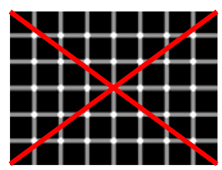
- "Everything should be made as simple as possible, but not simpler." ~Albert Einstein

A word of caution

We will use phrases like

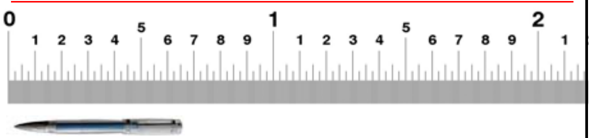
- The observer sees
- It appears to him
- It looks like

These **do not** refer to optical illusions, but to what an observer would measure with scientific instruments (rulers and clocks)



Count the number of black dots

Example: How to measure a pen

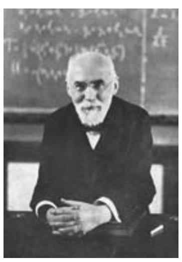


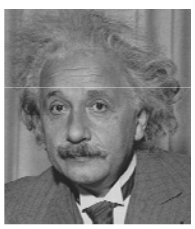
- At rest
- In a moving frame
  - Make marks on a ruler at the same time as the pen flies by
  - If the mark at the front is made before the mark at the back, the pen is measured to be shorter than it "actually is".
- Time and space are connected!

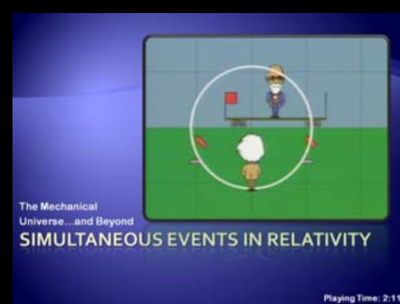
Simultaneous events

- Two events are said to be simultaneous if light from the events reaches an observer located half way between the events at the same time.

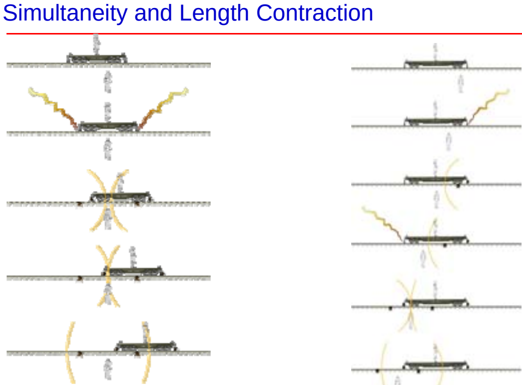
Hendrik Lorentz and Albert Einstein, the stars of relativity







Simultaneity and Length Contraction



Length Contraction

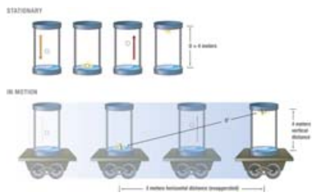
- Length measurements of moving objects require simultaneous measurement of positions
- An observer moving with respect to the thing to be measured will always measure the front first. (According to the observer who is moving with the ruler)
- Moving object are measured to be shorter than when they are at rest ("length contraction")

Light Clock

- Each tick marks a unit of time

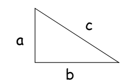
  speed of light = distance / time

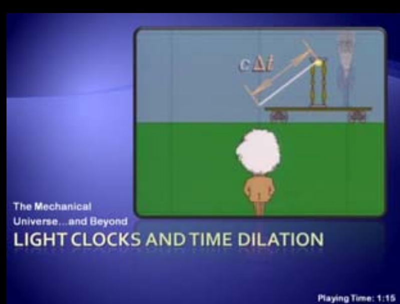
  time = distance / speed of light
- A moving clock runs slow.
  - Traveling a longer distance at the same speed takes more time.



Explanation of light clock video

- c is the speed of light
- v is the speed of the moving frame
- Δt is a time interval in the "at rest" frame
- $\Delta t'$ is a time interval in the moving frame
- distance = rate x time
- Pythagoras Theorem: $a^2 + b^2 = c^2$

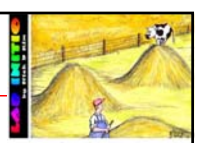




On to reality…

- Mu Mesons
- Hafele / Keating
- GPS satellites

Muon Decay

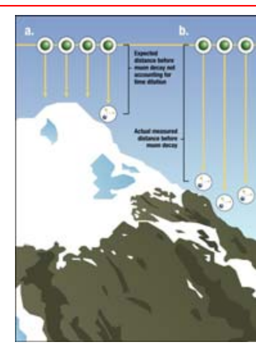

Discovery of the Muon.

- Cosmic ray muons created in upper atmosphere
- These muons travel close to the speed of light
- Muons live such a short time, they can't travel very far
  - With an average lifetime of 2×10^{-6} sec, they should only travel ~600 meters at the speed
- So how doe they get from the top to the bottom of a tall mountain?

video

Muon Decay

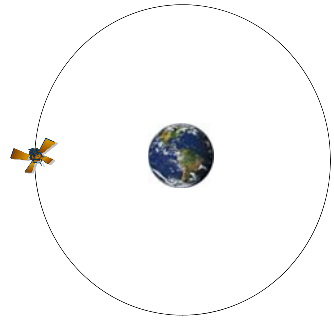
- In our frame, the muon's time slows down, so they live longer.
- In the muon's frame, the mountain is only a few feet tall.



Hafele - Keating

- Atomic clocks sent on trips come back running slow.

GPS systems rely on very precise clocks in orbit around the earth. These are moving clocks!



The "twin paradox"