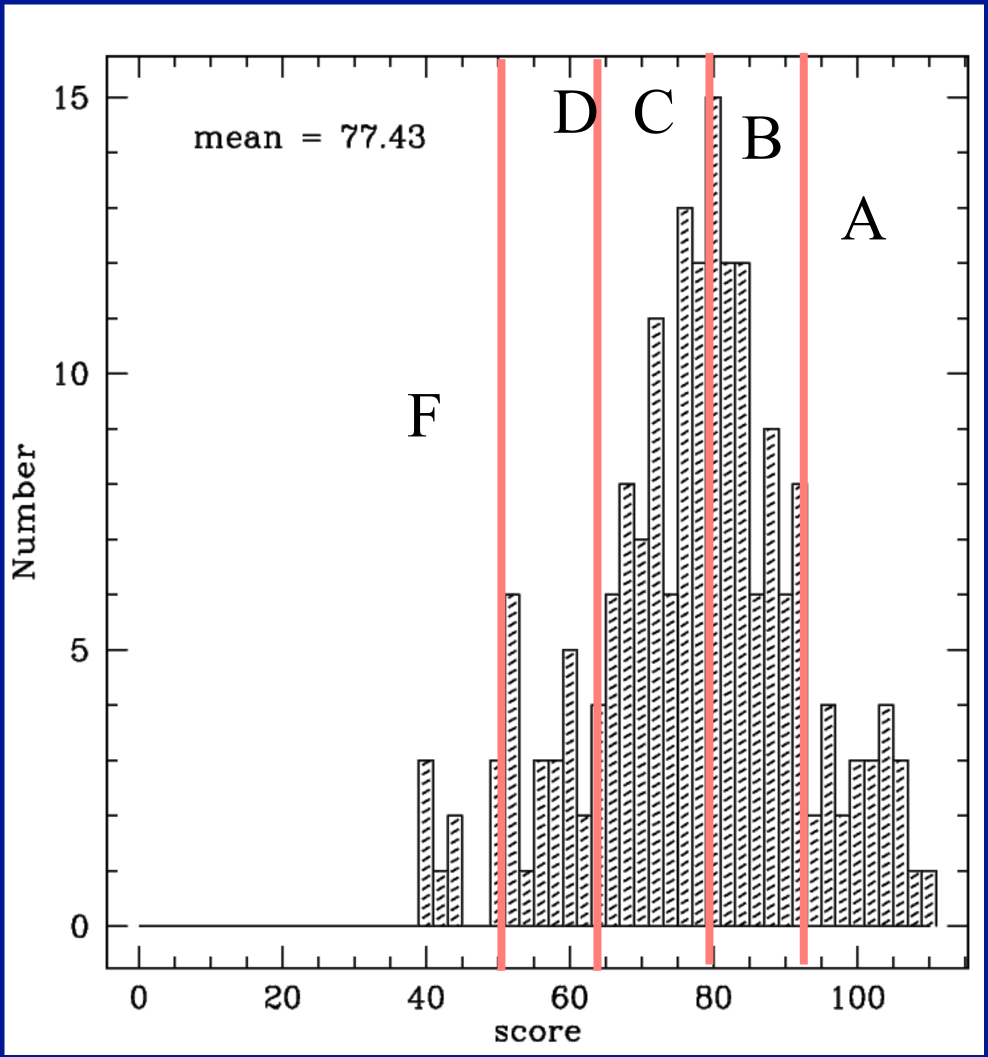
Test 3 results

Grades posted in Learn

End of the Semester approaches - make sure that your test, clicker and homework grades are what you think they should be on Learn



Clicker Question:

What is a planetary nebula?

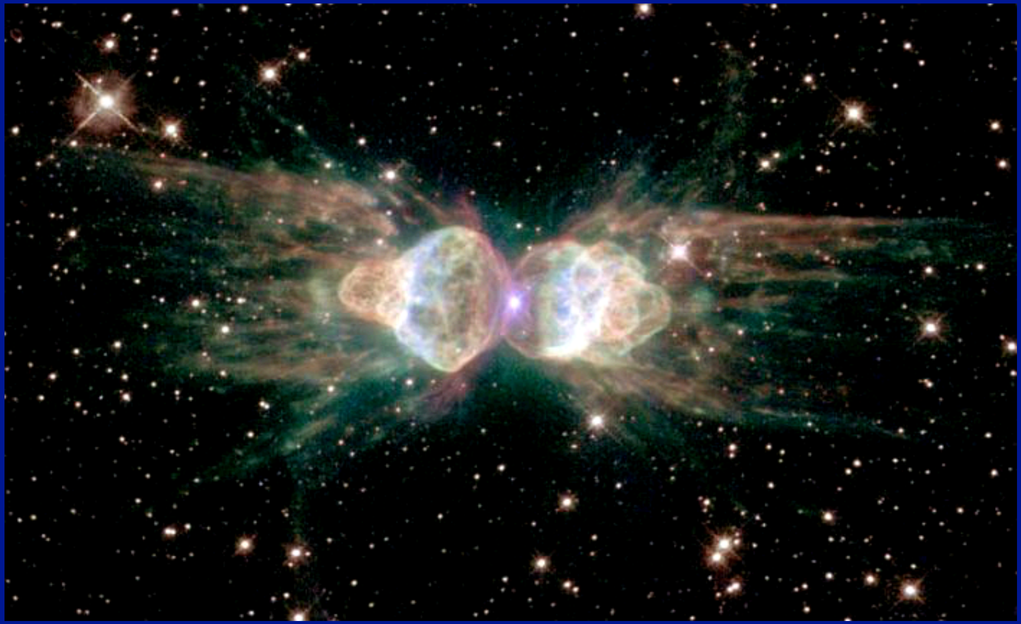
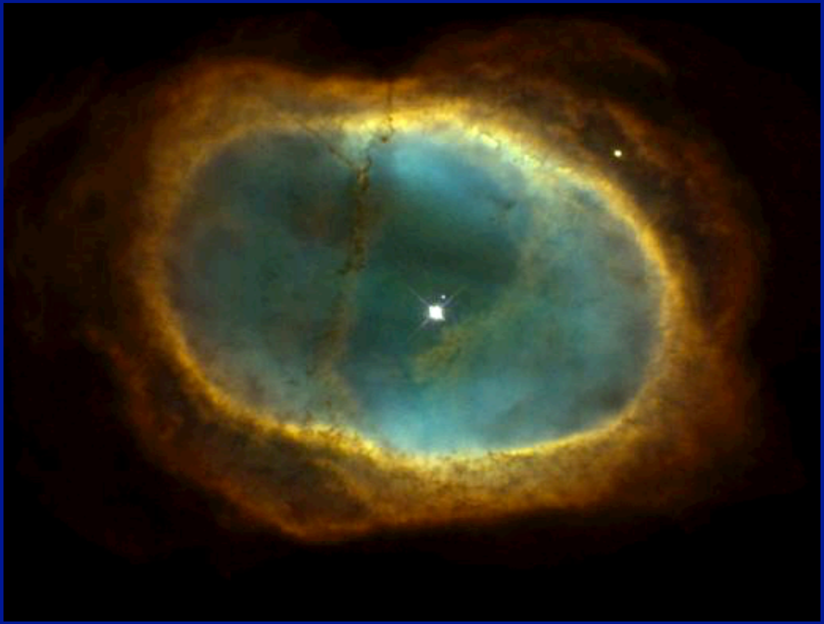
A: A hot ionized region around a planet.

B: A hot ionized region around a neutron star.

C: A hot ionized region around a white dwarf.

D: A hot ionized region around a black hole.



Clicker Question:

When they say that the Sun is a spectral type G2 star, what does that tell us about it?

A: mass

B: radius

C: temperature

D: luminosity

Clicker Question:

We can use stellar parallax to measure distances to stars because:

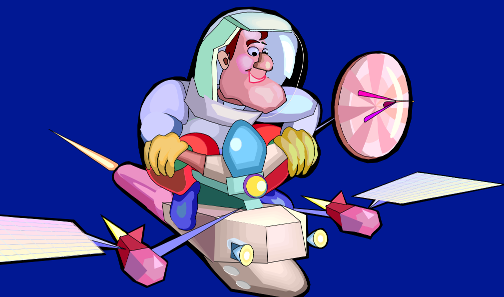
A: The Earth moves in space around the Sun

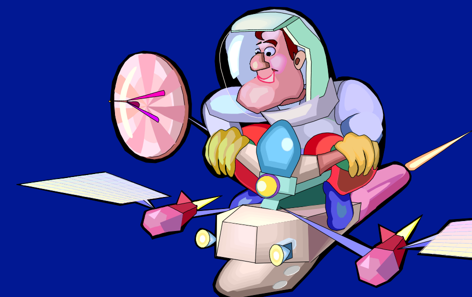
B: The stars orbit around the Sun.

C: The Earth rotates on its axis.

D: Stars have large angular sizes.

Classical Relativity

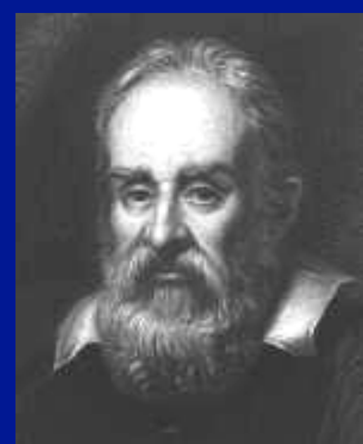




1,000,000 m/s

1,000,000 m/s

- How fast is Spaceship A approaching Spaceship B?
- Both Spaceships see the other approaching at 2,000,000 m/s.
- This is Classical Relativity.

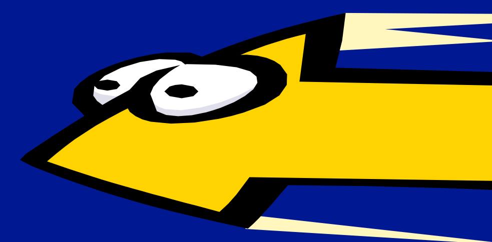


Animated cartoons by Adam Auton

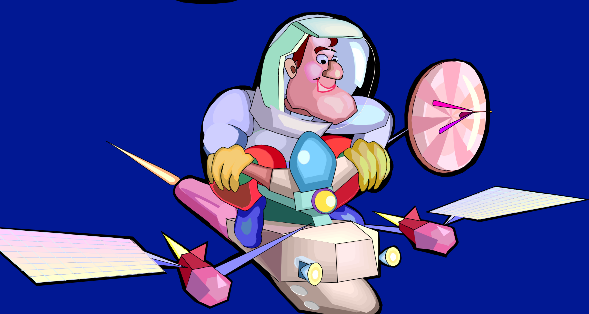
Einstein's Special Relativity

0 m/s

There was an old lady called Wright
who could travel much faster than light.
She departed one day
in a relative way
and returned on the previous night.



300,000,000 m/s



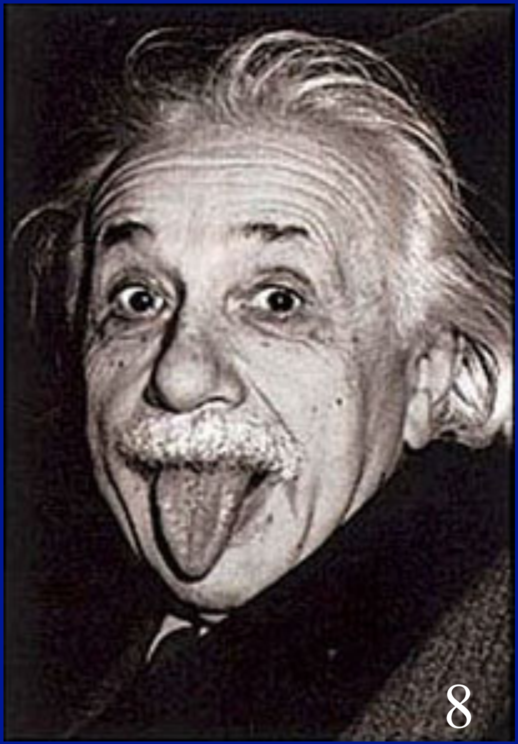
1,000,000 m/s

- Both spacemen measure the speed of the approaching ray of light.
- How fast do they measure the speed of light to be?

Special Relativity

- Stationary man measures 300,000,000 m/s
- Man traveling at 1,000,000 m/s
  - Moving at 300,000,000 m/s - press A
  - Moving at 301,000,000 m/s – press B

All observers measure the SAME speed for light.



Postulates of Special Relativity

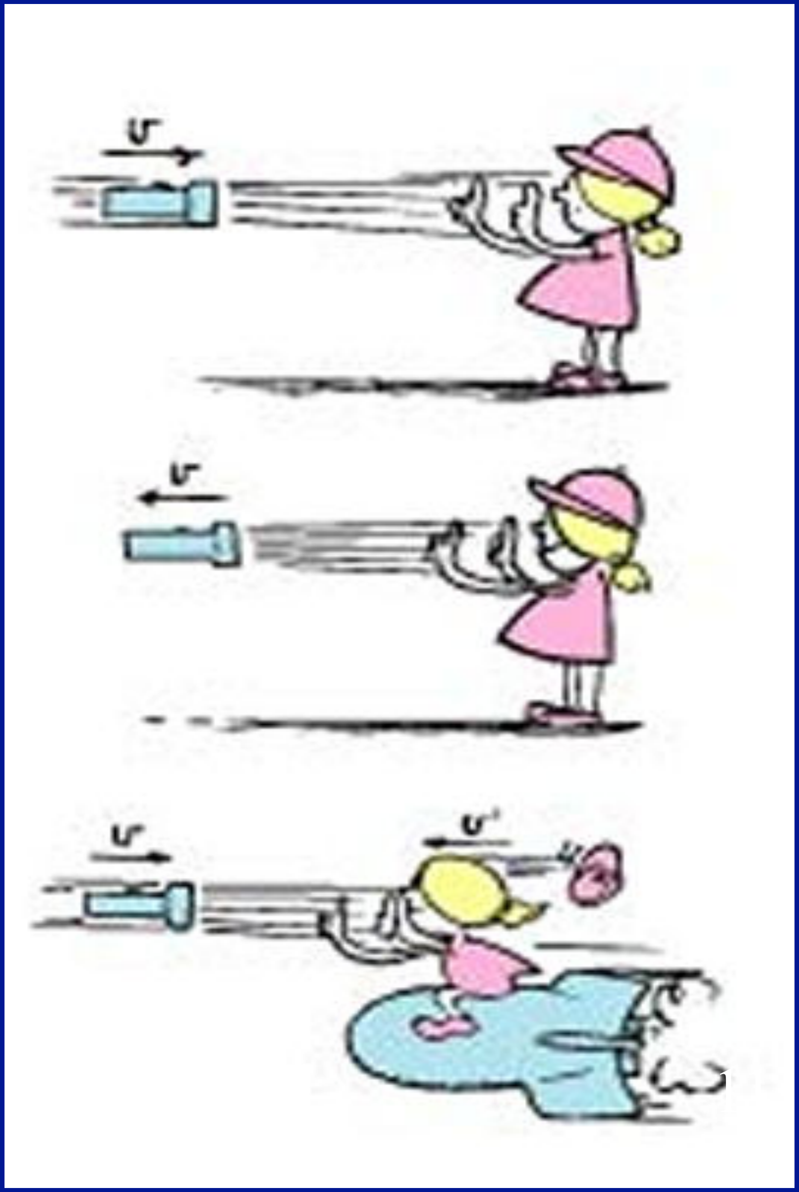
- 1st Postulate
  - The laws of nature are the same in all uniformly moving frames of reference.
    - Uniform motion – in a straight line at a constant speed
- Ex. Passenger on a perfectly smooth train
  - Sees a train on the next track moving by the window
    - Cannot tell which train is moving
  - If there are no windows on the train
    - No experiment can determine if you are moving with uniform velocity or are at rest in the station!
- Ex. Coffee pours the same on an airplane in flight or on the ground.

Combining "Everyday" Velocities

- Imagine that you are firing a gun. How do the speeds of the bullet compare if you are:
  - At rest with respect to the target?
  - Running towards the target?
  - Running away from the target?

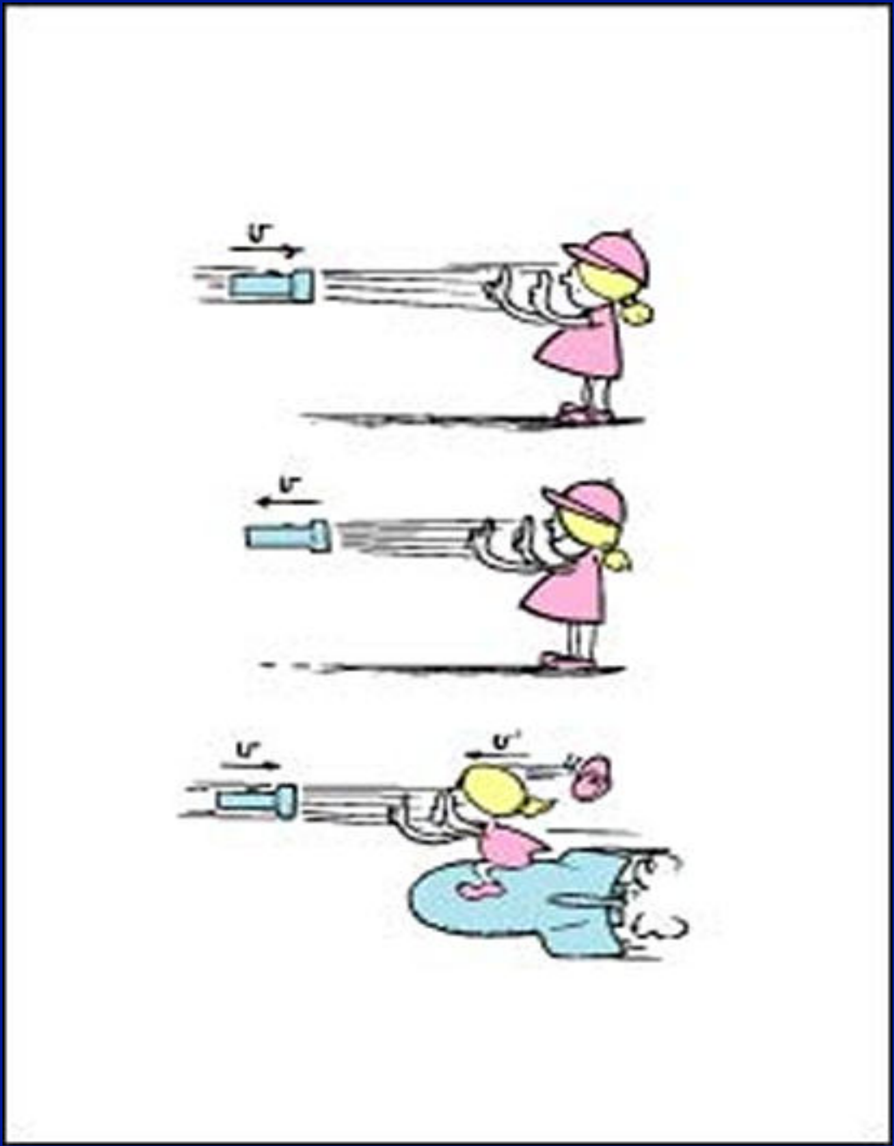
The Speed of Light

- How does the measured speed of light vary in each example to the right?



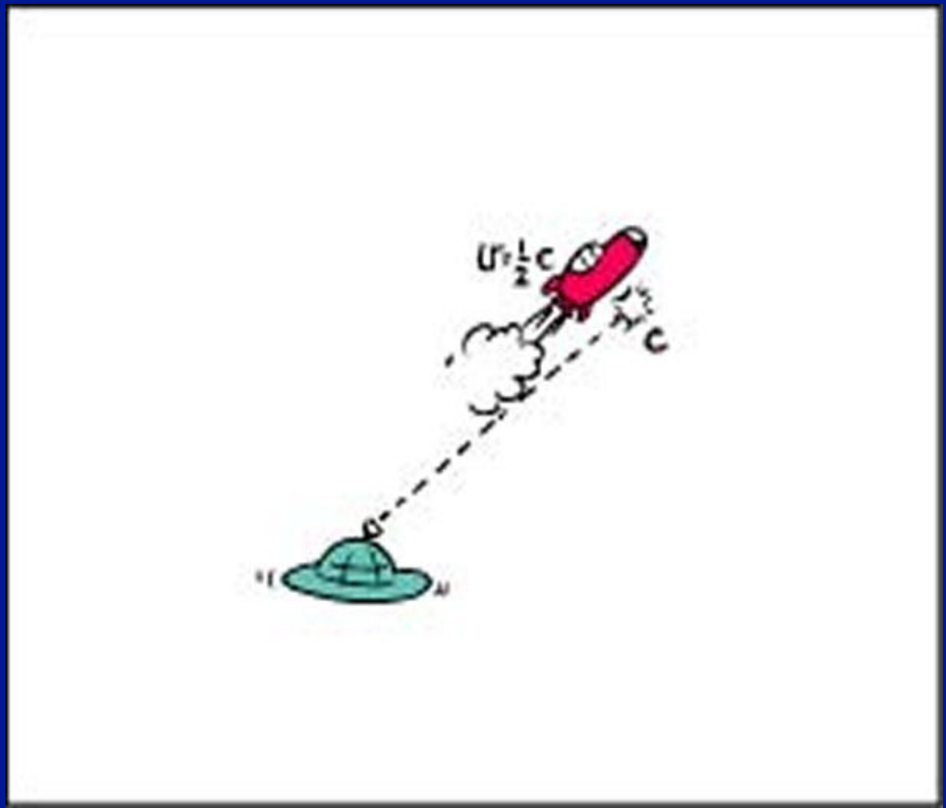
The Speed of Light

- How does the measured speed of light vary in each example to the right?
  - In each case the measured speed is the same!
- 2nd Postulate of Special Relativity
  - The speed of light is the same for all observers!



Postulates (cont.)

- 1^{st} Postulate
  - It impossible for two observers in relative motion to determine who is moving and who is at rest!
- 2^{nd} Postulate
  - The speed of light is the same for <u>all</u> observers!



Observers on the ground and in the rocket both measure *c*!

Relativistic Velocity Addition

- Classically: $V = v_1 + v_2$
- **Relativistically:**

$$V = \frac{v_1 + v_2}{1 + \frac{v_1 v_2}{c^2}}$$

- **Ship moves away from you at 0.5*c* *and fires a rocket with velocity (relative to ship) of 0.5c***
  - ***How fast (compared to the speed of light) does the rocket move relative to you?***

Relativistic Velocity Addition

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- **Ship moves away from you at 0.5*c and fires a rocket with velocity (relative to ship) of 0.5c***
  - ***You see rocket move at 0.8c***
    - ***No massize object can be accelerated to the speed of light!***
- ***If instead the ship fires a laser at speed c, what speed do you measure for the light?***

Relativistic Velocity Addition

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    - ***No massize object can be accelerated to the speed of light!***
- ***If instead the ship fires a laser at speed c***
  - ***You would measure c for the speed of light***

Clicker Question:

Compare the velocity of sunlight for somebody on a rocketship headed straight for the sun at half the speed of light and somebody standing on Earth. Which of the following is true?

A: the person on the rocket measures a higher velocity for the light from the Sun.

B: the person on the Earth measures a higher velocity for the light from the Sun.

C: they both measure the same velocity

Clicker Question:

Suppose that you are in a jet airliner traveling at a constant speed of 400 km/h in a constant direction. All windows are closed so that you cannot see outside and there are no vibrations from the engines. What experiment can you do to determine that you are in fact moving?

A: Measure the speed of a sound wave traveling up the aisle (toward the nose of the plane) and another traveling down toward the tail, and calculate the difference between the two results.

B: None. All experiments will give the same results as when you are at rest on the ground.

C: Suspend a ball by a thread from the ceiling and measure the angle the thread makes with the vertical.

D: Drop a rock and measure the distance it moves backward down the aisle as it falls.

Clicker Question:

If you have a time machine and can go backwards in time, what is the maximum velocity can you achieve:

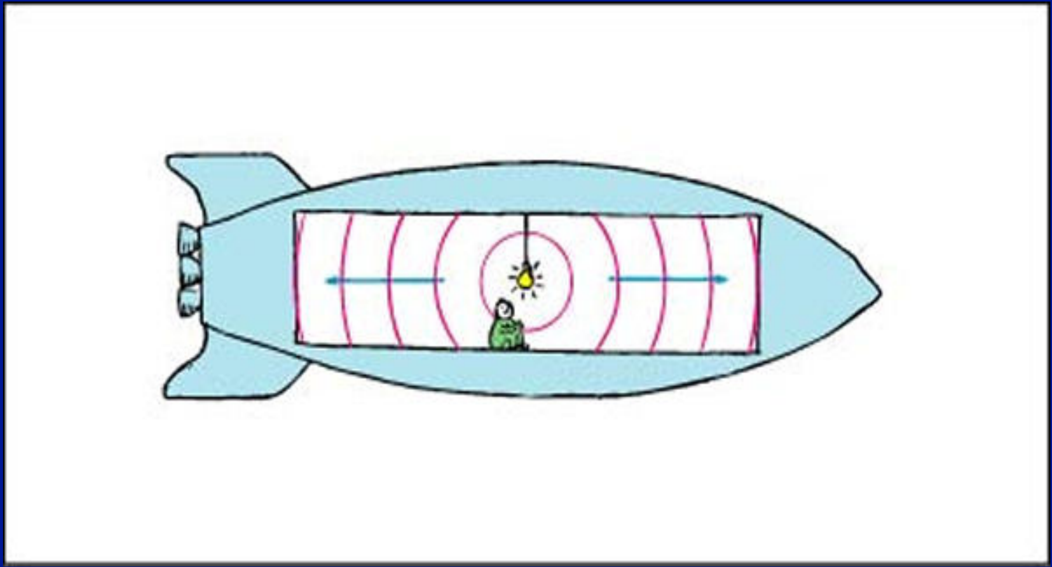
A: the speed of light

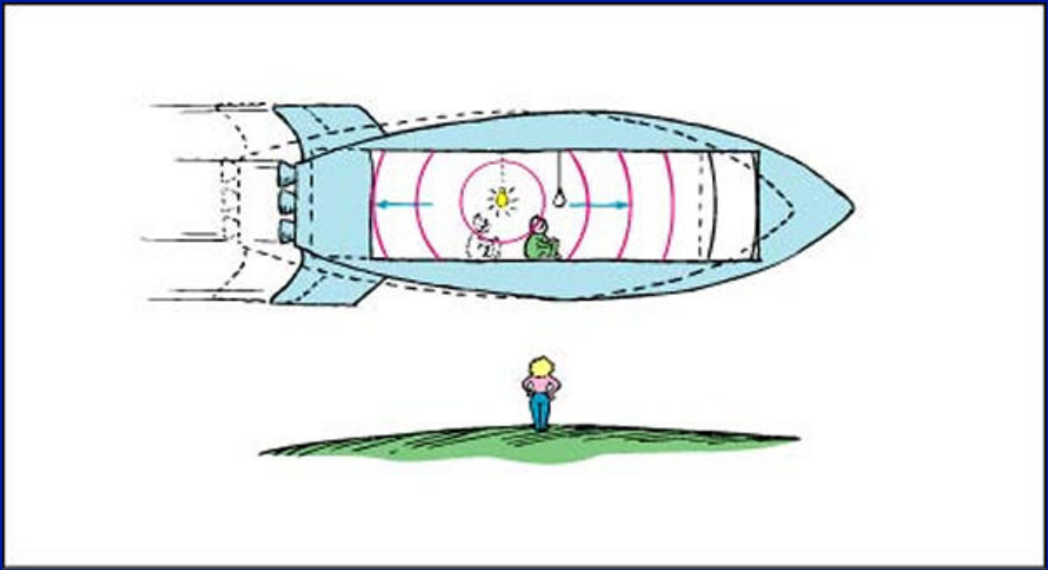
B: close to the speed of light, but not equal to it

C: infinitely large velocity

Simultaneity

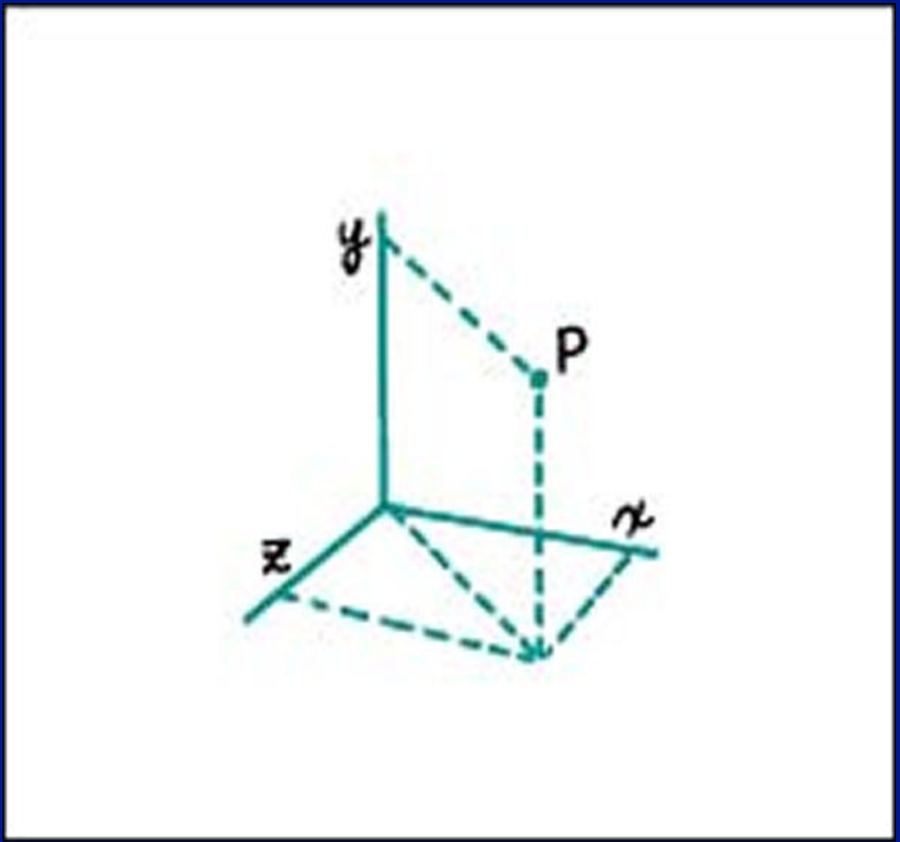
- Two events that happen at the same time in one frame of reference may or may not be simultaneous in a frame moving relative to the first.
  - Result of constancy of speed of light
  - How do the observations of the internal and external observers differ?
    - Who is right?





Spacetime

- 3-D space
  - Three numbers to locate any point
  - Objects with size: Length, width, height
- Time (fourth dimension)
  - Intimately tied to space
    - Most distant galaxies are also the youngest!
    - Seen as they were billions of years ago!



Spacetime (cont.)

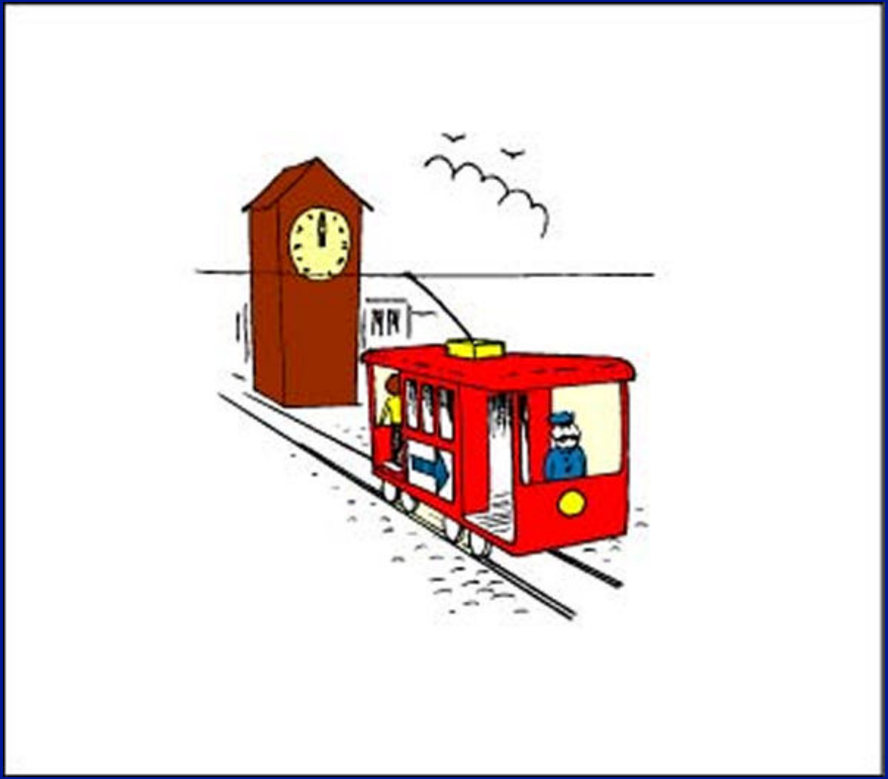
- Two side-by-side observers agree on all space and time measurements
  - Share same spacetime
- Two observers in relative motion disagree on space and time measurements
  - But always same ratio!
    - Differences imperceptible at low speeds
    - Important at speeds near *c (relativistic speeds)*

Observers in relative motion experience space and time differently, but speed of light is always constant!

Time Dilation

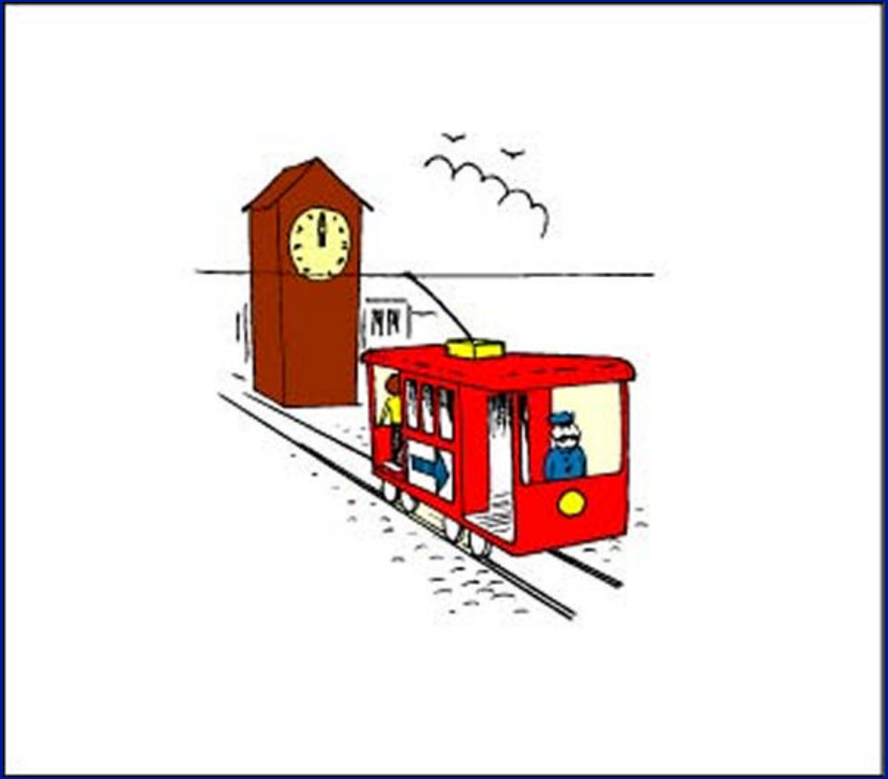
If clock reads 12pm, an observer 1 light hour away reads 11am!

- Travel at speed of light for one hour towards observer and stop
  - What does the clock tower read when you stop? Do you read the same time as the stationary observer?



Time Dilation

- If clock reads 12pm, observer 1 light hour away reads 11am!
  - Travel at speed of light for one hour towards observer and stop
    - What do you read at the end of your trip?
      - Both read 12pm
      - Time stood still for you!
    - So if you traveled at speed < *c* *what would you observe?*



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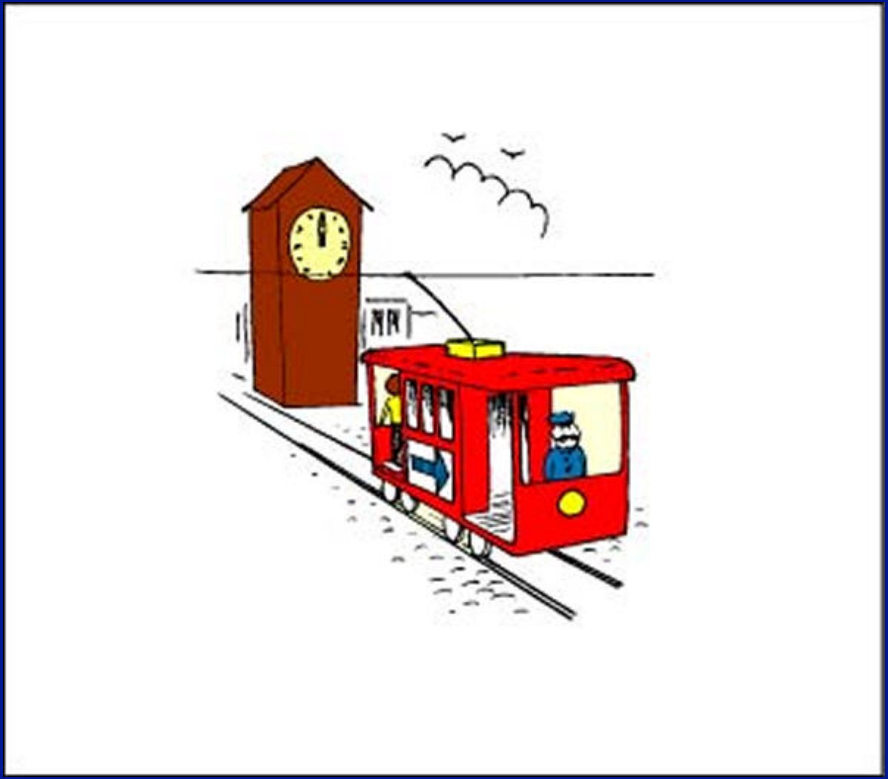
- If clock reads 12pm, observer 1 light hour away reads 11am!
  - Travel at speed of light for one hour towards observer and stop
    - Both read 12pm
      - Time stood still for you!
    - If you travel at speed < *c, clock runs slower than normal!*
  - *Now travel at high speed back towards clock*
    - *See tower clock speed up!*
    - *Will the two effects cancel?*



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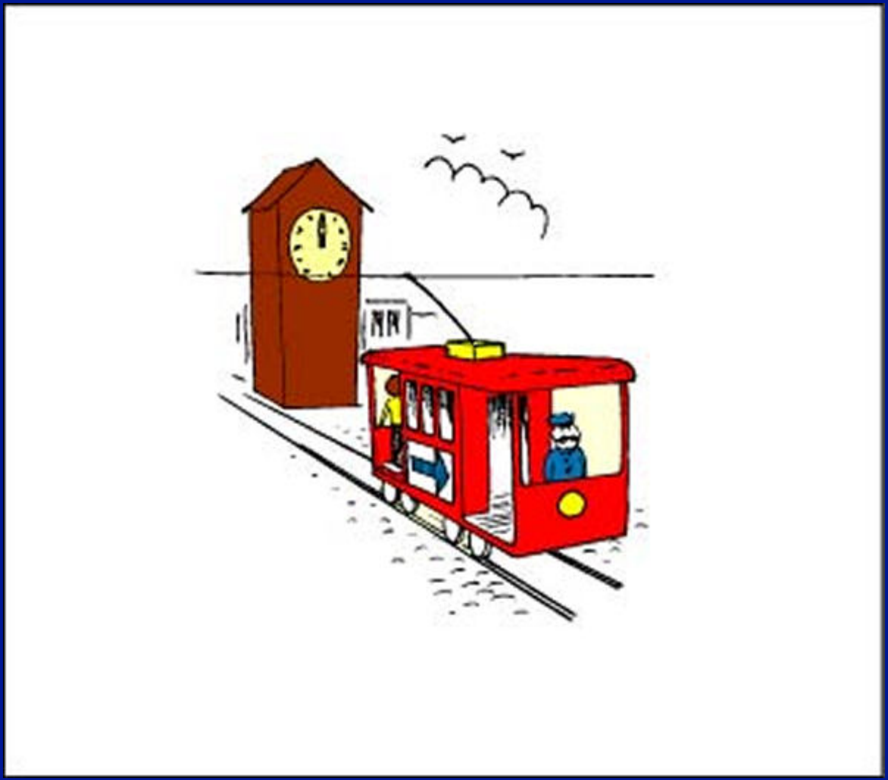
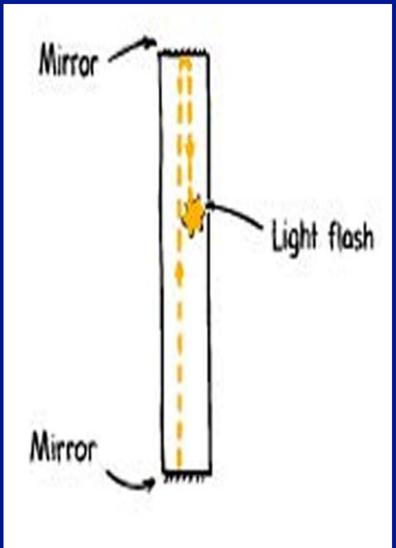
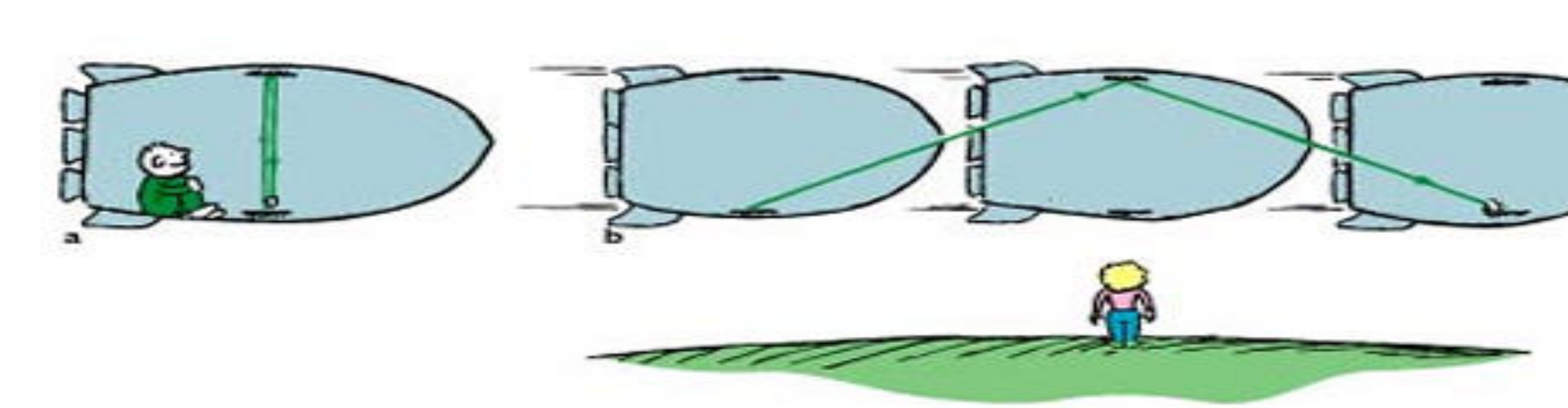
  - *Now travel at high speed back towards clock*
    - *See tower clock speed up!*
    - *Will the two effects cancel?*
      - *No! Your wristwatch will disgree with town clock! How?*



Time Dilation (cont.)



- Moving clocks run slow!
  - Light clock: time between mirrors = 1 tick
  - Observer moving with clock: no dilation!
  - External observer: Light travels longer path
    - But, speed of light constant => each tick takes longer!
- True for all clocks! Property of spacetime!



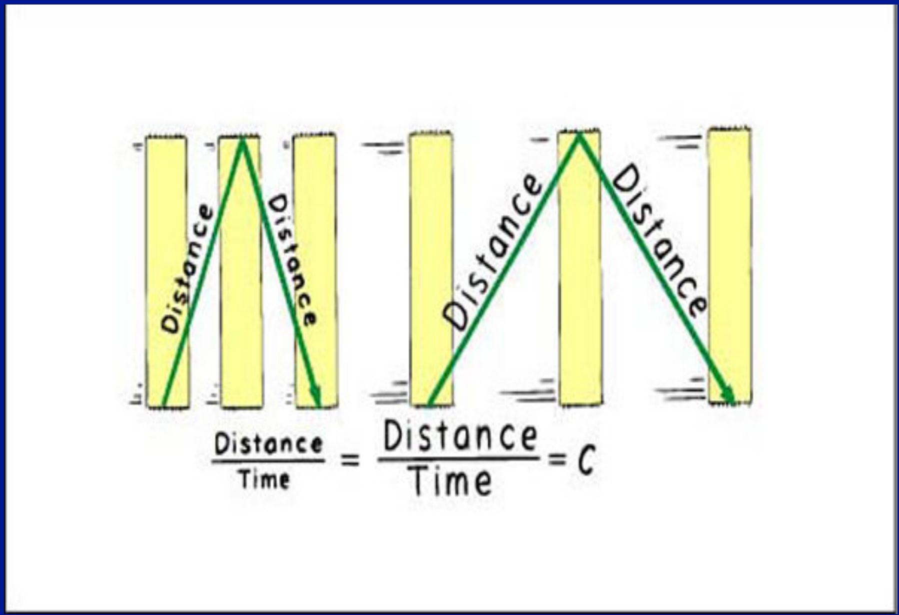
Time Dilation Animated

- Time between ‘ticks’ = distance / speed of light
- Light in the moving clock covers more distance…
  - …but the speed of light is constant…
  - …so the clock ticks slower!

- Moving clocks run more slowly!

Time Dilation (cont.)

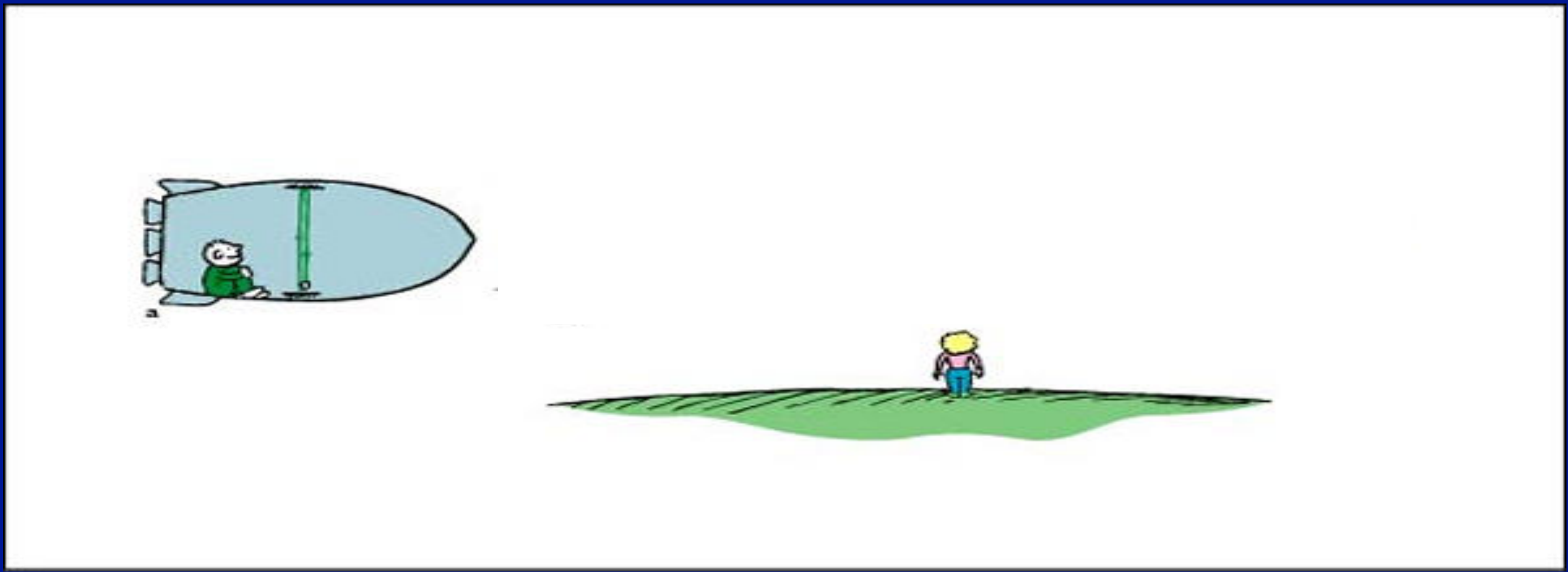
- Experimentally confirmed
  - Particle accelerators
  - Atomic clocks: Jets & GPS



- *Only relative velocity matters!*
  - *Observer moving with clock would see external clocks run slower! How can this be?*

Twin Paradox

- Suppose there are two twins, Al and Bill age 10. Al goes to summer camp 25 light-years away. If he travels at 0.9999c then it takes 25 years each way and Bill is age 60 when Al gets back. But Al is only 10 and a half because time for him was moving slower. But from Al's point-of-view Bill was the one moving so how did Bill get so old?



Truck and Garage Paradox

- Suppose you have a truck 20 ft long and you want to park it in a Garage that is only 10 ft deep. Is there a way to make it fit?
- Yes! If you move the truck in at 0.865c then it will be contracted in length to just 10 feet. At 0.99c it will measure just 2.8 feet and fit easily (until it hits the wall of the garage).

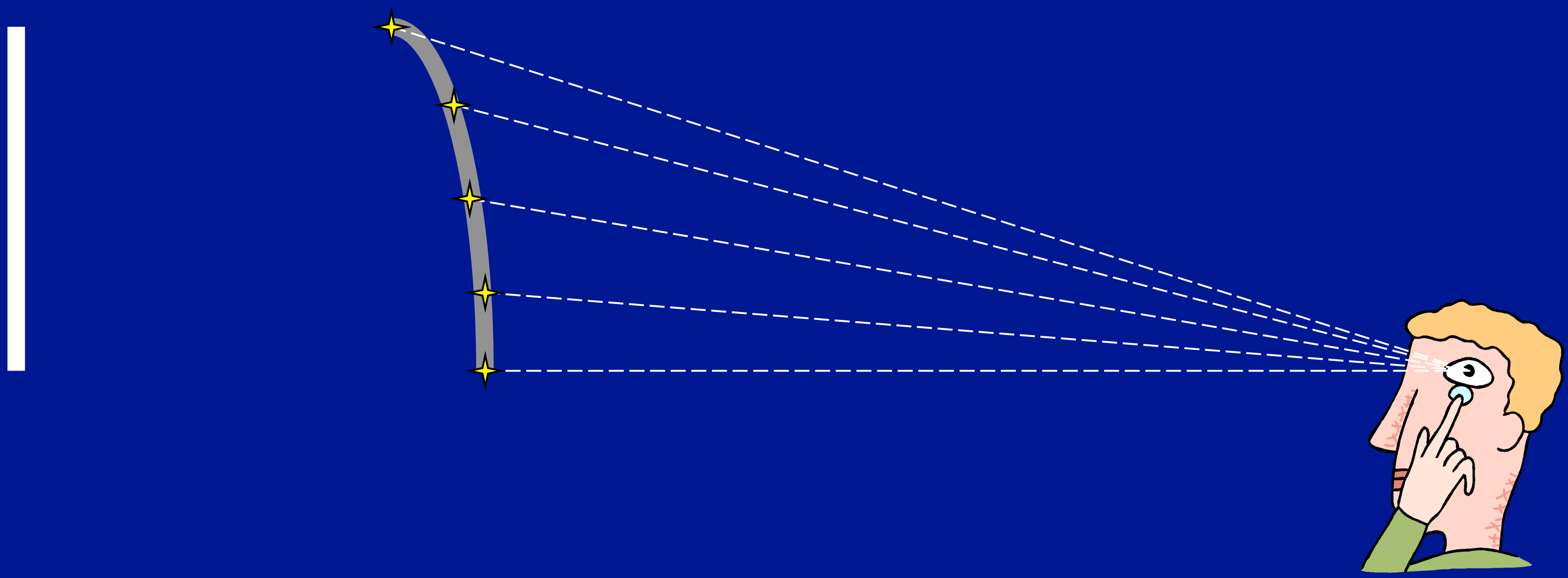
Relativistic Mass

- There is an increase in the effective mass of an object moving at relativistic speeds given by:

- $m = \gamma m_0$ where $\gamma = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}}$

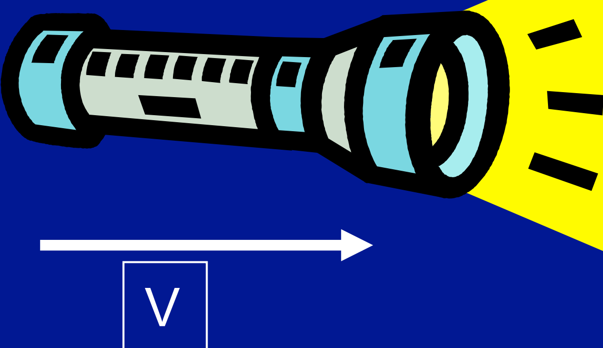
- you have to reach 0.14c to change the mass by 1%
- at 0.99c the mass is 7.14 times greater than rest mass

Lorentz Transformations



- Light from the top of the bar has further to travel.
- It therefore takes longer to reach the eye.
- So, the bar appears bent.
- Weird!

Headlight effect



- Beam becomes focused.
- Same amount of light concentrated in a smaller area
- Flashlight appears brighter!

Clicker Question:

Photons (packets of light) move at the speed of light. Their rest mass is therefore:

A: the same as their relativistic mass

B: much greater than their relativistic mass

C: less than their relativistic mass

D: zero

Clicker Question:

The speed of protons in a big accelerator must be:

A: equal to the speed of light

B: greater than the speed of light

C: less than the speed of light

D: zero

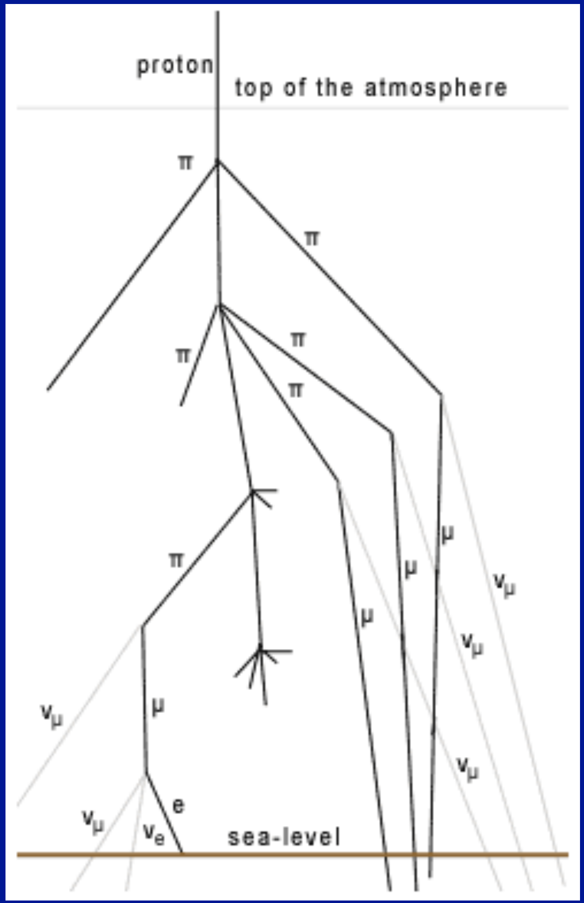
Clicker Question:

Suppose a muon is created 5 km up in the atmosphere. If it is moving at 0.998c and has a lifetime of 2×10^{-6} seconds, can it reach the ground?

A: No

B: Yes

C: can't say



Relativistic Summary

- time dilation : $t = t_0/\gamma$
- length contraction: $L = L_0/\gamma$
- mass increases: $m = \gamma\, m_0$
- where

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

- 0.14c --> $\gamma = 1.01$
- 0.99c --> $\gamma = 7.14$
- 0.998c --> $\gamma = 15$