Astronomy 150:

Killer Skies

This Class (Lecture 24):
Black Holes Are Fun

Next Class:
Death by Black Hole:
Spaghettification

Night Obs/Computer labs due in class on Nov 9th.
HW 2 due on the 7th.
Exam 2 on Friday!

Music: ***Where Gravity is Dead– Laura Veirs***

Exam 2

- Exam 2 in this classroom on Friday
- 35 Multiple choice questions
- Will cover material from Lecture 12 to 22.
- May bring 1 sheet of paper with notes
  - Both sides
  - Printed/handwritten/whatever.. I don't really care
- Major resources are lecture notes, in-class questions, and homeworks
- Created and posted a study guide

1st Week of Nov

- Lecture is cancelled for the first week of Nov (2nd, 4th, and 6th).
- Instead of iclicker, we will do credit through a Compass discussion topic (before the 8th).
- To get full credit for the three days, you will have to:
  - Create 1 new post (a weblink relevant to class from a news source) and make a comment, plus make 2 relevant posts on someone else's post or post comment.
  - Or, make 5 relevant posts on someone else's post or post comment.

1st Week of Nov

- So far, I am very happy with the posts and comments.
- Already seen some interesting links and discussions.
- For some reason, there is two possible posting sections. Try to keep it in the one by itself.

Outline

- Einstein's Special Theory of Relativity
  - Speed of light is a constant, hilarity ensues
- Einstein's General Theory of Relativity
  - What is gravity?

Physics of Black Holes

- Black holes are simple, yet strange objects
- Intense gravity due to compactness
- Newton's Laws cannot describe what happens in the nearby presence of such an intense gravitational field
- We need Einstein's *Theory of Relativity*

We got a speed limit!

- No matter what we do, we can not go faster than the speed of light!
- That naturally occurs when one demands that the speed of light *must* be the same regardless of who measures it.
- This is completely counter-intuitive!
- Basis of Einstein's Theory of Special Relativity.

http://www.rpi.edu/dept/phys/Dept2/APPhys1/optics/optics/node4.html

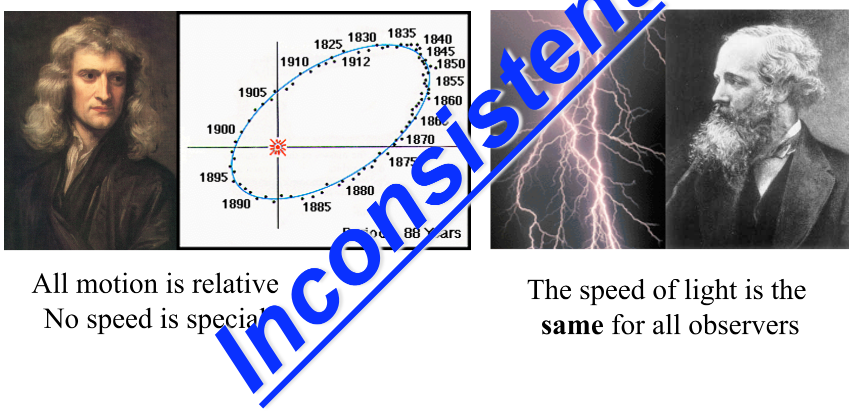
How Fast is Light?

- The speed of light is $c = 3\times10^8$ m/s (186,000 miles per second)!
- How fast is that?
  - Around the Earth over 7 times in a second
  - From Earth to the Moon in under 2 seconds (it took the astronauts 2 weeks)
  - From the Sun to the Earth in a little over 8 minutes
  - From the Sun to Pluto in about 5½ hours
  - From the nearest star to Earth, about 4 years

Two Threads of Thought in Physics up to 1900

Mechanics
(Newton's Laws)

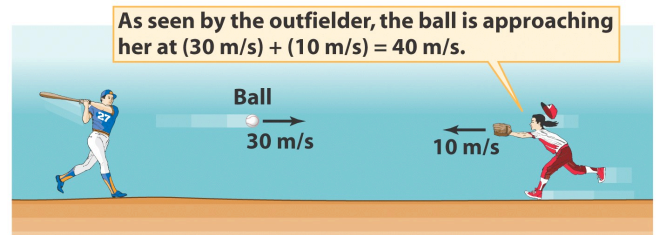
Electromagnetism
(Maxwell's Equations)



All motion is relative
No speed is special

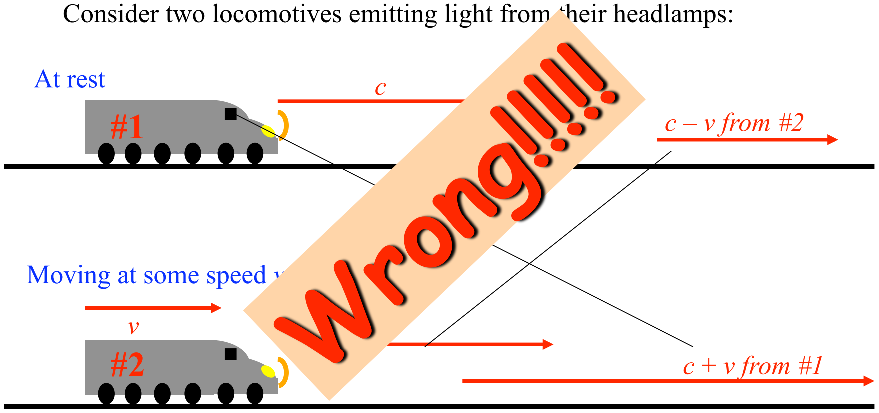
The speed of light is the **same** for all observers

Why Newton and Maxwell Can't Both Be Right

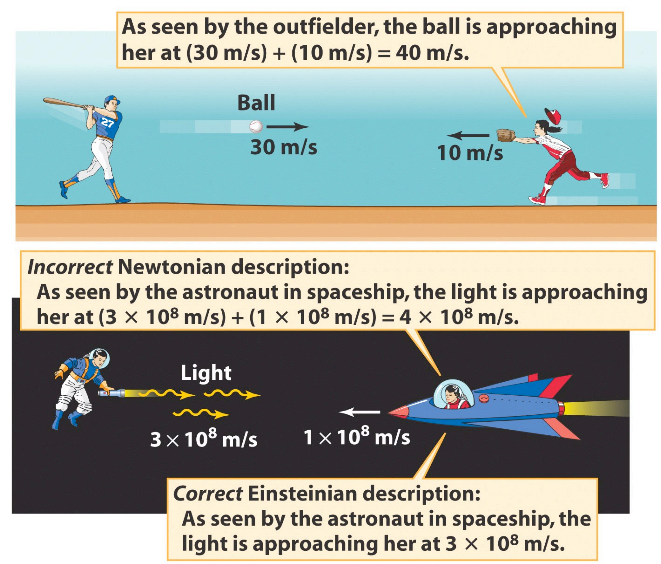


Why Newton and Maxwell Can't Both Be Right

Consider two locomotives emitting light from their headlamps:



Why Newton and Maxwell Can't Both Be Right



Why Newton and Maxwell Can't Both Be Right

So the speed of light can't be the same for everyone if Newton – and our intuition – are right. But Maxwell says it is constant!

Something must happen. And what must happen for Newton and Maxwell to be both right, is that there is a modification of time and distance. Remember

$$speed = \frac{dist}{time}$$

Distance and time become relative to the observer.

Question

You are at the back of a jet traveling at 400 mph. You shine a laser toward your friend in first class. What speed does your friend measure for the laser light?

a) c+400 mph
b) c-400 mph
c) c
d) c/400 mph
e) $c/(c^2-400^2)$ mph

Where c is the speed of light.

Approaching the "c"

- Time dilation – Moving clocks run slow.
- Length contraction – Moving objects contract along direction of motion.
- Mass increase – moving clocks get more massive

http://www.richard-seaman.com/Travel/Japan/Hiroshima/AtomicBombMuseum/IndividualArtifacts/

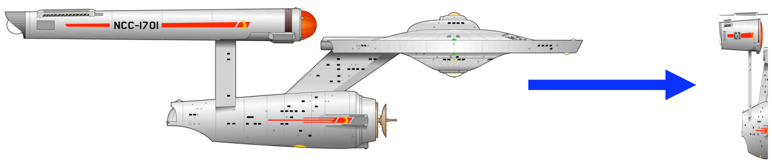
Approaching the "c": Impact

- The clocks on a ship accelerating to "c" would stop completely compared to someone at rest.
- The ship would appear to be infinitely thin in length along its direction of motion for someone at rest.
- The mass of an object as it approaches "c" becomes infinite for someone at rest.
  - So does its kinetic energy– requires more power.

http://www.richard-seaman.com/Travel/Japan/Hiroshima/AtomicBombMuseum/IndividualArtifacts/

Counterintuitive Result #1

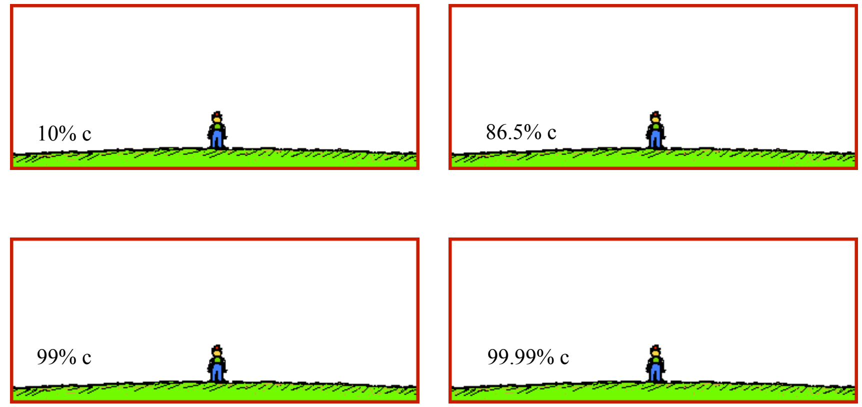
Moving objects appear shorter in the direction of relative motion



Fraction of the speed of light	% of original length
0.00	100%
0.001	99.99995%
0.01	99.995%
0.1	99.5%
0.5	86.6%
0.9	43.6%
0.99	14.1%

Counterintuitive Result #1

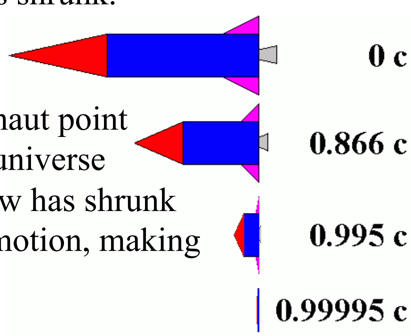
Moving objects are shorter in the direction of relative motion



http://www.physicsclassroom.com/mmedia/specrel/lc.html

Length Contraction

- This effect has some benefits:
  - Outside observers will measure that the length of the spaceship has shrunk.
    - This doesn't really help or harm us
  - But, from the astronaut point of view, the entire universe outside their window has shrunk in the direction of motion, making the trip shorter!
- It's all relative.



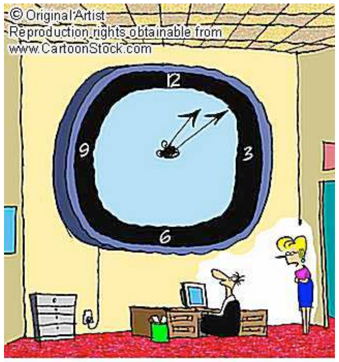
Question

Your best friend is going on a near light speed trip. When at rest you measure her spaceship to be 100 feet long. Now, she's in flight and you're on the Earth, and you measure her spacecraft to be

a) Exactly 100 feet long.
b) Less than a 100 feet long.
c) More than a 100 feet long.

Counterintuitive Result #2

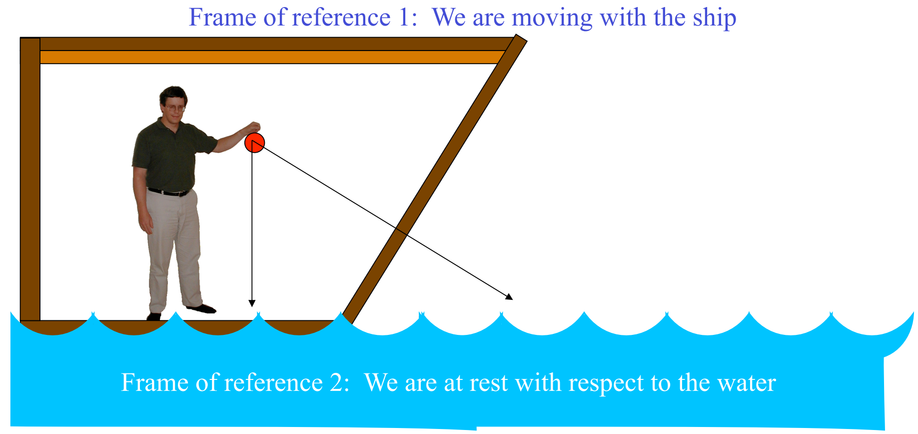
Clocks on Moving objects slow down



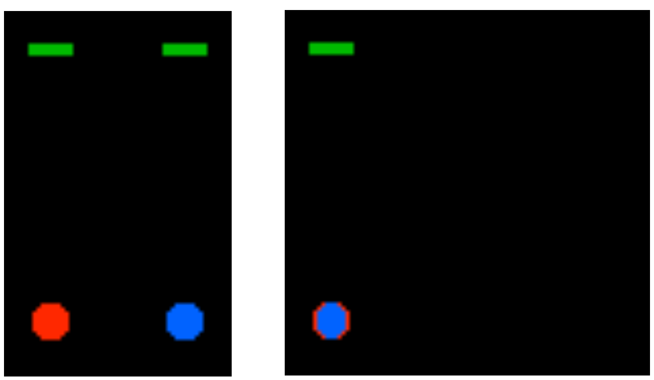
"Try not to watch the clock. It only makes the day go slower."

Galileo's ship thought experiment

No experiment within the ship's cabin can detect the ship's motion if the ship moves in the same direction at a constant velocity. This is still true, even when considering the speed of light.



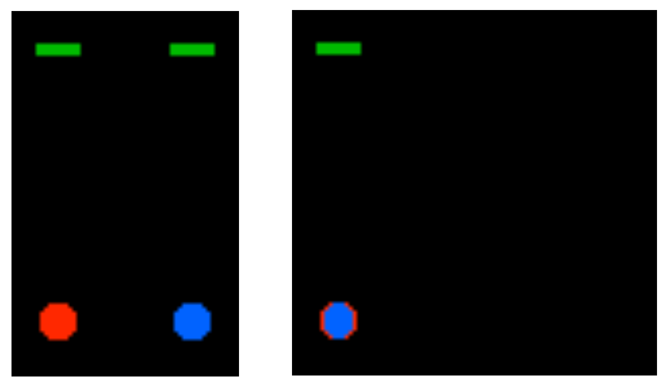
If the Ball is light?



A. Hamilton (Colorado)

Counterintuitive Result #2

Time appears to advance more slowly for moving objects (<u>time dilation</u>)

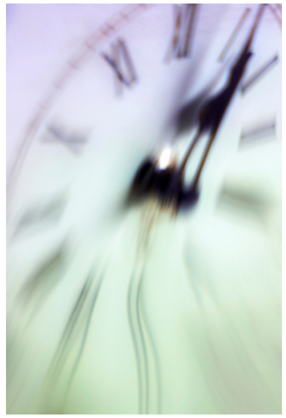


Red & blue at rest   Blue moving to right

http://www.youtube.com/watch?v=KHjpBjgIMVk   A. Hamilton (Colorado)

Time Dilation

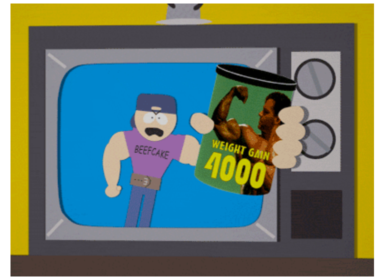
- The effects of time dilation are curious but not prohibitive for space travel
  - Astronauts will age less than the Earth-bound folks waiting for the return. Can spoil the homecoming celebrations.
  - The faster you go, the bigger difference between astronaut time and Earth time



- Example: Trip to the center of the Galaxy and back. Accelerate at 1g for the first half and decelerate for second half and you can go 30,000 ly in 20 years! But more than 30,000 years has elapsed on Earth!

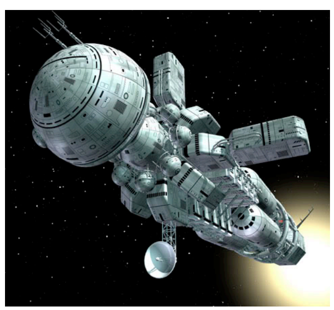
Counterintuitive Result #3

Mass increases for moving objects



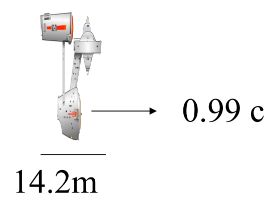
Mass Increase

- The increase of effective mass (and kinetic energy) with velocity makes acceleration and deceleration more difficult if you intend to travel close to "c"
  - This translates to very costly starflight in terms of required energy.
  - And now the interstellar dust that you strike at relativistic speeds appear as larger mass.
  - For 99% speed of light travel, 5.5 meters of shield would erode every year.

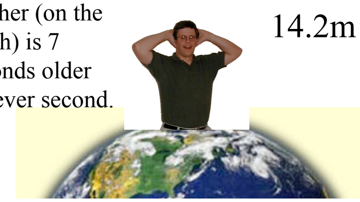


So, what does that mean?

- If you're on a 100m spaceship going near the speed of light (.99 c), the spaceship measures100m long, but someone on the Earth would measure the spaceship to only be 14m long.
- As you speed by the Earth your clock would tick 1 second, and an observer would tick about 7 seconds.



Paul's Twin brother (on the Earth) is 7 seconds older for ever second.

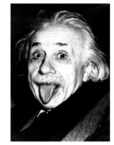


And Paul's measured mass increased by a factor of 7.

Question

You are traveling near light speed. You see the Earth slide past your window. You notice that you left a clock (readable from space), and for every second that pasts on the spacecraft

a) Exactly 1 second pasts on Earth.
b) Less than a second pasts on Earth.
c) More than a second pasts on Earth.



Special Relativity Summary

All motion is relative, except for that of light. Light travels at the same speed in all frames of reference.

Objects moving close to the speed of light appear to shrink in the direction of travel.

Time appears to advance more slowly for objects moving close to the speed of light.

Mass of the moving object appears to rapidly increase as an objects moves close to the speed of light.

Question

Okay, so length and time can change, then what exactly is a constant?

a) The speed of light.
b) The length of an iron pipe.
c) The time it takes for a photon to cross the Universe.
d) The speed of sound.
e) The speed of a class.. it is always too slow.