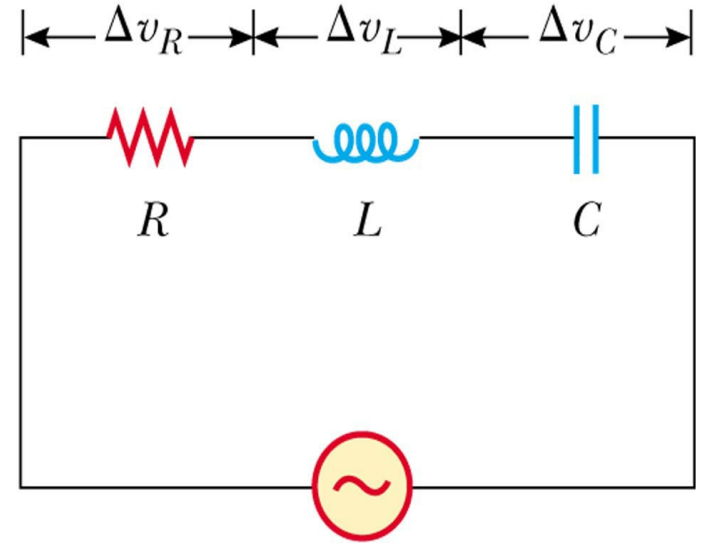
Physics 294H

- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **Help-room hours: 12:40-2:40 Monday (note change); 3:00-4:00 PM Friday**
  - **No hand-in problem for this Wed**
- Quizzes by iclicker (sometimes hand-written)
- Average on 2nd exam (so far)=71/120
- **Final exam Thursday May 5 10:00 AM – 12:00 PM 1420 BPS**
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

Example

- I have an AC circuit with a generator that supplies an rms voltage of 110 V at 50 hz connected in series with a 0.3 H inductor, a 4.5 μF capacitor and a 280 Ω resistor
- What is the impedance of the circuit?
- What is the rms current through the resistor?
- What is the phase ϕ?
- What is the power factor?



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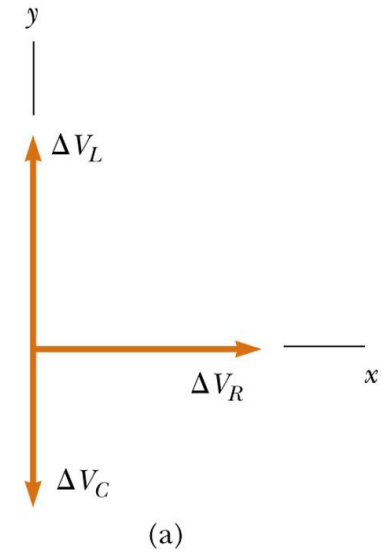

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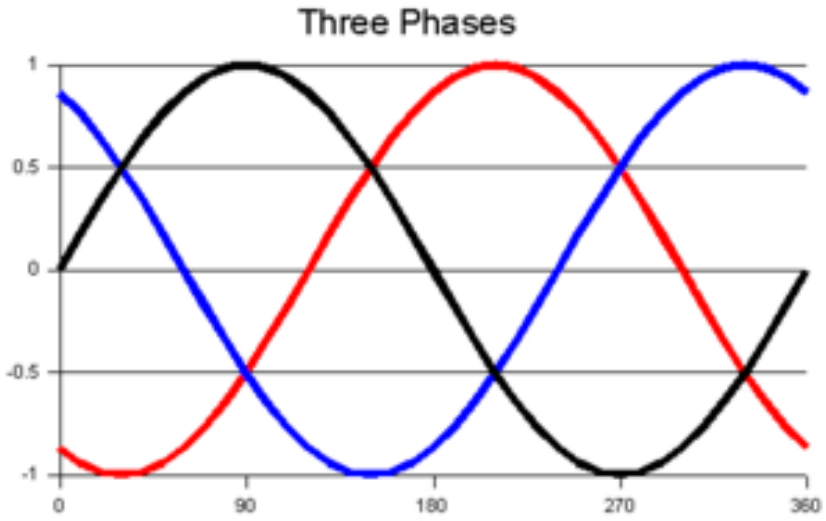
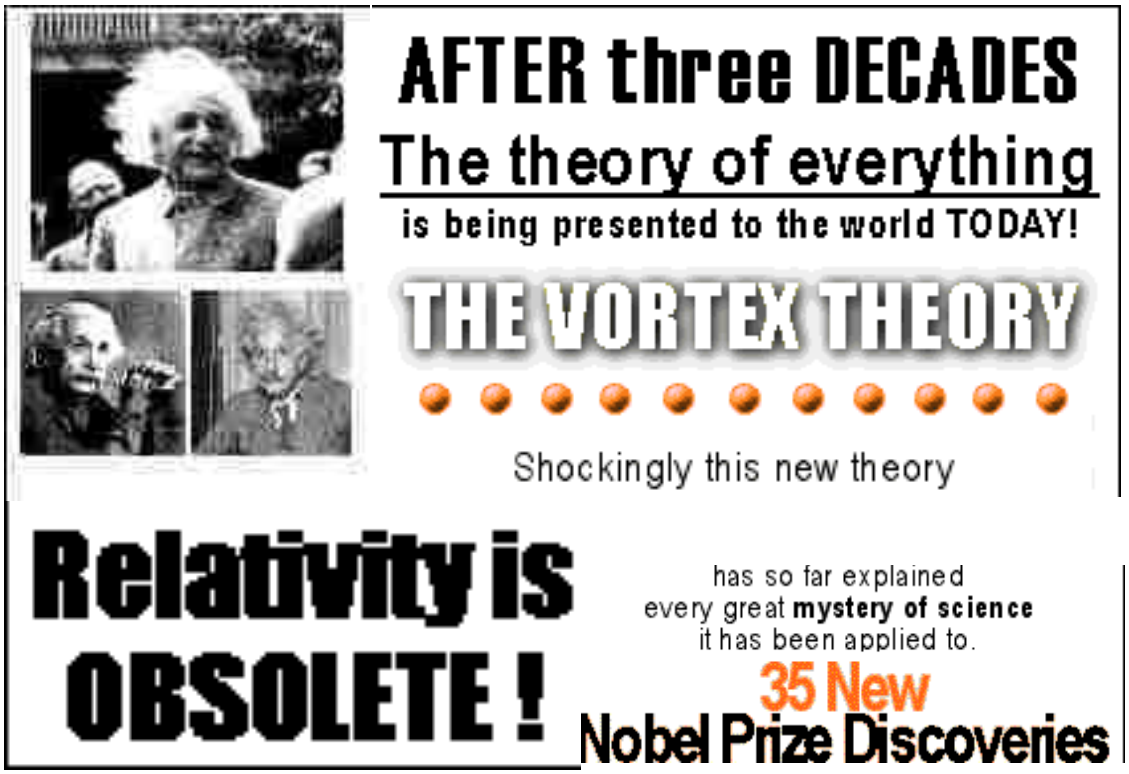
3-phase power

- Three phase has properties that make it very desirable in electric power systems. Firstly the phase currents tend to cancel one another (summing to zero in the case of a linear balanced load). This makes it possible to eliminate the neutral conductor on some lines. Secondly power transfer into a linear balanced load is constant, which helps to reduce generator and motor vibrations. Finally, three-phase systems can produce a magnetic field that rotates in a specified direction, which simplifies the design of electric motors. Three is the lowest phase order to exhibit all of these properties.Most domestic loads are single phase. Generally three phase power either does not enter domestic houses at all, or where it does, it is split out at the main distribution board.



3 phases
+ neutral

Relativity



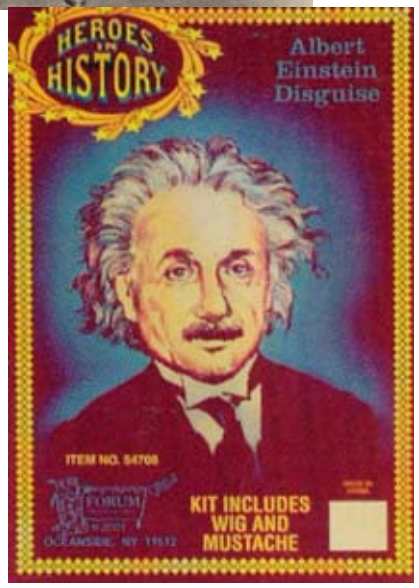
Not quite

Modern Physics

- Physics life near the end of the 19th century seemed pretty sedate
- Mechanics was very successful in describing phenomena both on earth and in the heavens
- Maxwell's equations described E&M
  - Heinrich Hertz confirmed Maxwell by discovering electromagnetic radiation
- A few flies in the ointment
  - for example, the discovery of radioactivity
    - who asked for atoms to be unstable?
- Another revolution took place in physics between 1900 and 1930: quantum mechanics
  - classical mechanics is highly successful in describing behavior for objects of macroscopic size
    - not so on the atomic level
  - classical mechanics is also very successful at describing the behavior of objects travelling at slow speeds
    - but not at high speeds

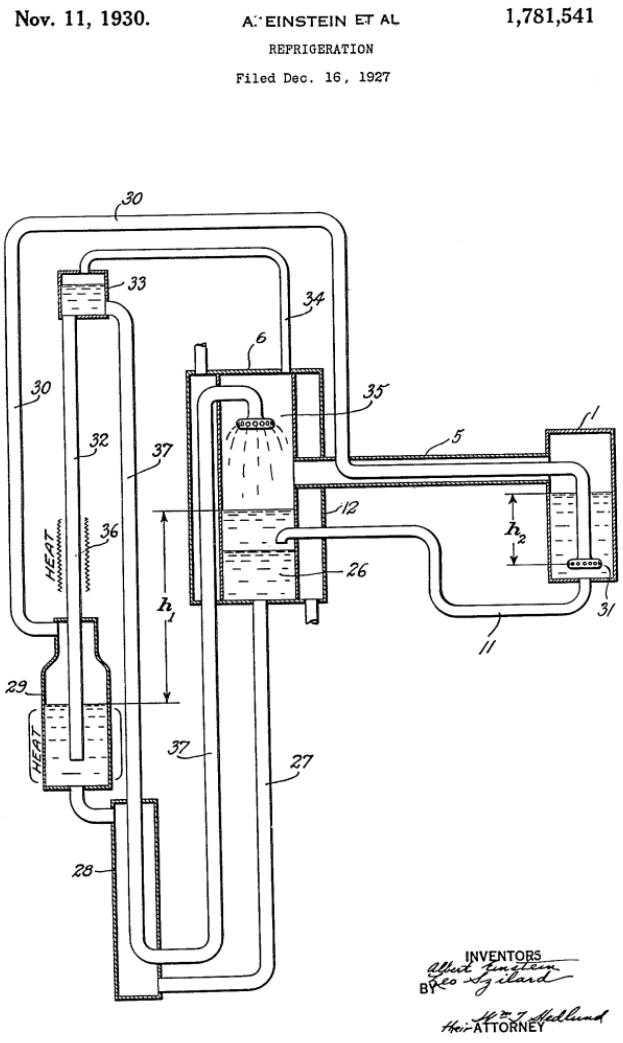
Enter Einstein

- 1879-1955
- One of greatest physicists of all time
- Teacher once told him: "*You will never amount to anything Einstein*"
- Began speaking late, but gifts were evident from an early age
- In 1905, while working as a patent clerk, he published four papers that revolutionized physics
  - 1 on Brownian motion (convincing evidence that atoms exist)
  - 2 on special relativity
  - 1 on photoelectric effect
    - for which he received the Nobel prize in 1921
- Over 350 papers in career and a few patents
- And a great idea for a Halloween costume



Costume Kits Albert Einstein Costume Kit costume kit includes: wig and moustache.

Patents on what?



The **Einstein refrigerator** is a type of refrigerator co-invented in 1926 by Albert Einstein and former student Leó Szilárd, who were awarded patent number US1781541 on November 11, 1930. The machine is a single-pressure absorption refrigerator, similiar in design to the gas absorption refrigerator. The refrigeration cycle uses ammonia (pressure equalizing fluid), butane (refrigerant), and water (absorbing fluid). The Einstein refrigerator is portable; made of inexpensive, nonmoving parts; operates silently; and is very reliable.

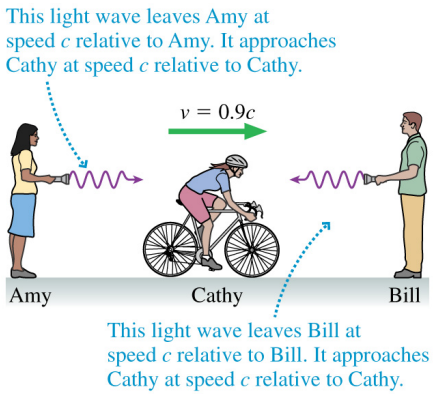
- …but he doesn’t have a square dance song dedicated to him
- …or does he?

Special theory of relativity

- Applies at all speeds, slow and fast
- What do we mean by fast?
  - approaching the speed of light
    - 186,000 miles per sec
    - 3 X 10^8 m/s
  - not your typical highway speeds
  - but ones approached for example by the particles at the LHC

Special relativity

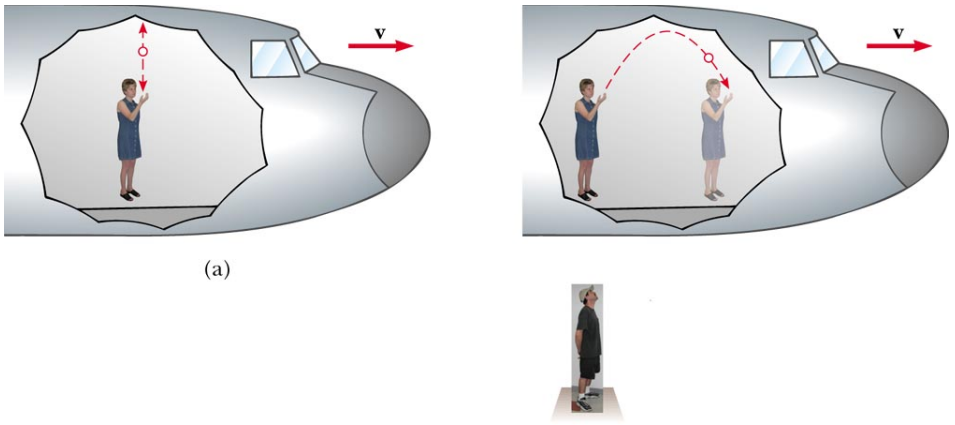
- The special theory of relativity can be summarized with two simple statements →
- Some of the consequences are not so intuitive
  - slowing down of clocks
  - lengths contracting
  - masses increasing



- The laws of physics are the same in all coordinate systems either at rest or moving at constant speed with respect to one another
- The speed of light in a vacuum has the same value regardless of the velocity of the observer or the velocity of the source emitting the light

Frames of reference

- Need to define a frame of reference
  - for example a coordinate system for making measurements
- Consider a person on an airplane tossing a ball in the air and catching it
- The person on the plane has one frame of reference
- A person observing from the ground has another frame of reference
- This is an example of a *gedanken*, a thought experiment

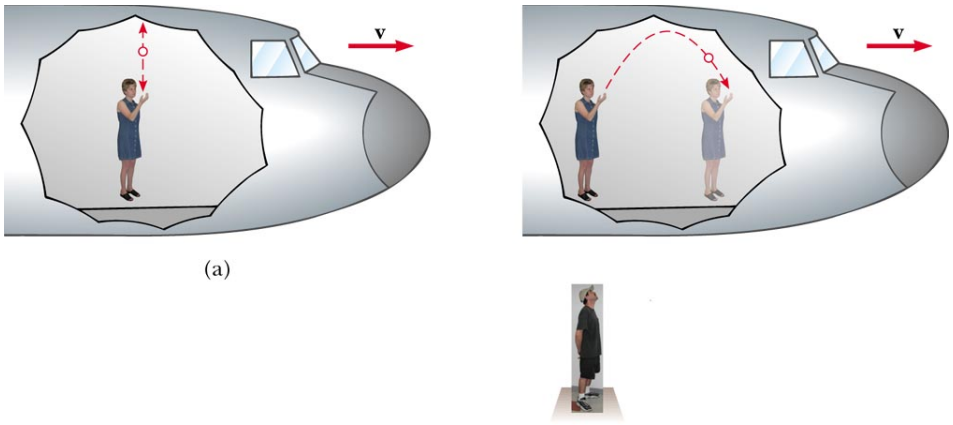


Newton's first law (law of inertia) should be the same in both (inertial) frames of reference

According to principle of Galilean relativity, laws of mechanics must be the same in all inertial frames of reference

Frames of reference

- The observer on the plane sees the ball go straight up and come straight down
- The observer on the ground sees the ball follow a parabolic path, since the ball has the horizontal velocity of the plane (from his perspective)
- Both observers agree that the ball obeys the law of gravity and Newton's law of motion; both see the same amount of time for the ball to come back into the hand



According to principle of Galilean relativity, laws of mechanics must be the same in all inertial frames of reference

There is no preferred frame of reference for describing the laws of mechanics

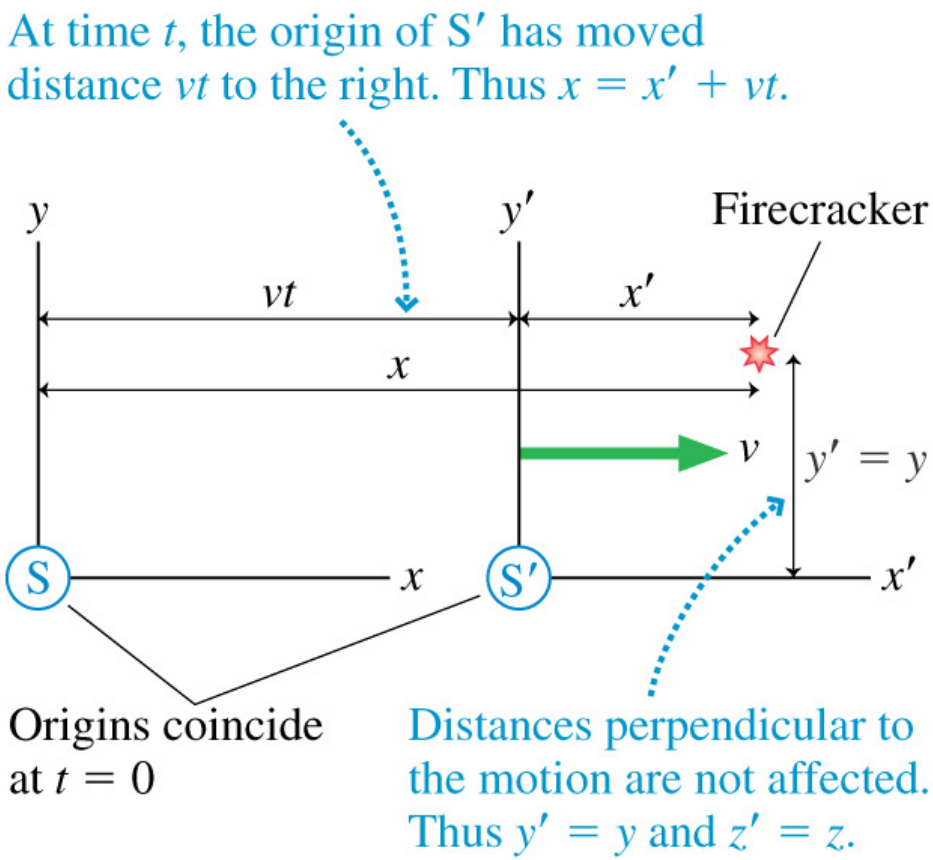
Galilean transformations

- Take 2 inertial reference frames, with S' moving with a velocity v with respect to S
- Suppose there's an event in S' at location (x',y',z'); how does that compare to the position (x,y,z) in S
- Galilean transformation equations

$$x = x' + vt \qquad x' = v - vt$$

$$y = y' \qquad y' = y$$

$$z = z' \qquad z' = z$$



Velocity transformations

- We can calculate velocities in the two frames of reference

$$u_x = \frac{dx}{dt} = \frac{dx'}{dt} + v = u_x' + v \qquad u_x' = u_x - v$$

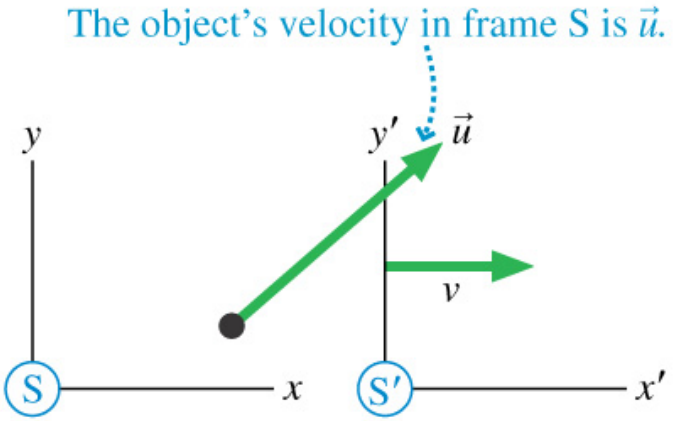
$$u_y = u_y' \qquad u_y' = u_y$$

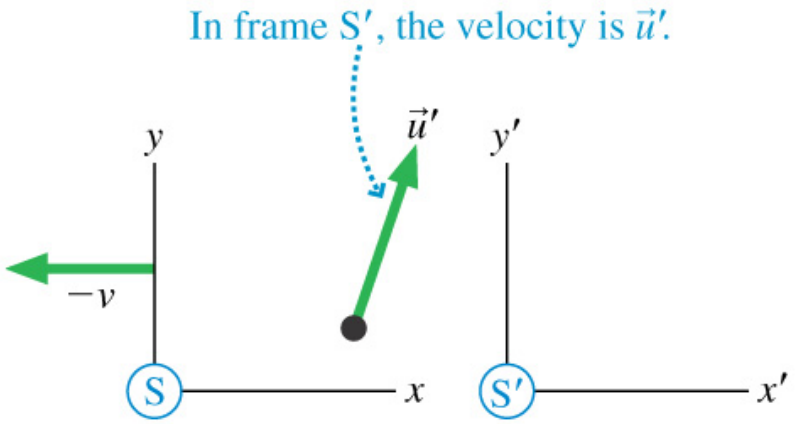
$$u_z = u_z' \qquad u_z' = u_z$$

- We can also calculate the accelerations

$$a' = \frac{du'}{dt} = \frac{du}{dt} = a$$

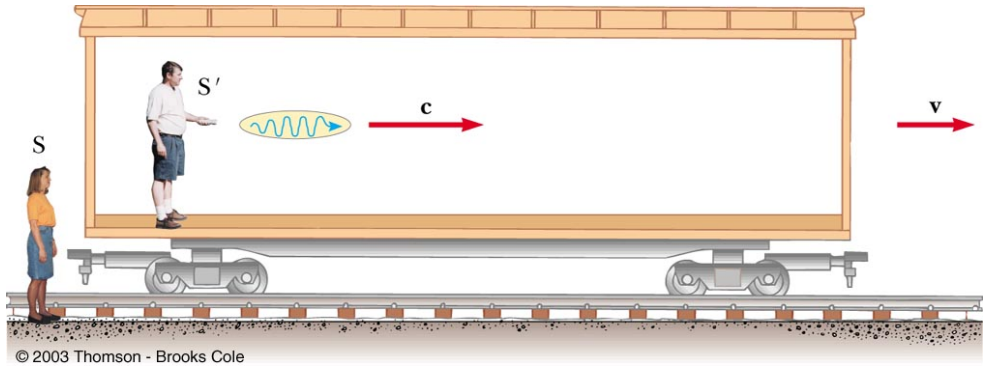
$$F' = ma' = F = ma$$





All is not well with Galilean relativity

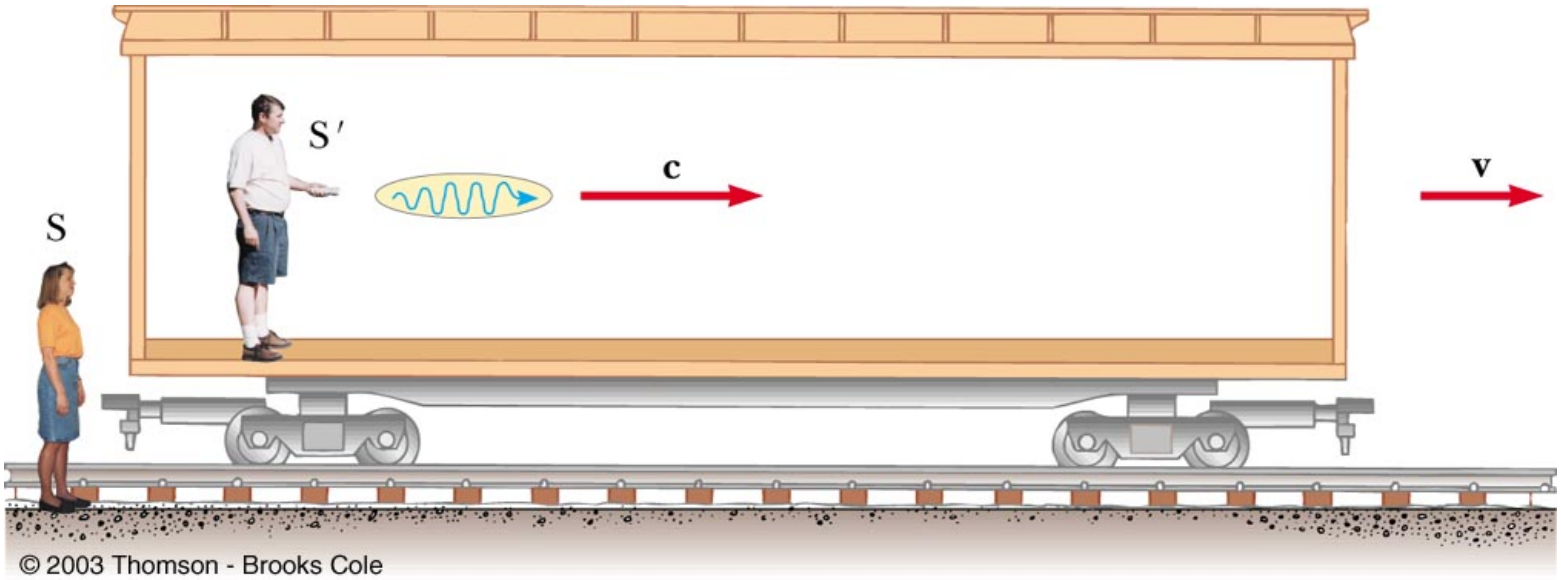
- Speed of light is supposed to have one value in vacuum
  - 3 X 10^8 m/s
  - …or more precisely 2.99792458 X 10^8 m/s
- But consider the gedanken experiment to the right
- The observer inside a railway car (S') travelling at a velocity v shines a flashlight
- He measures the light beam as travelling at c (3X10^8 m/s)



The woman S standing by the side of the track measures the speed of light at what value?
Common sense says c+v
But if the answer is c+v, then Maxwell's description of E&M is not right; Maxwell said that light can move only at one speed.

All is not well with Galilean relativity

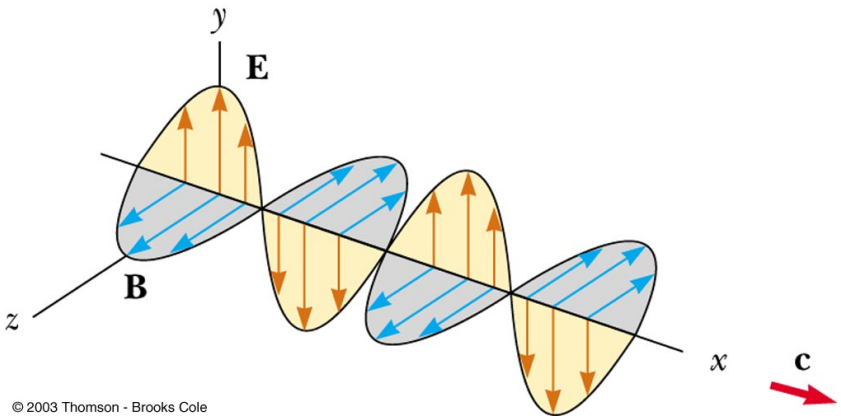
- Either
  - the law of addition of velocities is incorrect
  - …or the laws of electricity and magnetism are not the same in all frames of reference



Their brains hurt

- Remember our picture of an electromagnetic wave
- Electric and magnetic fields propagating through space
- But through what medium
- In the 19th century, every wave phenomenon scientists knew had to propagate through some medium
  - air
  - water
  - slinky
- They thought that the laws of electromagnetism were valid in only one frame of reference, that of the ether

What did electromagnetic waves propagate through?



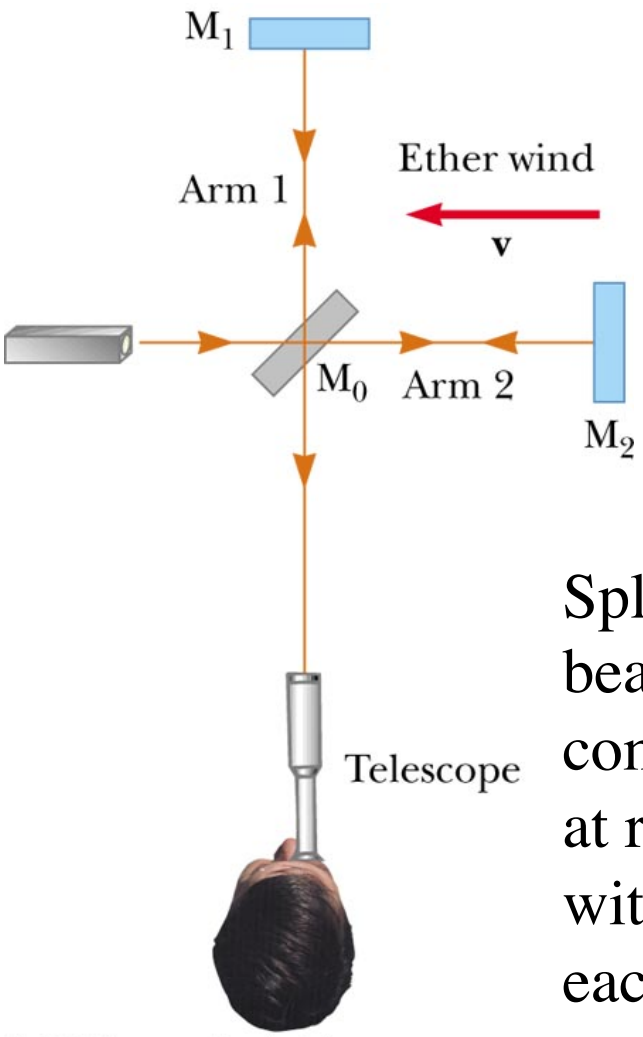
They don't need air, so there must be something else.
Enter the luminiferous *ether*.

Ether

- Ether had the following properties
  - massless
  - provides no resistance to motion of objects through it
  - has to have properties of a *stiff* elastic solid
  - had to be considered to be at rest with respect to *absolute space*
  - electromagnetic waves travel at a speed c with respect to the ether
  - strange stuff

Starting in 1881, Albert Michelson, a young American, began a series of experiments intended to measure the motion of the Earth through the ether, the *ether drift*

Basic idea



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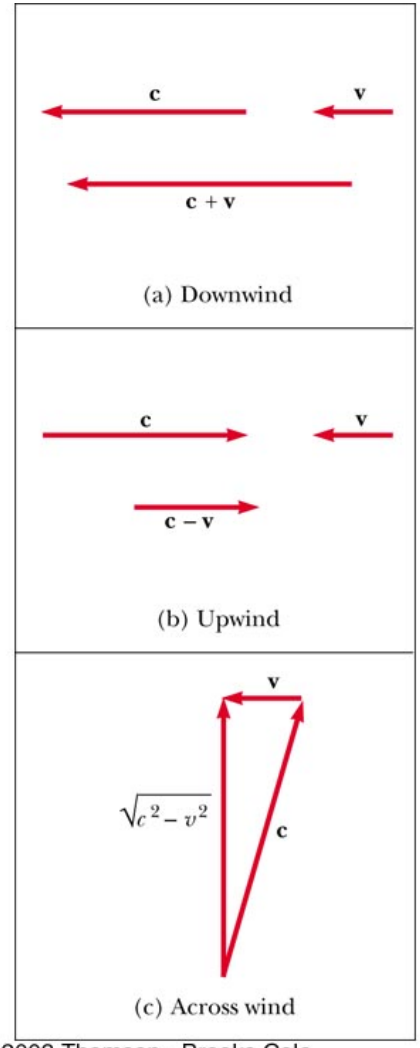
Split a light beam into 2 components at right angles with respect to each other



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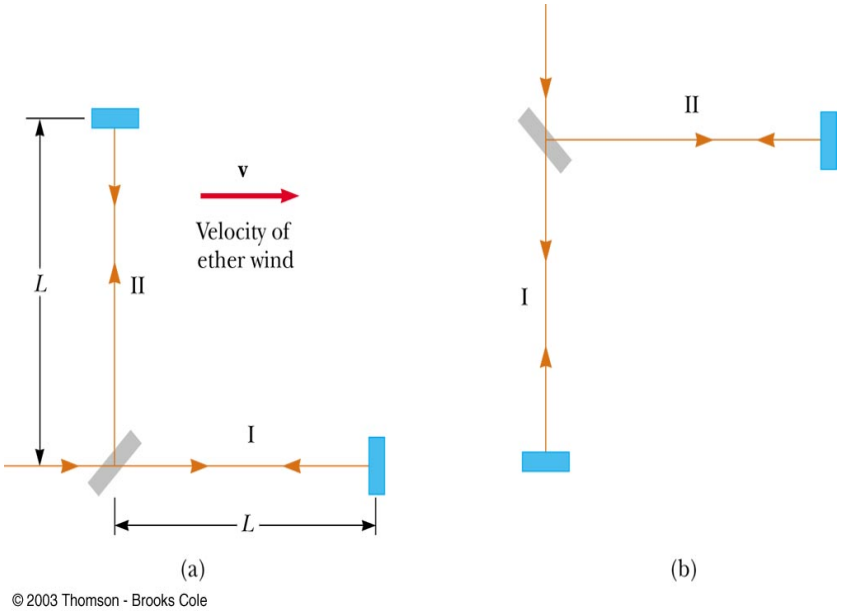
Ether drift

- If light travels at a constant speed with respect to the ether and if the earth is moving with respect to the ether, then light should travel at different speeds along paths I and II (which are arranged to be the same distance)
- The light starts out in phase but if it travels at different speeds, then it will be out of phase when it recombines
- …an interference pattern



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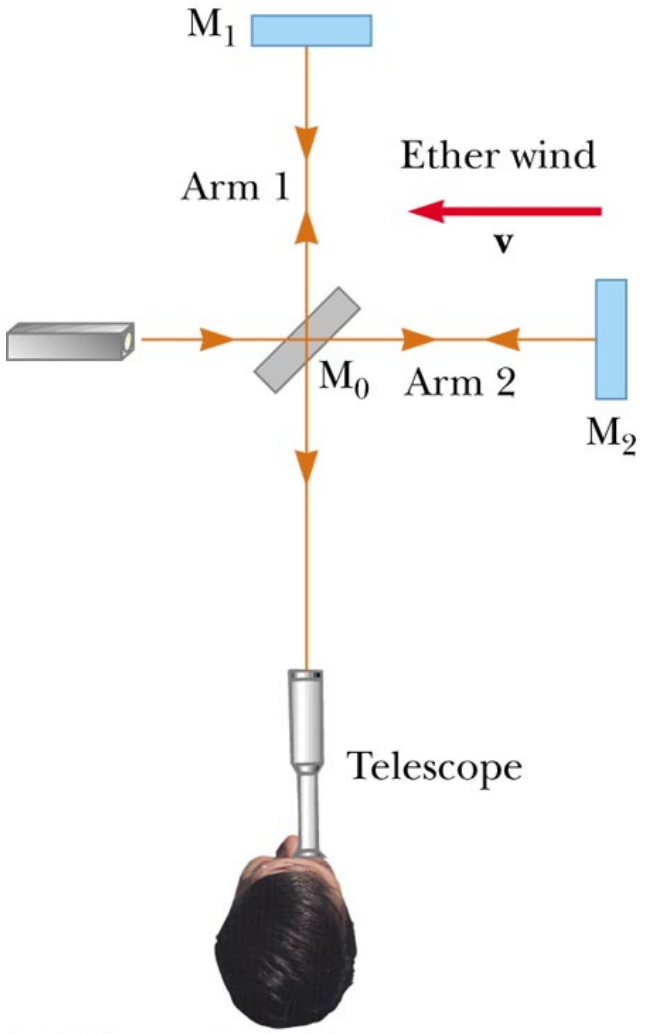
Orbital speed of the earth is about $3X10^4$ m/s, about 10^{-4} of the speed of light

Ether drift

- Of course, we don't know which way the ether wind is blowing with respect to the earth's motion, but the apparatus was designed to be able to rotate
- There should be some difference in the interference patterns when the apparatus is set up at different angles
- Nope, they found no difference; and the sensitivity of their experiment was 40X as large as the effect they were trying to measure
- Sometimes you have to give up old ideas
- Sometimes a negative search is still a discovery



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New York Times article

- **315 Physicists Report Failure In Search for Supersymmetry**
  - January 5, 1993, TuesdayBy MALCOLM W. BROWNE (NYT); Science DeskLate Edition - Final, Section C, Page 1, Column 1, 1734 words- Three hundred and fifteen physicists worked on the experiment. Their apparatus included the Tevatron, the world's most powerful particle accelerator, as well as a $65 million detector weighing as much as a warship, an advanced new computing system and a host of other innovative gadgets. But despite this arsenal ...

Enter Fitzgerald and Lorentz

- In 1882, 2 physicists, G.F. Fitzgerald and H.A. Lorentz, suggested a solution to problem posed by Michelson-Morley experiment
- Fitzgerald: moving through ether generates a resisting force which compresses apparatus
  - 1/2 millionth of 1 percent
  - enough to explain lack of ether drift caused by Earths motion through the ether
- Lorentz was looking for transformation equations between inertial frames of reference that would leave electromagnetic forces invariant
- Same transformation as found by Fitzgerald; interesting consequences
  - moving objects would contract
  - time would slow down
- Poincare also pointed out that mass would increase with speed and that the maximum speed for any object would be the speed of light