- Phys 301 Modern Physics

  Class 2: Galilean Transformations, Postulates of Special Relativity

Last Time:

- What is a reference frame?
- What is an inertial reference frame?

True or False? (Keep in Mind)

Since the laws of physics are the same in every reference frame, an object must have the same kinetic energy in all inertial reference frames.

Today:

- Mathematical transformations between inertial reference frames.
- Prove the laws of physics still work.
- Introduce the postulates of special relativity.

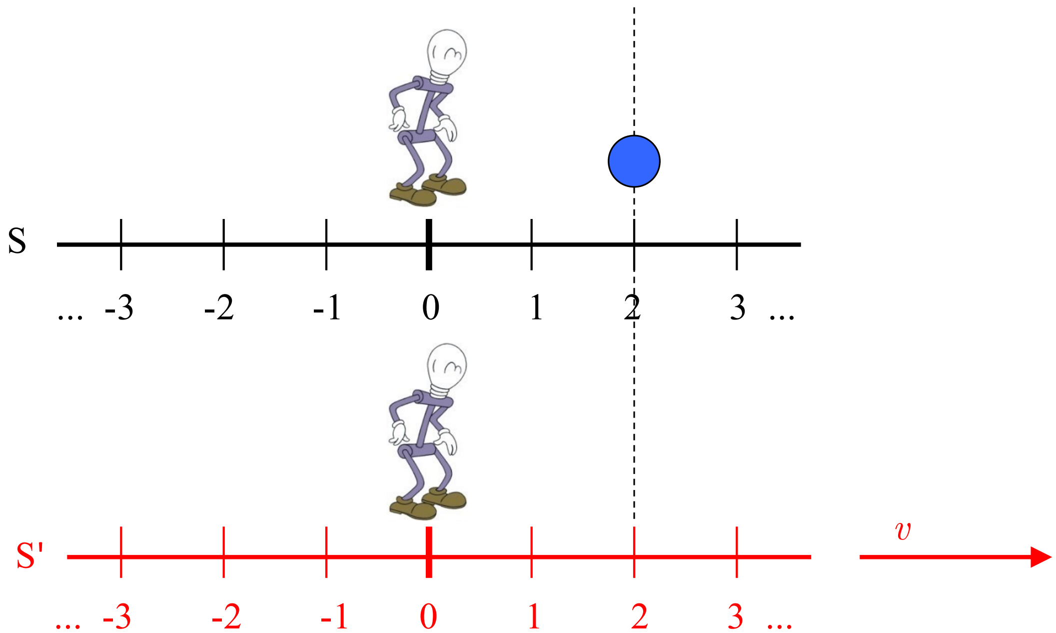
Galilean Transformations of Position

$$x = x' + v_x t \qquad x' = x - v_x t$$
$$y = y' \qquad y' = y$$
$$z = z' \qquad z' = z$$

Let's put words to each variable and discuss the assumptions.

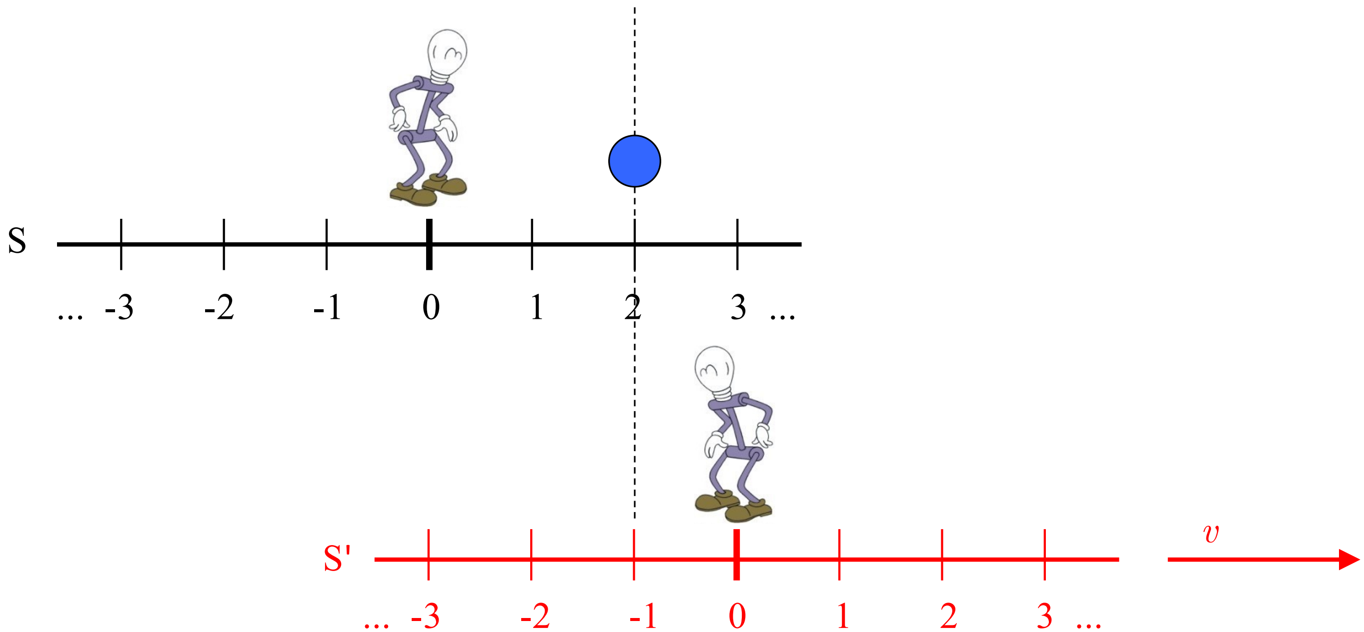
Galilean Transformations:

- Frames S and S′
- Origins coincide at $t = 0$
- $v_x =$ velocity at which frame S′ moves relative to S, along x-axis.



At time $t = 0$ s, the two frames coincide. A ball is at rest in frame S. Its position is

- $x = 2$ m
- $x' = 2$ m



Frame S′ is moving to the right (relative to S) at $v = 1$ m/s. At time $t = 3$ sec, the position of the ball is

- $x = 2$ m
- $x' = -1$ m

Important conclusion

- *Where* something is depends on *when* you check on it (and on the movement of your own reference frame).
- Time and space are not independent quantities; they are related by relative velocity.

- Definition: An ***event*** is a measurement of where something is and when it is there.

$$(x, y, z, t)$$

Galilean Transformations of Position

In the classroom, Chris walks past one end of the front table at $(x_1, t_1) = (3\text{ m}, 1.5\text{ s})$. He walks past the other end of the table at $(x_2, t_2) = (5\text{ m}, 2.5\text{ s})$. What are the coordinates of these two events *in Chris' reference frame*?

Galilean Transformations of Velocity

$$u_x = u_x' + v \qquad u_x' = u_x - v$$
$$u_y = u_y' \qquad u_y' = u_y$$
$$u_z = u_z' \qquad u_z' = u_z$$

(Show derivative)

Important to distinguish u and v.

Galilean Transformations of Velocity

While Chris is walking in front of the classroom, someone throws a ball directly at him (to his front; not back) at a speed of 3 m/s.

What is the velocity of the ball in each reference frame we've discussed (Chris' and the classroom's)?

Newton’s Laws

Chris catches the ball (flawlessly) and throws it back, while walking at a constant velocity. He must apply a force to the ball to do so.

Is the force applied to the ball the same in all reference frames? If so, is the acceleration? Prove mathematically!

Conservation of Momentum

The textbook uses an equation for elastic collisions that we did not derive in Phys 211.

Example Problem: Handout

True or False? (Revisited)

Since the laws of physics are the same in every reference frame, an object must have the same kinetic energy in all inertial reference frames.

Galilean Relativity

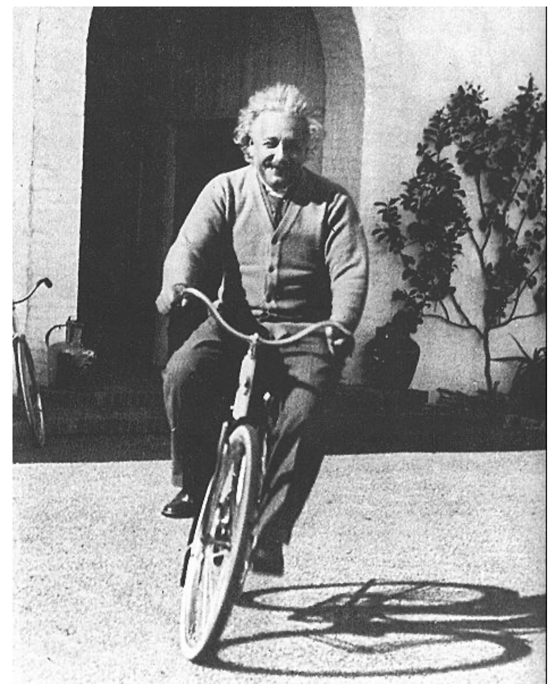
The laws of mechanics are the same in any inertial reference frame.

Newton's Laws,
Conservation Laws (as we know them…)

Einstein's Postulate of Relativity

All the laws of physics are the same in all inertial reference frames.

Including… electricity & magnetism.

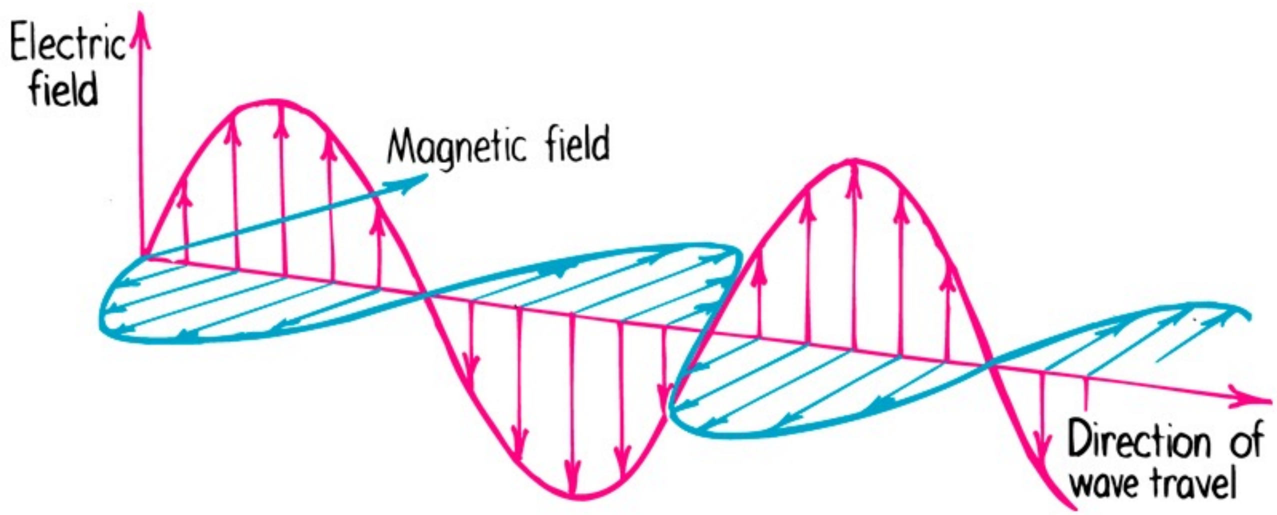


Maxwell's Equations for Vacuum*

Name	Equation	
Gauss' law for electricity	$\oint \vec{E}\cdot d\vec{A} = \frac{q}{\varepsilon_0}$	Relates net electric flux to net enclosed electric charge
Gauss' law for magnetism	$\oint \vec{B}\cdot d\vec{A} = 0$	Relates net magnetic flux to net enclosed magnetic charge
Faraday's law	$\oint \vec{E}\cdot d\vec{s} = -\frac{d\Phi^{mag}}{dt}$	Relates induced electric field to changing magnetic flux
Ampére – Maxwell law	$\oint \vec{B}\cdot d\vec{s} = \mu_0\varepsilon_0\frac{d\Phi^{elec}}{dt} + \mu_0 i$	Relates induced magnetic field to changing electric flux and to current

*Written on the assumption that no dielectric or magnetic materials are present

Changing B-Field → E-Field…
Changing E-Field → B-Field…



“The Speed of Light”

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

Let’s calculate it from fundamental constants!

$c = 3.00 \times 10^8 \mathrm{~m/s}$

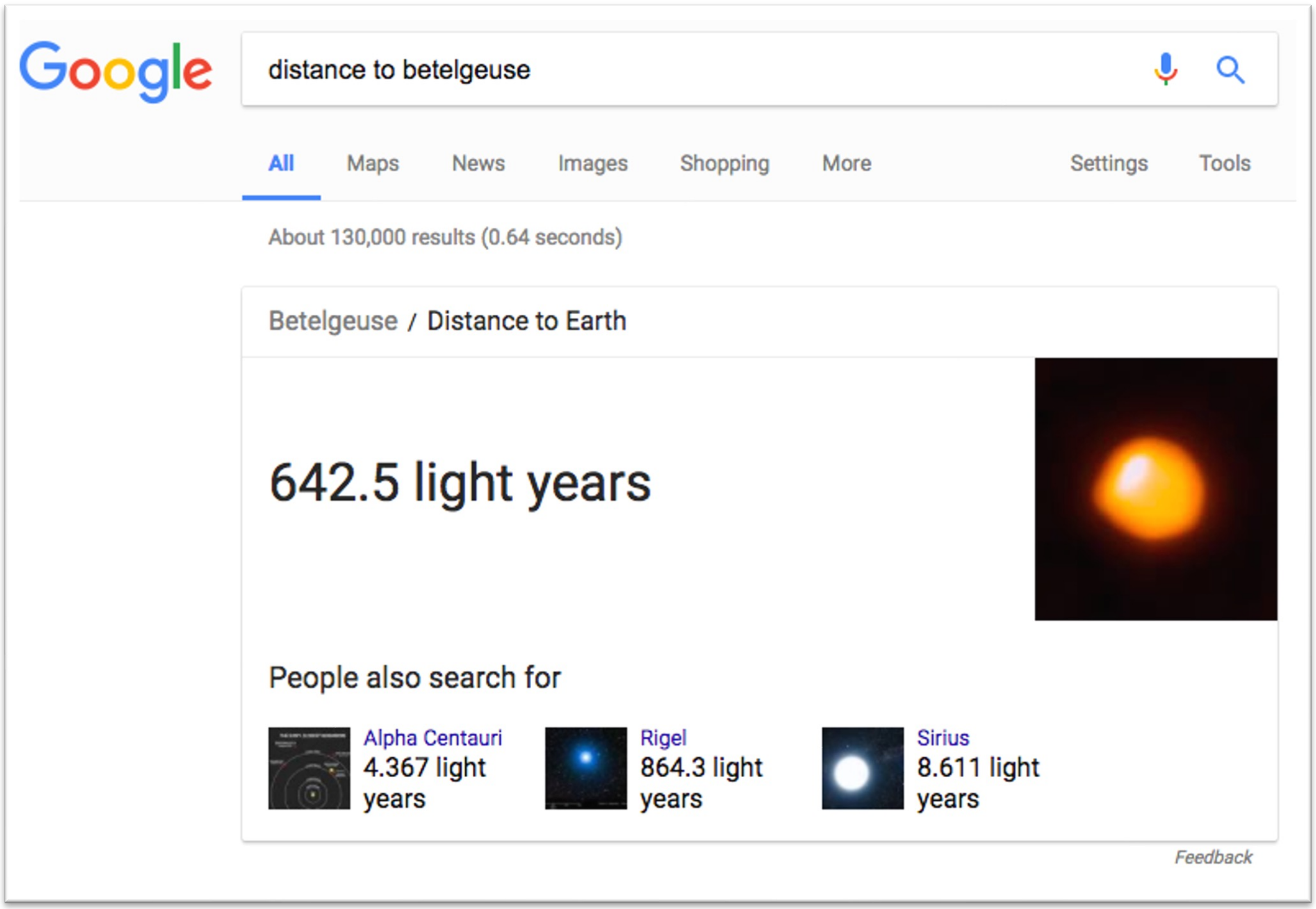
If laws of physics are the same… then $\mu_0 \epsilon_0$ must be the same… D’OH!

Example: A Finite Speed Of Light

The star Betelgeuse will likely go supernova (die spectacularly) soon (by astronomer's terms). It is approximately $6.079 \times 10^{18}\text{m}$ away.

If today, our telescopes on Earth detect Betelgeuse as going supernova, how many years ago did the supernova actually occur?

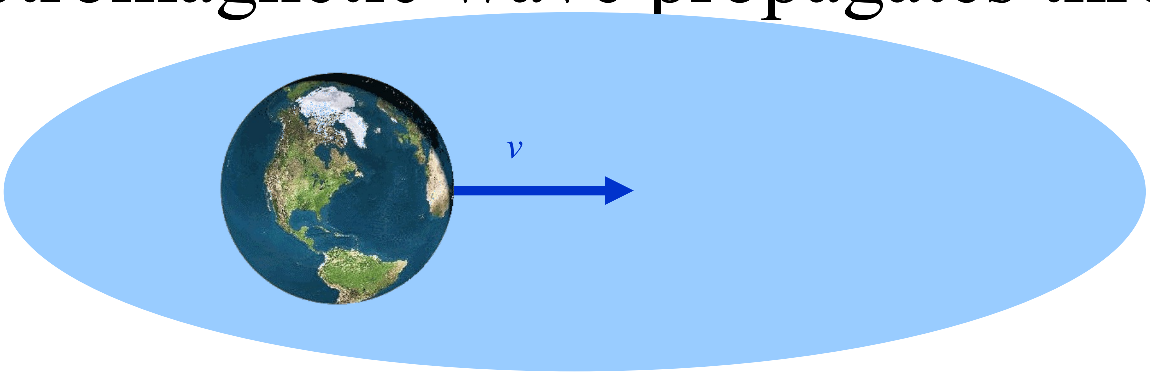
"The light took 642.5 years to reach us from Betelgeuse" = "Betelgeuse is 642.5 light years away."



Lightyear = measure of the distance that light travels in one year (in a vacuum).

Peculiar light-waves

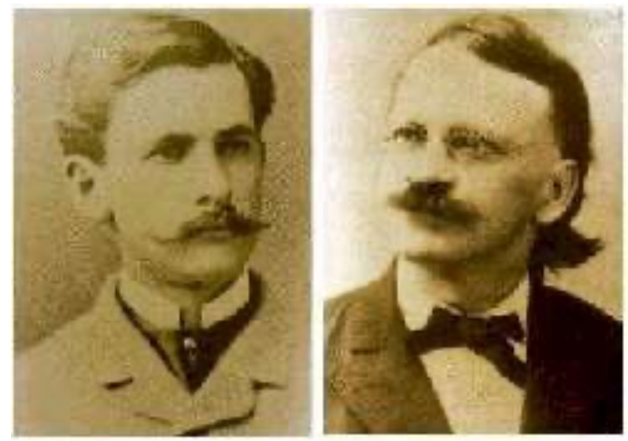
- A sound wave propagates through air, with a velocity relative to the air (~330 m / sec)
- A water wave propagates through water, with a velocity relative to the water (1.100 m / sec)
- An electromagnetic wave propagates through...



Answer: (19th century physics) The “luminiferous ether.”

Michelson and Morley

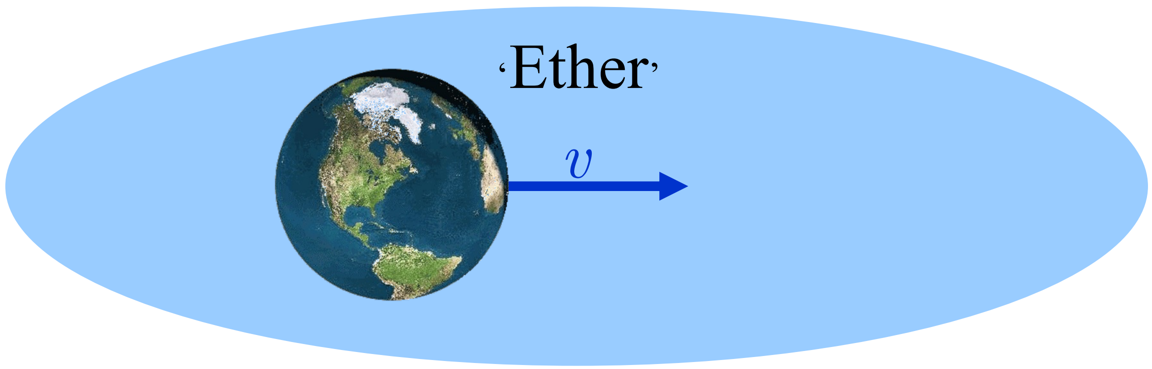
…performed a famous* experiment that effectively measured the speed of light in different directions with respect to the “**ether wind.**”



A.A. Michelson 1852 - 1931   E.W. Morley 1838 - 1923

*some say, the most successful failure…

Observer on the sun:



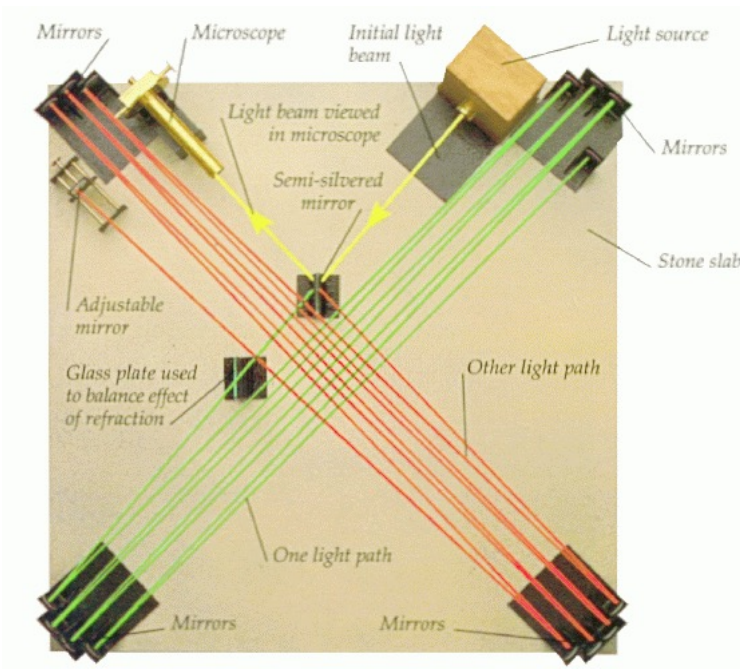
Ether 'viewed' in the laboratory on the earth:

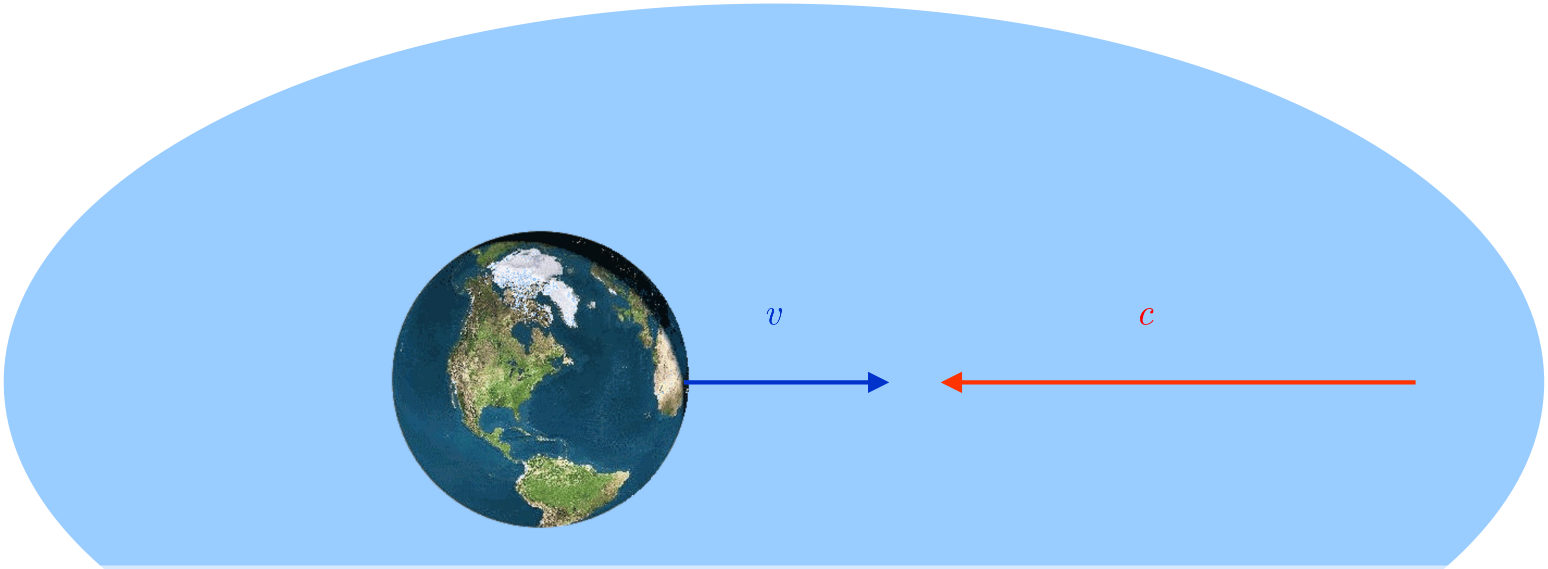
Wolfram Alpha Demonstration

- http://demonstrations.wolfram.com/MichelsonMorleyExperiment/

- (Instructions will appear on how to download the free Wolfram Alpha CDF Player.)

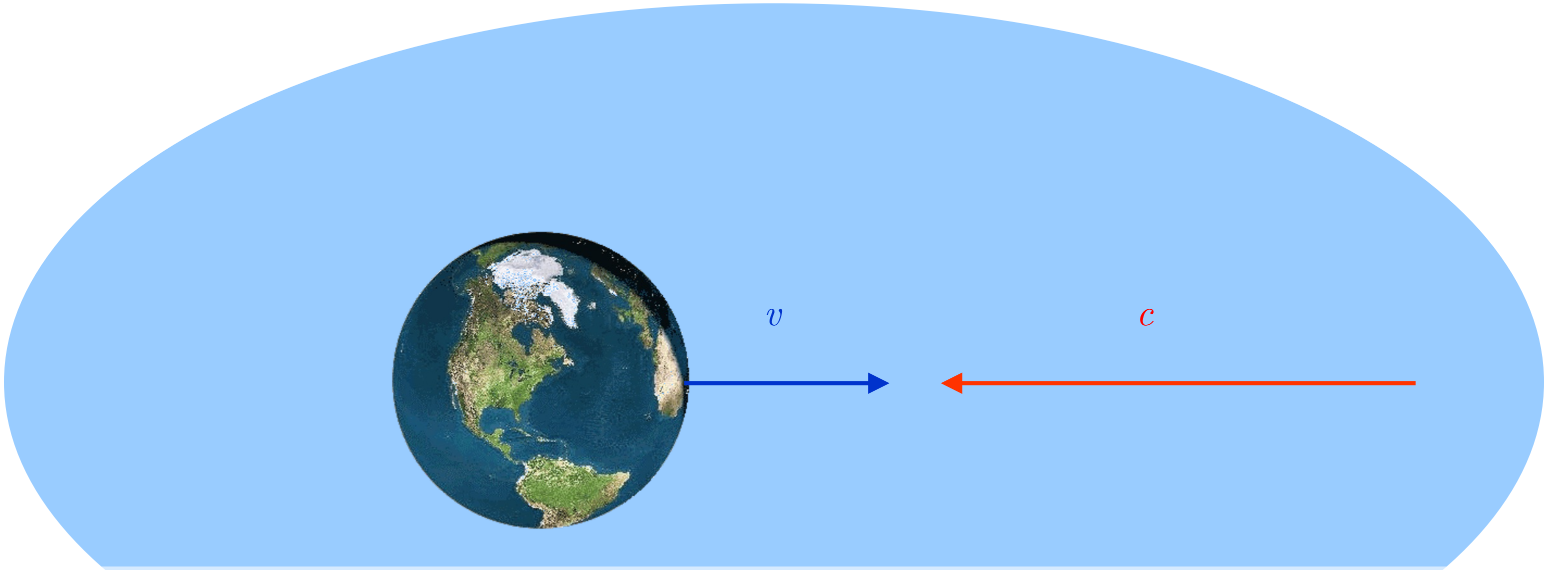
The Historic Setup (~1887)





Suppose the earth moves through the fixed ether with speed v.
A light wave traveling at speed c with respect to the ether is heading in the opposite direction. According to ***Galilean relativity***, what is the **magnitude** of the speed of the light wave as viewed from the earth?

a) $|c|$ b) $|c|+|v|$ c) $|c|-|v|$ d) $|v|-|c|$ e) something else



Suppose the earth moves through the fixed ether with speed v.
A light wave traveling at speed c with respect to the ether is heading in the opposite direction. According to ***Einstein's relativity***, what is the **magnitude** of the speed of the light wave as viewed from the earth?

a) $|c|$ b) $|c|+|v|$ c) $|c|-|v|$ d) $|v|-|c|$ e) something else

The speed of light is the same in all inertial frames of reference. *Einstein*, 1905

For a light wave: $u = u'$

$$\frac{\Delta x}{\Delta t} = \frac{\Delta x'}{\Delta t'}$$

$$If\ \Delta x \neq \Delta x'\ then\ \Delta t \neq \Delta t'$$

NEXT TIME: We will re-evaluate the nature of time.